# Perioperative Care of the Orthopedic Patient

C. Ronald MacKenzie
Charles N. Cornell
Stavros G. Memtsoudis
*Editors*

Springer

# Perioperative Care of the Orthopedic Patient

C. Ronald MacKenzie • Charles N. Cornell •
Stavros G. Memtsoudis
Editors

# Perioperative Care of the Orthopedic Patient

Springer

*Editors*
C. Ronald MacKenzie, MD
Professor of Clinical Medicine
[Medicine, Rheumatology, Medical Ethics]
Department of Medicine
Hospital for Special Surgery
Weill Cornell Medical College
New York, NY, USA

Charles N. Cornell, MD
Professor of Clinical Orthopedic Surgery
Weill Cornell College of Medicine
Department of Orthopedic Surgery
New York, NY, USA

Stavros G. Memtsoudis, MD, PhD
Clinical Professor of Anesthesiology
and Public Health
Senior Scientist
Director, Critical Care Services
Weill Cornell Medical College
Hospital for Special Surgery
Department of Anesthesiology
New York, NY, USA

ISBN 978-1-4614-0099-8 ISBN 978-1-4614-0100-1 (eBook)
DOI 10.1007/978-1-4614-0100-1
Springer New York Heidelberg Dordrecht London

Library of Congress Control Number: 2014940929



Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

*This book is dedicated to*
*~~Philip Wilson, Jeremiah Barondess, and Paul Heerdt~~*
*Mentors and Role Models All*

# Foreword

Over the last half-century, millions of patients worldwide have benefitted from significant advances in orthopedic care. These benefits have allowed patients to live longer lives, with less pain and greater mobility. Innovations in surgical techniques, perioperative medicine, and anesthesia practice over this time period have helped facilitate this progress. As a consequence of these advances, orthopedic surgical procedures are increasingly extended to a wider range of patients, including the elderly and those with significant medical comorbidities. The opportunities provided by these life-changing procedures, together with the growing need for a multidisciplinary approach to assure optimal outcomes, have stimulated the development of the new clinical and academic discipline that is comprehensively described in this volume.

The perioperative care of patients presenting for orthopedic surgery requires a team approach, a model of the delivery of care that is coordinated and optimized by a physician-directed, multidisciplinary group working together throughout the perioperative continuum. The process begins with the decision to perform surgery and requires preparation of the patient and an optimization of their general medical condition. Intraoperatively, the most current anesthetic and surgical techniques are utilized to minimize complications and to support the patient's ability to recover from the trauma of surgery. Postoperatively, a seamless transition of care from the recovery room, occasionally the intensive care unit, and then to the hospital floors is achieved by minimizing pain, maximizing the patient's ability to rehabilitate, and ensuring that postoperative medical care mitigates the impact of preexisting comorbidities. This entire continuum is carried out in a safe, cost-efficient, and patient-centered manner. Perioperative care at Hospital for Special Surgery is premised on these principles.

Our model of care, presented comprehensively in this book, is responsible for an unparalleled surgical, medical, and anesthesiologic record of success. However, as an innovative domain of surgical practice, advances in orthopedics will continue to challenge those engaged in perioperative care far into the future. Those challenges will drive the refinement of our current system of collaborative care to increasingly incorporate evidence-based approaches and innovative research to achieve the highest level of quality and outcomes for all patients. The expert contributions to this book, brought together by Drs. MacKenzie, Cornell, and Memtsoudis, provide a roadmap by which the challenges of the future can be met.

New York, NY

Thomas P. Sculco
Mary K. Crow
Gregory A. Liguori

# Preface

Arthritis is the leading cause of disability in the adult US population. Twenty-one percent of adults report physician-diagnosed arthritis, a prevalence projected to increase markedly for the foreseeable future. As conditions for which surgery is often required, the arthritides, in their various presentations, will continue to fuel the need for surgical intervention for years to come. Further societal demographics underscore the importance of these projections, especially for elderly patient populations, since the elderly are not only the fastest growing segment of western society, but arthritis as a disease category reaches its peak in older populations. Even today, this is the demographic group that already accounts for the majority of such procedures, particularly total joint arthroplasty.

Medical management in the setting of surgery is a relatively new consultative arena, one spurred on in contemporary times by the aging patient population, a rising prevalence of complex chronic disease, and an ever-expanding surgical armamentarium. Nowhere has the confluence of these forces been more evident than in orthopedic surgery, a highly innovative field, the advances of which continue to enhance the functional capacity and quality of life of patients across the entire span of life.

Although a number of comprehensive textbooks pertaining to perioperative medicine are currently available, none focus exclusively and comprehensively on the patient undergoing orthopedic surgery. The format of this book was developed with several purposes in mind. A primary goal was the development of the first published comprehensive overview of the challenges presented by the orthopedic surgical environment; as such, the book covers most of the relevant domains of orthopedic surgery. A second ambition was to provide an overview of the innovative and sometimes unique approaches to anesthesia in this patient population. A third objective was a presentation of a general approach to the preoperative evaluation of patients, while the fourth and final aim was to offer an up-to-date review of the disease-specific challenges to the care of patients undergoing surgery, maintaining a particular focus on orthopedic procedures whenever possible. In order to achieve these goals, the book is divided into five primary sections: (1) Preoperative Considerations; (2) Anesthesiologic Management; (3) Medical Management in Specific Clinical Settings; (4) Specific Perioperative Problems in Orthopedic Surgery; (5) Role of Allied Services. The book closes with a chapter providing a number of cases and clinical vignettes illustrating the challenges of caring for patients in the orthopedic surgical setting.

A word about us and our institution also seems appropriate. Hospital for Special Surgery is one of the world's premier hospitals devoted to orthopedic and rheumatologic care, its functions are supported by 140 inpatient beds, over 60 recovery room/acute carebeds, and 35 in- and outpatient operating rooms. A full complement of orthopedic subspecialties is backed by the Department of Medicine, Rheumatology, and Perioperative Medicine as well as a 57 member Department of Anesthesiology. Fourteen thousand inpatient and a comparable number of outpatient orthopedic procedures generate over 13,000 preoperative consultations annually. Given this extensive experience, we felt the time was right to contribute in a comprehensive and multidisciplinary way our collective approach to perioperative orthopedic care. The editors, whose tenures at HSS date back 30 years, feel well positioned to lead this effort.

Much has changed from the days during which most of our surgery was conducted on an inpatient basis, all patients admitted (and usually evaluated medically for the first time) the day before their procedure; 5–7 days of postoperative care and rehabilitation generally followed, even after routine total joint arthroplasty. Indeed, the modernization of care, driven though it was by outside forces and unwelcome in its time, has forced greater efficiencies in care, promoted (not stifled) innovation, and lowered cost, while minimizing patient exposure to the hospital environment—all outcomes for the better.

In closing, the editors want to express their gratitude first to the contributors to this book. As a "ground-up" endeavor, we appreciate your efforts, diligence, and particularly your patience. Thanks is also extended to Liz Corra, our development editor at Springer for her encouragement and endurance. Finally, a word to our readers, ultimately the judges of this effort: we hope you find this reference useful in your daily striving to provide the best possible care for patients. While we take full responsibility for its content, we recognize there may be shortcomings and even important omissions in this first edition. Thus, at a time when knowledge and innovation are advancing medical care on a daily basis, we invite commentary and constructive criticism from the broader perioperative and surgical community. Future editions can only benefit from such collective wisdom.

New York, NY

C. Ronald MacKenzie
Charles N. Cornell
Stavros G. Memtsoudis

# Contents

# List of Contributors

**John W. Barnhill, M.D.** Division of Psychiatry, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA

**Anne R. Bass, M.D.** Department of Medicine, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA

**Friedrich Boettner, M.D.** Department of Surgical Arthritis, Hospital for Special Surgery, New York, NY, USA

**Barry D. Brause, M.D.** Division of Infectious Diseases, Department of Medicine, Hospital for Special Surgery, New York, NY, USA

**Janet B. Cahill, P.T., D.P.T., M.B.A., C.S.C.S.** Department of Rehabilitation, Hospital for Special Surgery, New York, NY, USA

**James M. Chevalier, M.D.** Department of Nephrology, New York Hospital, Weill Cornell Medical College, New York, NY, USA

**Jeme Cioppa Mosca, M.B.A., P.T.** Department of Rehabilitation, Hospital for Special Surgery, New York, NY, USA

**Charles N. Cornell, M.D.** Department of Orthopedic Surgery, Hospital for Special Surgery, Weill Cornell College of Medicine, New York, NY, USA

**Christie L. Custodio-Lumsden, Ph.D., R.D., C.D.N.** Section of Social and Behavioral Sciences, Department of Food and Nutrition Services, Hospital for Special Surgery, Columbia University College of Dental Medicine, New York, NY, USA

**Kathryn R. DelPizzo, M.D.** Department of Anesthesiology, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA

**Naomi Dong, M.D.** Department of Anesthesiology, Hospital for Special Surgery, New York, NY, USA

**Shawna Dorman, M.D.** Department of Anesthesiology, Hospital for Joint Diseases, New York University Medical Center, New York, NY, USA

**Shivi Duggal, B.S., M.B.A.** Department of Orthopaedic Surgery, Hospital for Special Surgery, New York, NY, USA

**Sotiria Everett, Ed.D., R.D., C.S.S.D., C.D.N.** Department of Food and Nutrition Services, Hospital for Special Surgery, New York, NY, USA

**Susan Flics, R.N., M.A., M.B.A.** Executive Office, Hospital for Special Surgery, New York, NY, USA

**Matthew R. Garner, M.D.** Department of Orthopaedics, Hospital for Special Surgery, New York, NY, USA

**Stephanie Goldberg, M.S.N., R.N., N.E.A.-B.C.** Department of Nursing Administration, Hospital for Special Surgery, New York, NY, USA

**Alejandro González Della Valle, M.D.** Department of Orthopaedic Surgery, Hospital for Special Surgery, Weill Medical College of Cornell University, New York, NY, USA

**Susan M. Goodman, M.D.** Department of Medicine, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA

**Douglas S. T. Green, M.D.** Department of Anesthesiology, Hospital for Special Surgery, New York, NY, USA

**Naina Sinha Gregory, M.D.** Division of Endocrinology, Department of Medicine, Weill Cornell College of Medicine, New York, NY, USA

**Carrie R. Guheen, M.D.** Department of Anesthesiology, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA

**Michelle Horváth, M.S.N., R.N., C.P.H.Q.** Department of Quality Management, Hospital for Special Surgery, New York, NY, USA

**Kethy M. Jules-Elysee, M.D.** Department of Anesthesiology, Hospital for Special Surgery, New York, NY, USA

**Richard L. Kahn, M.D.** Department of Anesthesiology, Hospital for Special Surgery, New York, NY, USA

**M. Michael Khair, M.D.** Department of Orthopedics, Hospital for Special Surgery, New York, NY, USA

**Susan S. Kim, M.D.** Department of Rheumatology, Lehigh Valley Health Network, Allentown, PA, USA

**Cassie Kuo, M.D.** Department of Anesthesiology, Mid-Atlantic Permanente Medical Group, Rockville, MD, USA

**Dale J. Lange, M.D.** Department of Neurology, Hospital for Special Surgery, Weill Cornell College of Medicine, New York, NY, USA

**Darren R. Lebl, M.D.** Department of Orthopaedic Surgery, Hospital for Special Surgery, New York, NY, USA

**Dora Leung, M.D.** Department of Neurology, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA

**Lawrence F. Levin, M.D.** Department of Cardiovascular Disease, Hospital for Special Surgery, New York, NY, USA

**Milton T. M. Little, M.D.** Department of Orthopaedics, Harborview Medical Center, Seattle, WA, USA

**Spencer S. Liu, M.D.** Department of Anesthesiology, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA

**John P. Lyden, M.D.** Department of Orthopaedics, Hospital for Special Surgery, New York, NY, USA

**C. Ronald MacKenzie, M.D.** Department of Medicine, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA

**Steven K. Magid, M.D.** Department of Rheumatology and Medicine, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA

**Charles Maltz, M.D., Ph.D.** Division of Gastroenterology and Hepatology, Weill Cornell Medical College, New York, NY, USA

**Stavros G. Memtsoudis, M.D., Ph.D.** Department of Anesthesiology, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA

**Andy O. Miller, M.D.** Division of Infectious Diseases, Department of Medicine, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA

**Jad Bou Monsef, M.D.** Department of Orthopaedic Surgery, Hospital for Special Surgery, New York, NY, USA

**Stephen Paget, M.D.** Department of Rheumatology, Hospital for Special Surgery, Weill Cornell Medical School, New York, NY, USA

**Michelle Perna, B.A.** Department of Orthopaedics, Hospital for Special Surgery, New York, NY, USA

**Patricia Quinlan, M.P.A., Ph.D., R.N., C.P.H.Q.** Department of Nursing, Hospital for Special Surgery, New York, NY, USA

**Brion Reichler, M.D.** Department of Neurology, Hospital for Special Surgery, New York, NY, USA

**Melissa H. Rosen, M.D.** Department of Gastroenterology, New York University Langone Medical Center, New York, NY, USA

**Linda A. Russell, M.D.** Department of Rheumatology, Hospital for Special Surgery, New York, NY, USA

**Anas Saleh, M.D.** Department of Orthopaedic Surgery, Cleveland Clinic Foundation, Cleveland, OH, USA

**Alexander Shtilbans, M.D., Ph.D.** Department of Neurology, Hospital for Special Surgery, New York, NY, USA

**Ottokar Stundner, M.D.** Department of Anesthesiology, Perioperative Medicine, and Intensive Care Medicine, Paracelsus Medical University, Salzburg, Austria

**Cephas P. Swamidoss, M.D., M.S., M.P.H.** Department of Anesthesiology, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA

**Samuel A. Taylor, M.D.** Department of Sports Medicine, Hospital for Special Surgery, New York, NY, USA

**Michael K. Urban, M.D., Ph.D.** Department of Anesthesiology, Hospital for Special Surgery, New York, NY, USA

**Ettore Vulcano, M.D.** Department of Orthopaedic Surgery, Hospital for Special Surgery, Weill Medical College of Cornell University, New York, NY, USA

# Part I

# Preoperative Considerations

# General Principles and Practices of Perioperative Medicine

1

C. Ronald MacKenzie

**Objectives**

- To review the rationale for the preoperative medical evaluation.
- To review the goals of the preoperative medical evaluation.
- To review the literature pertaining to the efficacy of preoperative medical evaluation.

**Key Points**

- Medical evaluation of a patient prior to surgery remains a widespread clinical practice.
- Such consultation is supported by clinical investigation, growing literature, and national conferences.
- The principles and practices of perioperative medicine have been evolving, influenced by the quality movement of the last 15 years.
- An orderly structure for the preoperative evaluation includes: the identification of the nature, severity, and degree of control of all comorbid conditions that may impact perioperative decision-making; the optimization of treatment of all active medical problems; the assessment of anesthesia and surgery-associated risk; education of patients and families concerning the perioperative experience; and motivation of the patient to commit to preoperative preventive practices.

C.R. MacKenzie (✉)
Department of Medicine, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA
e-mail: mackenzier@hss.edu

## Introduction

Growing numbers of patients of ever increasing age and often advanced medical conditions undergo surgery annually. Owing to advances in surgical technique as well as advances in the understanding of perioperative medicine, patients of much greater complexity are being considered suitable surgical candidates. Nowhere is this confluence of developments greater than in the field of Orthopedics where advances in total joint arthroplasty, spine, and trauma-related surgery have expanded the indications for surgery and pushed the boundaries of perioperative care. As such a familiarity with the literature pertaining to medical care in the perioperative setting is required for those who provide care to the orthopedic patient undergoing surgery [1–5].

This chapter reviews the clinical domain and literature pertaining to the perioperative medical evaluation emphasizing, where appropriate, the patient undergoing orthopedic procedures. A stepwise approach to the preoperative consultation and the assessment of perioperative risk is presented supported by the literature pertaining to perioperative evaluation and care.

## Preoperative Consultation

As a consequence of medical advances as well as the impact of financial and resource constraints on the medical system at large, a substantial trend toward the performance of surgery in the ambulatory setting has evolved in the recent decades. Indeed, the percentage of all surgical procedures performed on an outpatient basis in the USA rose from 20 % in 1982 to 60 % in 1995, a trend particularly relevant to the arthroscopic techniques of orthopedic surgery [6, 7]. Amongst the benefits of these developments has been the opportunity to move the preoperative medical evaluation to the outpatient arena as well, often weeks prior to the surgical

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_1, 

date. This change in practice allows sufficient time for discourse with other physicians' involved in the patient's care, for supplementary consultation and investigation, and the institution of therapy directed at optimizing the patient's medical status prior to the contemplated surgery. Practiced in this manner, the preoperative evaluation becomes a focal point of communication between all professionals involved in caring for the patient, enhancing the deliberative and collaborative nature of the consultative process and ultimately the patient's care. While the boundaries of such consultation may vary, influenced by patient and surgery-related factors, a growing literature pertaining to perioperative medicine supports various core principles that underlie effective medical consultation in this setting.

Depending on the setting and institutional approach to perioperative care, the preoperative consultation may be conducted by an MD (Internist, Medical Subspecialist, Hospitalist, or Anesthesiologist) or by physician extenders (Nurse Practitioners, Physician Assistants) under MD supervision. Owing to the complexity of medicine, especially the growth in pharmacology, challenges of the elderly with their comorbidities and restricted physiologic reserve, and productivity and reimbursement pressures that keep surgeons in the operating room (as opposed to rounding on the floors), surgeons are desirous of a more involved consultant [8]. This may take the form of a more active participation in the patient's care (ordering rather than recommending medications), adopting a comanagement strategy for the patient's postoperative care, or in some instances assuming full responsibility for the patient after completion of the surgery. Regardless of the institutional model, communication between the referring and consulting physicians remains essential to the provision of optimal perioperative care. Evolving from earlier guidelines regarding effective consultation [9], a recent conceptual revision stressed such considerations as determining the customer, establishing the urgency, gathering your own information, being brief, being specific and talking to the referring physician, establishing contingency plans, establishing one's turf, teaching with tact, talking with the primary physicians, and providing follow-up [8]. While each of these tenants is central to the whole, the first priority is to insure clarity regarding the question asked, as a lack of transparency about the stimulus for the consultation is sure to get the process off on the wrong foot.

Given its essential purpose, consultation as a practice is the provision of advice regarding diagnosis and management. In the context of general medical care, it affords an opportunity to initiate or modify treatment whether primary or secondary (preventive). Although the goals may be of shorter term in the preoperative setting, such consultations can still be most complex, taxing the knowledge and skill of the medical consultant and anesthesiologist alike. Further, the role of the preoperative medical consultant may subsume even broader responsibilities, going beyond the evaluation of the patient's current medical status. Additional responsibilities, especially germane in the preoperative setting, include the estimation of the patient's risk for surgery, decisions regarding the need for additional testing prior to surgery, and the preoperative optimization of the patient's medical condition, the purpose of which is to reduce the risk of postoperative complications [10]. Further, in the domain of orthopedics, the assessment of bone quality is a new and increasingly appreciated preoperative consideration, highly relevant in the setting of spine and hip surgery. This emerging topic is extensively reviewed in Chap 25.

The success of this process therefore depends on a number of elements including a thorough knowledge of those illnesses which impact upon surgical outcome, an understanding of the surgical procedure and anesthetic strategies that might be employed, and an integration of a management plan across the range of physicians and other professional staff who will be caring for the patient [10]. Implicit is the need for effective communication, as the consultant's clinical judgment will impact outcome only if the recommendations are conveyed and then implemented effectively.

Finally a word about the concept of surgical "clearance" is in order. Though widely ensconced in the clinical vernacular, this notion has been decried by the perioperative medical community citing its lack of specification and that the term "cleared" implies that patients will not experience postoperative complications, a sequel that can never be guaranteed [10]. As you will see shortly, the term "optimized for surgery" is more appropriate and better aligned with the goals of preoperative consultation. What are these goals and how do we approach them?

## Goals of the Preoperative Medical Consultation

The goals of the preoperative medical evaluation are as follows:

- Identification of the nature, severity, and degree of control of all *comorbid conditions* that may affect perioperative clinical decision-making and medical care;
- *Optimization* of the treatment of all active medical problems;
- Assessment of anesthesia and surgery-associated *risk* (magnitude and type);

- *Education* of patients and families concerning the perioperative experience;
- Motivation of the patient to commit to preoperative *preventive* practices.

## Identification of Conditions That Affect Postoperative Outcome

The needs of the patient in the perioperative context depend on a number of considerations notably age, comorbidity, functional capacity, and the type of anesthesia and surgery to be performed. A complete medical history and physical examination constitutes the bedrock preoperative evaluation providing a clinically relevant framework upon which informed decisions concerning the value of additional ancillary testing can be premised. The focus and content of the preoperative history does differ from general medical practice, however. For instance the indication for any type of surgery is an essential component, as the perioperative risk will vary with the magnitude and urgency of the procedure. Patients should also be asked about their prior experience with surgery and anesthesia. Further, the presence, severity, and stability of all comorbid conditions should be established. In the setting of orthopedic procedures, particularly lower extremity arthroplasty, a patient (or family history) of thromboembolic phenomenon may denote the patient at heightened risk for this well-recognized complication of these procedures. Also relevant to this consideration is the association of various connective tissue diseases with antiphospholipid antibodies, a disorder of (hyper) coagulation that places patients at high thrombotic risk after surgery. This condition presents significant management challenges in the perioperative setting and is reviewed elsewhere (Chap. 20). The use of tobacco, alcohol, and other drugs should also be documented, as should the patient's allergic history. All prescription and over-the-counter medications, including the use of herbs and supplements, should be recorded with their dosages and dosing schedules, as decisions need to be made concerning which therapies should be continued (and which should not) prior to surgery. In addition to a traditional review of systems, certain anesthesia related checks are also important: these include airway problems and a history of snoring, daytime sleepiness, and hypertension which, if present in the morbidly obese patient, suggest the presence of sleep apnea, a medical problem underappreciated both in the general and perioperative settings (Chap. 5).

An understanding of specific intraoperative events and practices associated with the range of orthopedic procedures cannot be overemphasized when performing preoperative evaluations and may help avoid delays and cancellations on the day of surgery. For example the simple knowledge of positioning practices may alert the examiner to evaluate the patency of potential femoral vascular grafts, ventriculoperitoneal shunts and the accessibility of implanted cardiac defibrillators in the prone or lateral position as is utilized for spine and hip procedures, respectively. Further, an appreciation of factors like expected blood loss and specialized ventilation strategies such as one-lung ventilation, will allow for a better assessment of the impact of such an approach on various organs and the ability for any given patient to tolerate such interventions. Lastly, consideration of anesthetic practices for specific procedures (i.e., neuraxial versus general approaches) and their physiologic impact, such as effects on cardiac preload and afterload, should be taken into account when evaluating patients with specific diseases. The effect of prone positioning on positive pressure ventilation may be another example to consider specifically in the obese patient. Thorough evaluation of a patient's possible spinal pathology, including the extent and type of prior back fusions, may avoid confusion on the day of surgery when a neuraxial technique is planned for lower extremity arthroplasty. In selected patients a preoperative consultation with an anesthesiologist may be indicated as to more accurately assess the compatibility of a patient's pathophysiology with an anticipated surgical and anesthetic approach.

Last there has been considerable interest in the estimation of the patient's functional capacity, a surrogate for cardiopulmonary fitness, in the prediction of postoperative outcome [11, 12]. Exercise capacity, quantified in metabolic equivalents (METS), can be easily estimated according to the ability to perform simple everyday tasks of living [10]. Patients with functional limitations so determined have been shown to be at risk for postoperative complications [10]. Although often cited as an easily measured predictor of surgical outcome, the applicability of such assessments is restricted in orthopedic populations. Owing to the disability associated with chronic arthritis, painful joint conditions preclude most of the activities that make up the METS-based methodology, thus limiting its applicability in the orthopedic patient.

The physical examination confirms and often amplifies information obtained from the medical history. In the preoperative context, the examination should focus on patient characteristics known to adversely impact upon postoperative course. In addition to the vital signs, body mass index (BMI) should be calculated (Wt/Ht) as not only this parameter is associated with the development of various chronic diseases but obesity is also an important independent risk factor for surgery and highly correlated with the underappreciated condition, sleep apnea syndrome. Careful auscultation of the heart is important as the presence of third and fourth

heart sounds may indicate left ventricular dysfunction or incipient congestive heart failure while cardiac murmurs imply the presence of valvular heart disease. Depending on the nature and severity of the valvular anomaly, valvular heart disease may compromise cardiac function at times of physiological stress such as surgery. Obesity, large neck circumference, and hypertension predict obstructive sleep apnea; obesity is also associated with insulin resistance and thus diabetes mellitus.

The benefit of preoperative laboratory testing has been examined in many studies and its benefit (or lack thereof) continues to be widely debated. Several comprehensive reviews pertaining to the commonly performed preoperative studies have been published. Should the determinants of such testing be disease-related or procedure-related? Is the common practice of screening laboratory panels justified in the preoperative setting? With respect to testing when there are no clinical indications, less than 1 % of such testing has been shown to provide useful information [13]; indeed, there is evidence that overall this approach may actually be harmful [14]. Not surprisingly, preoperative diagnostic tests ordered as a consequence of a finding uncovered on history and physical examination are more likely to be abnormal [15]; of particular importance is the previously abnormal result that is associated with new or persistent abnormalities [16]. Finally there is the economics of such testing. Although not extensively examined, one study relevant to the orthopedic population, examined the costs associated with routine urinalysis, prior to knee arthroscopy; $1.5 million dollars were spent in order to prevent a single urinary tract infection [17].

In response to observations from clinical practice and a literature that fails to demonstrate benefit, support from experienced perioperative clinicians for the global or "shotgun" approach to preoperative testing has waned in recent years [18]. The establishment of guidelines, the effect of which was to reduce preoperative testing, has been shown to have several advantages These include the standardization of practice, improved efficiency, and a substantial reduction in costs; further, these benefits occur with no adverse effect on outcome [19, 20]. Indeed, studies involving healthy patients undergoing minor procedures (i.e., cataract extraction), routine preoperative laboratory testing appears completely unnecessary [21–23]. Although definitive studies in an orthopedic population have not been conducted, a restrictive preoperative testing model might also apply to many of the minor or regional orthopedic procedures (i.e., hand and foot surgery, arthroscopy). Nonetheless, old practices "die hard" and what appears to be excessive preoperative testing remain a widespread practice. Further, depending on the patient and the nature and magnitude of the surgery, a number of investigations may be considered appropriate and are still commonly performed on patients prior to major surgical procedures.

## Optimization of Conditions That May Affect Postoperative Outcome

Patient related factors, specifically existing medical comorbidities, are now viewed as the most important determinant of postoperative outcome. Part III and Part II of this book presents a comprehensive overview of the perioperative management across the spectrum of chronic medical conditions encountered in orthopedic patients. Optimization of the treatment of these conditions is an important goal of the preoperative evaluation. Common examples of this practice includes the control of blood pressure in the patient with hypertension, the resolution of bronchospasm in the asthmatic, the achievement of satisfactory glucose control in the diabetic, electrolyte abnormalities (often medication-induced) and heart rate control in patients with coronary artery disease. Unfortunately, for many relevant conditions (i.e., obesity, smoking practices), time constraints and patient compliance impose substantial obstacles.

In practice, the process of optimization generally involves medication adjustments. Medications may be started, discontinued, or their dosages changed, before or on the day of surgery. Further, because perioperative care is a dynamic process, medication adjustments are often required after the surgical procedure as well. The medications involved encompass the entire pharmacopeia, including complementary and alternative therapies. Of note are such pharmacological categories as antihypertensive agents (including beta-blockers), antiarrhythmic agents, statin drugs, bronchodilators, insulin and oral hypoglycemic agents, drugs with effects on coagulation, antidepressants, and analgesics. For example, angiotensin enzyme (ACE) inhibitors and angiotensin receptor antagonists (ARA) are common antihypertensive agents and thus frequently encountered in the preoperative setting. Such medications, which are often combined with a diuretic, are associated with significant hypotension in association with anesthesia and should be held on the day of surgery [24, 25]. Particularly relevant to orthopedic populations are corticosteroids and the disease-modifying agents (DMARDs), drugs commonly employed in the treatment of connective tissue disease (Chap. 10). Other such disease related optimization strategies are dealt with in the individual chapters comprising Part III and Part II of the book.

A decision to hold medication prior to or on the morning of surgery must balance the potential adverse influences of those medications in the short term (in the setting of anesthesia and surgery) versus their long-term indications and

**Table 1.1** (A) Medications commonly discontinued several days before surgery. (B) Medications commonly withheld on morning of surgery (Used with permission from Rosenbaum SH, Silverman DG. The Value of Preoperative Assessment. In Newman MF, Fleisher LA, Fink MP (eds): Perioperative Medicine: Managing for Outcome. Philadelphia: Saunders/Elsevier; 2008:41–42)

| Medication | Special considerations and comments |
|---|---|
| *(A) Medications commonly discontinued several days before surgery* | |
| Tricyclic antidepressants | Continue for severe depression |
| Monoamine oxidase inhibitors (MAOIs) | Continue if severe condition (use MAOI-safe anesthetic that avoids meperidine) |
| Metformin | May stop 24–48 h to decrease risk of lactic acidosis |
| Birth control pills, estrogen replacement, tamoxifen | Prolonged risk of thromboembolism, especially after major oncologic and orthopedic surgery. Decision by surgeon or oncologist |
| Aspirin, clopidogrel (Plavix), cliostazol (Pletal), dipyridamole (Persantine) | May continue in patients with critical need for antithrombotic therapy and/or low risk of significant surgical bleeding. Duration of effect of cilostazol and dipyridamole < clopidogrel, aspirin, and ticlidopine. However, if major concern about intraoperative bleeding, stop for up to 10 days |
| Warfarin (Anticoagulants) | Generally stop for 2–5 days. If high risk of thromboembolism, may replace with heparin or low-molecular-weight heparin |
| Nonsteroidal anti-inflammatory drugs | May continue for severe inflammatory disorder |
| Cyclooxygenase type 2 inhibitors | May continue to avoid flare-up (despite potential thrombosis or delayed healing) |
| Fish oil, vitamin E (>250 U/day), and many herbal medicinals | Potential multisystem (anticoagulant, cardiovascular) effects. Standard vitamins acceptable |
| *(B) Medications commonly withheld on the morning of surgery* | |
| ACE inhibitors, angiotensin receptor blockers | Continue if refractory hypertension, fragile aneurysm, severe congestive heart failure (CHF), valvular insufficiency |
| Diuretics | May continue for CHF |
| Phosphodiesterase-5 inhibitors | May predispose to hypotension |
| Lithium | Interacts with anesthetic agents |
| Bupropion, trazodone | Predispose to exaggerated sympathetic response |
| Disulfiram (Antabuse) | Affects metabolism (e.g., phenytoin, warfarin). |
| Alendronate sodium (Fosamax) | Causes transient esophageal irritation |
| Particulate antacids | Cause pneumonitis if aspirated |
| Oral hypoglycemics | Risk of hypoglycemia in fasting patient |
| Long-acting insulin (no available IV access—e.g., day-of-surgery admission) | May also decrease dose night before surgery if patient is prone to morning hypoglycemia. Initiate tighter control when IV access available |
| Rapidly acting insulin | Administer preoperatively only if hyperglycemia |
| Insulin pump | Withhold bolus; may continue basal rate. |
| Pyridostigmine (for myasthenia gravis) | May complicate use of neuromuscular blocking drugs. Continue if risk of severe weakness or dysphagia |
| Low-molecular-weight heparin (enoxaparin) | Can replace warfarin; typically withhold for 12–24 h |

benefits. Such decisions must be made on an individual basis. Table 1.1 summarizes these considerations across a range of common medications.

## The Assessment of Perioperative Risk

The determinants of perioperative risk fall into four categories [26]. The first and least discussed in the perioperative literature involves various system-related phenomena, including the hospital–institutional model of perioperative care (general vs subspecialty, inpatient vs outpatient, comanagement methodologies), approaches to staffing (nursing, physician assistants, hospitalists), and the role of information systems, all of which are important determinant of outcome. This, the domain of the Quality Improvement movement, is discussed in Chap. 30. The second category of risk relates to anesthetic management and includes such factors as choice of anesthesia (regional vs general), monitoring techniques, airway considerations and the approach to postoperative pain control, topics covered in Part III and Part II of this book. The third includes the surgery-mediated risks, while the fourth category subsumes those influences arising as a consequence of existing medical comorbidity. The impact of preexisting medical conditions on postoperative complications is a subject about which an extensive literature now exists. Indeed, medical comorbidity is now viewed as the primary determinant of adverse surgical outcome. Apropos of this point an early study is illustrative. Of 599,548 anesthetics, perioperative death was

proportionately attributed to anesthesiological practices (1/2,680), the surgeon (1/420) and patient comorbidity (1/95) [27]. This, the first paper to feature the key role played by patient comorbidity in surgical outcome, was buttressed by a second report in which patient-related comorbidity was the major contributor to the mortality in 485,850 of surgical procedures [28].

The identification of the factors that may alter the risk associated with surgery has, until recently, been the purview of the anesthesiologist. Surgical practice has, however, changed. An ever-aging patient population, with an increasing burden of medical comorbidity, is now considered as a suitable candidate for surgical intervention. Such patient-related characteristics, coupled with the technical evolution of surgical practice, now require the input other clinical disciplines, specifically internal medicine or the medical subspecialists, professionals who by necessity have entered the perioperative arena and now play a key collaborative role.

The concept of preoperative risk assessment was ushered into to clinical practice by the anesthesiologists, who in the 1940s became interested in postoperative outcome [29]. Discouraged at first by the complexity of the problem, investigators initially regarded the challenge as too daunting owing to such problems as the magnitude of the data required, practice variation, and to the lack of agreement regarding key definitions and terms. Early investigators did, however, develop a scale for the assessment of the patient's state of health prior to surgery. Indeed, the *American Society of Anesthesiologists (ASA) Physical Status Scale* has proven amongst the most durable tools of clinical medicine [30]. Employed for decades in the setting of anesthesia and surgery, the ASA scale has high correlation with a patient's postoperative course. Five levels of risk based on the presence of a systemic disturbance (illness or comorbidity) are defined with the associated surgical mortality in parentheses: I absent (0.2 %), II mild (0.5 %), III severe/non-incapacitating (1.9 %), or IV incapacitating/threat to life (4.9 %), and V moribund/survival $<$24 h without surgery (NA); the sub-designation E, denotes emergency surgery which doubles the risk [31]. First proposed in 1941 [29], a revision of the scale remains in virtual universal use to this day [32]. Although criticized for the vagueness of its criteria, it has proven an extraordinarily durable assessment tool. The search for more robust prediction methodologies has continues, however, and considerable success has been achieved in the assessment of cardiac risk specifically.

As discussed earlier the primary purpose of the preoperative medical evaluation is the identification of patients who are at higher risk for postoperative complications. While the standard history and physical examination remain the principle screening method for the detection of conditions likely to affect surgical outcome, rating systems have been developed to identify patients who are most likely to develop postoperative complications.

A sentinel example is the landmark work of Goldman on cardiac risk in patients undergoing noncardiac surgery [33]. The Goldman *Cardiac Risk Index*, a tool well known in the perioperative community, has undergone extensive study and subsequent revision yielding the *Revised Cardiac Risk Index* (Table 1.2) [34–36]. This is likely the next most employed scoring system developed to date, second only to the ASA scale previously discussed. In this index one point is assigned for each of the six independent factors associated with major cardiac complications in patients undergoing surgery. The incidence of such complications in patients with zero, one, two, or three risk factors was 0.4, 0.9, 7, and 11 % in a validation cohort [30]. Owing to its simplicity the index remains highly popular. Cardiac risk assessment has been taken to even higher levels with the American College of Cardiology/American Heart Association guidelines for perioperative cardiovascular evaluation in noncardiac surgery [37]. Integrating patient and surgical factors, the ACC/AHA algorithms assess patients' risk for postoperative cardiac events and then go further, guiding decision-making through the identification of patients who should undergo more extensive cardiac evaluation preoperatively and those who might benefit from risk factor modification prior to surgery. This approach is fully discussed and in Chap. 11. Further, other prediction tools have been developed. These include indices for pulmonary complications, specifically respiratory failure [38] and pneumonia [39]; a useful prediction tool for postoperative hepatic failure (MELD Score) is also in widespread use [40, 41].

The search for more global indicators of risk nonetheless continues. Investigators at the John Hopkins Medical Center have developed a surgical risk index, fashioned after the ASA scale, focused on the magnitude (invasiveness) of the surgery and anticipated blood loss. This system is limited by its failure to incorporate patient related factors. Alternatively Canadian investigators have proposed a risk classification that combines patient comorbidity and surgical severity [42]. Along these lines a more elaborate effort is that of Holt and Silverman who propose a *resilience* score for organ systems compromised by an underlying disease process [43]. In this methodology an overall resilience score for a given organ system is derived by adding the standard ASA class to a surgical complexity score (rated 1–5). The maximal score is therefore 10 and, the higher the score, the more likely that a given organ system will suffer injury or fail in the setting of a surgical stress. Individual scores for each organ system assigned a score of $\geq$3 are then added and reflect the impact of multisystem disease. Finally there is the methodology developed by the National Surgical Quality Improvement Program (NSQIP), whose risk calculator provides patient-specific risk estimates across a range of surgical procedures

**Table 1.2** Independent predictors of major cardiac complications and estimation of risk with revised cardiac risk index

| | |
|---|---|
| Revised cardiac risk index (RCRI[a]) | |
| High-risk surgery[b] | |
| Ischemic heart disease[c] | |
| History of congestive heart failure | |
| Insulin therapy for diabetes | |
| Preoperative serum creatinine >2.0 mg/dL | |
| Risk of major perioperative cardiac event[d] based on predictors in the RCRI[e] | |
| *No. of risk factors* | *Risk of cardiac event, % (95 % CI)* |
| 0 | 0.4 (0.1–0.8) |
| 1 | 1.0 (0.5–1.4) |
| 2 | 2.4 (1.3–3.5) |
| >3 | 5.4 (2.8–7.9) |

Used with permission from Ashton, JN, Hatton KW, Flynn JD. PerioperativeBeta-Blockade in Patients Undergoing Noncardiac Surgery. Orthopedics 2010; 22(7): 488–491

*CI* confidence interval

[a]Lee TH, Marcantonio ER, Mangione CM, et al. Derivation and prospective validation of a simple index for prediction of cardiac risk of major noncardiac surgery. Circulation. 1999; 100(10):1043–1049

[b]Includes vascular surgery and any open intraperitoneal or intrathoracic procedures

[c]History of myocardial infarction or a positive exercise test, current complaint of chest pain considered secondary to myocardial ischemia, use of nitrate therapy, or ECG with pathological Q-waves

[d]Includes cardiac death, nonfatal myocardial infarction, and nonfatal cardiac arrest

[e]Devereaux PJ, Goldman L, Cook DJ, Gilbert K, Leslie K, Guyatt GH. Perioperative cardiac events in patients undergoing noncardiac surgery: a review of the magnitude of the problem, the pathophysiology of the events and methods to estimate and communicate risk. CMAJ. 2005; 173(6):627–634

and is available via the web (www.riskcalculator.facs.org/Home/About/). While of significant interest, more work needs to be done utilizing these global preoperative predictors in order to determine their utility in diverse surgical populations.

## Patient Education and Preventive Practices

Patient education and the introduction of preventive practices represent the final goals of the preoperative evaluation. At our institution, preoperative classes are conducted daily for all patients scheduled for total hip and knee arthroplasty as well as those who are to undergo spinal surgery. These sessions review the entire inpatient and postoperative experience associated with these major orthopedic procedures. Supplemented by a comprehensive guide given to each patient, the classes provide an opportunity for patients and their family members to ask questions of the trained nursing educational leaders about the entire perioperative experience. Studies have been conducted in the orthopedic setting, demonstrating a number of benefits of such educational practices; these include a reduction in surgery-associated anxiety and pain [44] as well as a reduction in length of stay [45].

Arising logically from the educational ethos, the implementation of preventive measures has long been an aspirational element of the preoperative assessment. While the range of putative deterrent interventions and the clinical settings in which they might apply remains poorly characterized, there are few data substantiating the role and effectiveness of such approaches. Smoking cessation has received the most attention, in part because it is a sound health promoting recommendation in general. Nonetheless, the termination of cigarette smoking is often not practical, as smoking cessation needs to take place many weeks prior to the procedure, generally well before the preoperative consultation takes place. In the realm of orthopedic surgery, however, the opportunity to implement effective prevention is enhanced by the often, elective nature of the procedure. Weight loss is another important target for prevention, as obesity is not uncommon in the orthopedic setting. Indeed, obesity remains a relevant issue with respect to such concerns as prosthetic longevity in the setting of total hip and knee arthroplasty and the long-term results from spinal surgery; obesity as a medical problem remains a major societal challenge fraught with well-known challenges.

## Efficacy of Preoperative Consultation

Until recently the efficacy of preoperative assessment has essentially been assumed [46, 47], justified by the aging and increasing complexity of modern-day surgical patients. The anticipated benefits of consultation in the preoperative setting include the documentation of comorbid disease, to optimize such preexisting conditions through the selective performance of additional investigations and timely referral for subspecialty consultation, the initiation of interventions intended to reduce risk, to anticipate the postoperative needs of the patient, and to defer and occasionally cancel surgery [48]. Studies examining a number of aspects of the preoperative consultation including their impact on such adverse outcomes as day of surgery cancellations [49, 50], duration of hospitalization [36, 51], and hospital costs [37, 52] and on patient anxiety [38]. Such studies have focused on quality concerns and the financial impact of preoperative consultation, but there are other important considerations. For example patient satisfaction is favorably influenced by the preoperative evaluation. In one study patients rated meeting with the anesthesiologist preoperatively a higher priority than that of obtaining information on pain relief, methods of anesthesia, and discussion concerning potential complications of surgery [53].

Data concerning the quality of the preoperative consultation have been published. Observations from the Australian Incident Monitoring Study (AIMS) shed light on this issue [54]. In this study 11 % of preoperative assessments were considered either inadequate or incorrect; 3.1 % of all adverse postoperative events were judged a direct result of these flawed practices. Amongst those patients experiencing postoperative complications, the morbidity was considered major and only 5 % of such events were considered unpreventable. Another study, of anesthetic-related deaths, further develops this theme. Thirty-nine percent (53/135) of such deaths involved suboptimal preoperative assessment and management [55].

The aforementioned entrenchment of the preoperative consultation has occurred despite a lack of evidence to support its widespread acceptance. One randomized trial of preoperative medical consultation showed little benefit on postoperative outcome or on quality of care [56]. In another study of 1,282 patients undergoing surgery, preoperative consultation resulted in no improvement in quality of care indicators (glucose in the diabetic, DVT prophylaxis, DVT) [57]. Two recent studies have examined the impact of preoperative consultation on a macro level [58, 59]. In these cohort studies Wijeysundera et al. utilized population-based databases to examine the impact of preoperative anesthesia and medical consultation on a large surgical population (270,000 patients) undergoing a broad range of major procedures. In addition to mortality and length of stay, a number of process-related phenomena were assessed in order to judge how preoperative consultation might influence differentials in outcome.

While modest differences were found according to whether the preoperative consultation was performed by an anesthesiologist or by a medically trained physician, several themes emerged from these reports. First, over the 10-year period (1994–2003) of the study, the rate of preoperative consultation increased from 19 to 53 %. Presumably reflecting a perceived benefit of consultation on the part of the referring surgeons, the withdrawal to the operating room by the surgical community is also likely responsible. Amongst the medical consultations, the majority (94.2 %) were performed in the outpatient setting, generally about 2 weeks before the surgery. Consultation was associated with higher rates of preoperative testing, the preoperative use (new) of beta-blockers and statin drugs, and preoperative cardiac interventions suggesting an active engagement in decision-making by the preoperative physicians. In terms of benefit, however, the results were disappointing. Regardless of who performed the consultation (anesthesiologist vs medical physician), no reduction in mortality could be shown; indeed, patients undergoing preoperative medical consultation had a modest increase in 1-year mortality. Length of stay was also longer (+0.67 days) in patients who underwent medical consultation (though −0.35 days shorter in those who saw an anesthesiologist prior to surgery). Given the support and general belief in the practice of preoperative consultation, these results were surprising, and the authors posit a number of potential explanations for their findings. These include the association of consultation with an apparent decrease in the use of epidural anesthesia, the higher use of beta-blockers (now believed to increase the rate of stroke after surgery), and the fact that the study population did not include patients whose surgery had been cancelled, nor were those undergoing urgent-emergent procedures considered. In addition, perhaps those surgeons who felt comfortable managing medical comorbidities on their own provided superior perioperative care, thus diluting the impact of the preoperative consultation.

So what additional approaches to care might be of incremental benefit? In addressing this question, Weed brings us back to one of the foundational elements of effective consultation, that is, communication [60]. Citing Chassin, a leader in the quality movement, Weeds shows that the "beneficial effect of process" emphasizes how the achievement of optimal outcomes (i.e., postoperative complications) is inextricably a function of the process used to deliver medical care. Thus, the preoperative consultation in itself is not sufficient. Success requires the fastidious attention to the implementation of the preoperative recommendations. Comanagement, a strategy of perioperative care that emphasizes the active participation of the medical consultant, may provide an effective template [61–63]. However, the experience with this model in the orthopedic and other surgical settings has been mixed and generated commentary of a cautionary nature [64].

Nonetheless, it seems unlikely that such qualifications represent significant offsets to the major conclusions of these influential studies. While surgeons, anesthesiologists, and internists alike continue to believe in preoperative evaluation, belief alone may not be enough. In an era of evidence-based medicine, these observations challenge the perioperative community to demonstrate the efficacy of their practices.

## Summary

The medical evaluation of a patient prior to surgery remains a widespread clinical practice. Although, as discussed previously, the overall utility of such assessments remains to be demonstrated, the enduring and widespread support for such consultation is supported by clinical investigation and

growing literature, even national conferences. Owing to this widespread acceptance, the underpinning of perioperative medicine, its principles and practices, is evolving influenced by the quality movement of the last 15 years. This chapter provides a general overview and approach to the patient in the perioperative setting and offers a template not only for this book but for clinical practice as well.

**Summary Bullet Points**

- The preoperative medical evaluation offers an important opportunity for communication between all professionals involved in the care of the surgical patient.
- The term surgical "clearance" should be replaced by the notion of preoperative "optimization" for surgery.
- The goals of the preoperative evaluation include the evaluation and optimization of patient comorbidity, the assessment of surgical risk, and to provide an opportunity for patient education and the implementation of preventive practices.
- The practice of the preoperative medical evaluation remains an unproven medical intervention.

## References


1. Newman MF, Fleisher LA, Fink MP. Perioperative medicine: managing for outcome. Philadelphia, PA: Saunders Elsevier; 2008.
2. Cohn SL, Smetana GW, Weed HG. Perioperative medicine: just the facts. New York, NY: McGraw-Hill; 2006.
3. Sweitzer BJ. Preoperative assessment and management. Philadelphia, PA: Wolters Kluwer Lippincott Williams & Wilkins; 2008.
4. MacKenzie CR, Sharrock N. Perioperative care of the patient with rheumatic disease. In: Paget S, Gibofsky A, Beary JF, et al., editors. Manual of rheumatology and outpatient orthopedic disorders: diagnosis and treatment. 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2006.
5. MacKenzie CR, Sharrock NE. Perioperative medical considerations in patients with rheumatoid arthritis. Rheum Clin N Am. 1998;24:1–17.
6. Schirmer B. Ambulatory surgery. Philadelphia, PA: WB Saunders; 1998.
7. MacKenzie CR, Mandle LA, Reyes C, et al. Are ambulatory surgical patients as health as we think? Using a self-reported health status questionnaire to identify unsuspected medical comorbidities. HSSJ. 2006;2:121–6.
8. Salerno SM, Hurst FP, Halvorson S, et al. Principles of effective consultation: an update for the 21st-century consultant. Arch Intern Med. 2007;167:271–5.
9. Goldman L, Lee T, Rudd P. Ten commandments for effective consultation. Arch Intern Med. 1983;143:1753–5.
10. Cohn S. Preoperative medical consultation. Med Clin N Am. 2003;87:1.
11. Hlatky MA, Boineay RE, Higginbotham MB, et al. A brief, self-administered questionnaire to determine functional capacity (the Duke Activity Status Index). Am J Cardiol. 1989;64:651–4.
12. Fleisher LA, Beckman JA, Borwn KA, et al (2007) ACC/AHA guidelines for perioperative cardiovascular evaluation and care for noncardiac surgery. J Am Coll Cardiol 50:e159–241. http://www.acc.org
13. Blery C, Szatan M, Fourgeaux B, et al. Evaluation of a protocol for selective ordering of preoperative tests. Lancet. 1986;18:139–41.
14. Apfelbaum JL. Preoperative evaluation, laboratory screening, and selection of adult surgical outpatients in the 1990s. Anesth Rev. 1990;17 Suppl 2:4–12.
15. Charpak Y, Blery C, Chastang C, et al. Usefulness of selectively ordered preoperative tests. Med Care. 1988;36:95–104.
16. Macpherson DS, Snow R, Logren RP. Preoperative screening: value of previous tests. Ann Intern Med. 1990;113:969–73.
17. Lawrence VA, Ganfi A, Gross M. The unproven utility of the preoperative urinalysis: economic evaluation. J Clin Epidemiol. 1989;42:1185–92.
18. Smetana GW, Macpherson DS. The case against routine preoperative laboratory testing. Med Clin N Am. 2003;87:7–40.
19. Mancuso CA. Impact of new guidelines on physician's ordering of preoperative tests. J Gen Intern Med. 1999;14:166–72.
20. Narr BJ, Hansen TR, Warner MA. Preoperative laboratory screening in healthy Mayo patients: cost-effective elimination tests and unchanged outcomes. Mayo Clin Proc. 1991;66:155–9.
21. Narr BJ, Warner ME, Schroeder DR, et al. Outcomes of patients with no laboratory assessment before anesthesia and a surgical procedure. Mayo Clin Proc. 1997;72:505–9.
22. Schein OD, Katz J, Bass ED, et al. The value of routine preoperative medical testing before cataract surgery. N Engl J Med. 2000;343:168–75.
23. Roizen MF. More preoperative assessment by physicians and less by laboratory tests. N Engl J Med. 2000;342:204–5.
24. Railton CJ, Wolpin J, Lam-McCulloch J, et al. Renin-angiotensin blockade is associated with increased mortality after vascular surgery. Can J Anesth. 2010;89:736–44.
25. Goodman SM, Krauser D, MacKenzie CR, et al. Cardiac arrest during total hip arthroplasty in a patient on an angiotensin receptor antagonist. HSSJ. 2012;8(2):175–83.
26. Tung A. Risk reduction and risk assessment. In: Sweitzer BJ, editor. Preoperative assessment and management. 2nd ed. Philadelphia, PA: Wolters Kluwer/Lippincott Williams & Wilkins; 2008.
27. Beecher HA, Todd DP. A study of the deaths associated with anesthesia and surgery: based on a study of 599,548 anesthesias in ten institutions 1948-1942. Ann Surg. 1954;140:2–34.
28. Lunn J, Devlin HB. Lessons from the confidential enquiry into perioperative deaths in three NHS regions. Lancet. 1987;330:1384–6.
29. Saklad M. Grading of patients for surgical procedures. Anesthesiology. 1941;2:281–4.
30. www.asahq.org/clinical/physicalstatus.htm.
31. Prause G, Ratzenhofer-Comenda B, Pierer G, et al. Can ASA grade or Goldman's cardiac risk index predict peri-operative mortality? A study of 16,227 patients. Anaesthesia. 1997;52:203–6.
32. Keats AS, The ASA. Classification of physical status - a recapitulation. Anesthesiology. 1978;49:233.
33. Goldman L, Caldera DL, Nussbaum SR, et al. Multifactorial index of cardiac risk in noncardiac surgical procedures. N Engl J Med. 1977;297:845–50.
34. Detsky A, Abrams H, McLaughlin J, et al. Predicting cardiac complications in patients undergoing non-cardiac surgery. J Gen Intern Med. 1986;1:211–9.

35. Eagle KA, Coley CM, Newell JB, et al. Combining clinical and thallium data optimizes preoperative assessment of cardiac risk before major vascular surgery. Ann Int Med. 1989;110:859–66.
36. Lee HT, Marcantonio ER, Mangione CM, et al. Derivation and prospective validation of a simple index for prediction of cardiac risk of major noncardiac surgery. Circulation. 1999;100:1043–9.
37. Fleisher LA, Beckman JA, Brown KA, et al. ACC?AHA guidelines on perioperative cardiovascular evaluation and care for noncardiac surgery. J Am Coll Cardiol. 2007;50:e159–241.
38. Arozullah AM, Daley J, Henderson WG, et al. Multifactorial risk index for predicting postoperative respiratory failure in men after major noncardiac surgery. The National Veterans Administration Surgical Quality Improvement Program. Ann Surg. 2000;232:242–53.
39. Arozullah AM, Khuri SF, Henderson WG, et al. Development and validation of a multifactorial risk index for predicting postoperative pneumonia after major noncardiac surgery. Ann Int Med. 2001;135:847–57.
40. Costa BP, Sousa FC, Serodio M, et al. Value of MELD and MELD-based indices in surgical risk evaluation of cirrhotic patients: retrospective analysis of 190 cases. World J Surg. 2009;33:1711–9.
41. www.unos.org
42. Pasternak LR. Risk assessment in ambulatory surgery: challenges and new trends. Can J Anaesth. 2004;51:R4.
43. Holt N, Silverman DG. Modeling perioperative risk: can numbers speak louder than words. Anesthesiol Clin N Am. 2006;24:427–59.
44. Giraudet-Le Quintrec HS, Coste J, Vastel L, et al. Positive effect of patient education for hip surgery: a randomized trial. Clin Ortho Rel Res. 2003;414:112–20.
45. Jones S, Alnaib M, Kokkinakis M, et al. Pre-operative patient education reduces length of stay after knee joint arthroplasty. Ann R Coll Surg Eng. 2011;93(1):71–5.
46. American Society of Anesthesiologist Task Force on Preanestheisa Evaluation. Practice advisory for preanesthesia evaluation: a report by the American Society of Anesthesiologist Task Force on Preanestheisa Evaluation. Anesthesiology. 2002;96:485–96.
47. Cohn SL, Macpherson DS. Overview of the principles of medical consultation. In: Rose ED, editor. UpToDate. Wellesley, MA: UpToDate; 2005.
48. Wijeysundera DN. Preoperative consultations by anesthesiologists. Curr Opin Anesthesiol. 2011;24:326–30.
49. Ferschl MB, Tung A, Sweitzer B, et al. Preoperative clinic visits reduce operating room cancellations and delays. Anesthesiology. 2005;103(4):855–9.
50. van Klei WA, Moons KG, Rutten CL, et al. The effect of outpatient preoperative evaluation of hospital inpatients on cancellation of surgery and length of hospital stay. Anesth Anal. 2002;94(3):644–9.
51. Pollard JB, Garnerin P, Dalman RL. Use of outpatient preoperative evaluation to decrease length of stay for vascular surgery. Anesth Analg. 1997;85(6):1307–11.
52. Ferschl MB, Tung A, Sweitzer BJ, et al. Economic impact of a preoperative clinic on operating room efficiency. Anesthesiology. 2005;103:855–9.
53. Lonsdale M, Hutchison GL. Patient's desire for information about anesthesia: Scottish and Canadian attitudes. Anesthesiology. 1991;46:410–2.
54. Kluger MT, Tham EJ, Coleman NA, et al. Inadequate preoperative evaluation and preparation: a review of 197 reports from the Australian incident monitoring study. Anaesthesia. 2000;55:1173–8.
55. Davis NJ, editor. Anaestheia-related mortality in Australia 1994-1996. Melbourne, VIC: Capital Press; 1999.
56. Macpherson DS, Lofgren RP. Outpatient internal medicine preoperative evaluation: a randomized clinical trial. Med Care. 1994;32(5):498–507.
57. Auerbach AD, Rasic MA, Sehgal N, et al. Opportunity missed Medical consultation, resource use, and quality of care of patients undergoing major surgery. Arch Int Med. 2007;167(21):2338–44.
58. Wijeysundera DN, Austin PC, Beattie WS, et al. A population-based study of anesthesia consultation before major noncardiac surgery. JAMA. 2009;169(6):595–602.
59. Wijeysundera DN, Austin PC, Beattie WS, et al. Outcomes and processes of care related to preoperative medical consultation. Arch Int Med. 2010;170(15):1365–74.
60. Weed HG. Outcomes of preoperative medical consultation. JAMA. 2011;171(4):367–8.
61. Macpherson DS, Parenti C, Nee J, et al. An internist joins the surgery service: does comanagement make a difference? J Gen Intern Med. 1994;9(8):440–4.
62. Huddleston JM, Long KH, Naessens JM, et al. Hospitalist-orthopedic team trial investigators: medical and surgical comanagement after elective hip and knee arthroplasty: a randomized, controlled trial. Ann Int Med. 2004;141(1):28–38.
63. Phy MP, Vanness DJ, Melton III LJ, et al. Effects of a hospitalist model on elderly patients with hip fracture. Arch Int Med. 2005;165(7):796–801.
64. O'Malley PG. Internal medicine comanagement of surgical patients: can we afford to do this? Arch Intern Med. 2010;170(22):1965–6.

# The Prevalence of Disabling Musculoskeletal Conditions and the Demand for Orthopedic Surgery in the Twenty-First Century

2

Anas Saleh and Charles N. Cornell

**Objectives**

- To document the prevalence of musculoskeletal diseases which require hospitalization and often surgical treatment.
- To present the typical outcomes of surgical treatment of musculoskeletal conditions.
- To present the risk and incidence of complications associated with surgical care of musculoskeletal conditions.

**Key Points**

- The majority of hospitalizations and indications for surgery for musculoskeletal conditions result from degenerative diseases of the spine and major lower extremity joints
- Spinal surgery, which follows careful selection criteria, typically results in pain relief, improved function, and improved quality of life which is maintained over long term periods of observation.
- Complications following spinal surgery are affected by age of the patient, anatomic location of disease and the surgical approach. Older patients with preexisting comorbidities, posterior approaches to the cervical spine and anterior approaches to the thoracolumbar spine are associated with higher risks of postoperative complications.
- Rapid growth in the demand for total hip and total knee arthroplasty has occurred over the past decade reflecting aging of the population as well as the success and safety of these procedures.
- Morbidity and mortality following total hip replacement (THR) and total knee replacement (TKR) are rare and the incidence of complications and death has decreased over time. Thromboembolic events have been reduced with adoption of routine prophylaxis protocols.
- Myocardial infarction occurs in approximately 3 % of patients and stroke in 0.5 % and patients over 70 years of age appear to be at greater risk.

## Introduction

Musculoskeletal conditions are among the most disabling and costly conditions affecting the American population. As the US population rapidly ages, musculoskeletal impairments will increase. By the year 2030, the number of individuals in America over the age of 65 will double, with people above 85 years of age constituting the fastest growing segment of our society [1]. Similar demographic changes are predicted for Europe. Bone and joint disorders account for more than one half of reported conditions in people over the age of 50 and are the most common cause of pain and disability.

The economic impact of musculoskeletal disease is enormous. The projection of direct costs of the medical care required to treat musculoskeletal conditions from 2002 to 2004 was $510 billion, or 4.6 % of our nation's gross domestic product (GDP). Indirect costs resulting from lost wages due to inability to perform ones job added another $331 billion, or 3.1 % of GDP [1]. Advances in the care of patients with musculoskeletal diseases that mitigate the long term suffering and economic impact of these conditions and help these patients return to full and active

A. Saleh (✉)
Department of Orthopaedic Surgery, Cleveland Clinic Foundation, Cleveland, OH, USA
e-mail: Anas.ar.saleh@gmail.com

C.N. Cornell
Clinical Orthopedic Surgery, Department of Orthopedic Surgery, Weill Cornell Medical College, and Hospital for Special Surgery, New York, NY, USA
e-mail: cornellc@hss.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_2, © Springer New York 2014

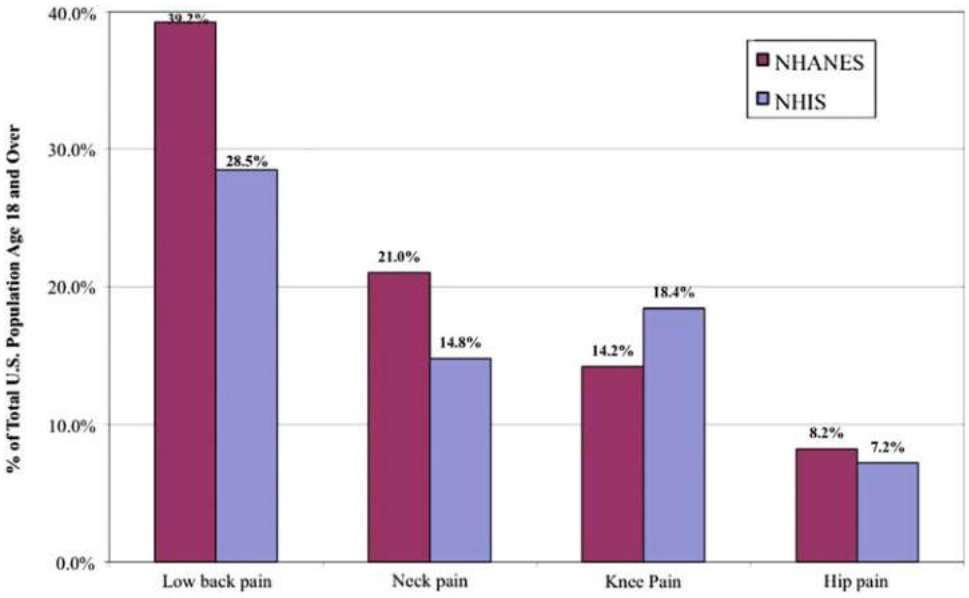


**Fig. 2.1** Prevalence of self-reported joint pain by site for persons aged 18 and over in two national health surveys, USA 1999–2005. *NHANES* National Health and Nutrition Examination Survey, *NHIS* National Health Interview Survey (Used with permission from Jacobs JJ. United States Bone and Joint Initiative. The Burden of Musculoskeletal Diseases in the United States: Prevalence, Societal and Economic Cost. Rosemont, IL: © American Academy of Orthopedic Surgeons, 2008)

lives are clearly the goal for all physicians involved in their care.

The majority of hospitalizations and indications for surgery for musculoskeletal conditions result from degenerative diseases of the spine and major lower extremity joints. The aims of this chapter are to review the current incidence of degenerative disorders of the spine that lead to reconstructive spine surgery, and to review the incidence of complications resulting from spine surgery as well as he incidence and prevalence of osteoarthritis of the hip and knee leading to the frequency of total hip and total knee arthroplasty procedures. The frequency of complications following these procedures will also be reviewed.

## Incidence of Degenerative Disorders of the Spine

Lumbar spine disorders are more common than cervical spine disorders but combined they represent one of the most frequent reasons for physician visits and hospitalization. The majority of patients presenting with back pain are in the age group between 18 and 64 years of age [1]. In many of these cases, patients lose work days compounding the financial and societal impacts of the problem.

Lower back pain is the most frequently reported single site of pain in the back. In 2004, between 30 and 40 % of people in the USA report experiencing low back pain in a previous 3-month period [2, 3]. Overall, about one in two persons report experiencing back pain at least once a year, which is a greater rate of pain than that reported for hips, knees, or upper limbs (Fig. 2.1). Degenerative disk disorder of the spine is the most common disease entity associated with lower back pain. In 2004, Lumbar disk disorders, including disk degeneration and herniation, comprised 27 % of hospitalizations, and were seen most frequently among persons aged 45–74. Although cervical/neck pain is less common than lower back pain, it is still a very common reason for physician visits, accounting for 1.5 % of all health care visits. Both low back pain and neck pain are found more commonly among females.

## Incidence of Spine Procedures

Nonsurgical intervention is usually the preferred initial treatment for back pain. Spine surgery may be indicated in cases of severe intractable pain that causes significant disability. The three most frequently performed spine procedures in 2004 were diskectomy, spinal fusion, and spinal decompression (Fig. 2.2).

Spinal diskectomy was the most common spine procedure in 2004, performed in 325,300 cases accounting for 34 % of all spine procedures [4]. Approximately 60 % of these diskectomies were performed for degenerative disease of the lumbar spine (disk degeneration, spondylosis, spinal stenosis), and around 30 % for cervical indications. The most

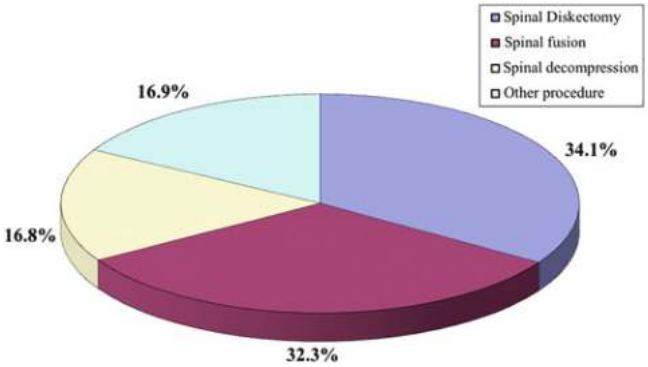


**Fig. 2.2** Select spine procedures as a proportion of all spine procedures, USA 2004 (Used with permission from Jacobs JJ. United States Bone and Joint Initiative. The Burden of Musculoskeletal Diseases in the United States: Prevalence, Societal and Economic Cost. Rosemont, IL: © American Academy of Orthopedic Surgeons, 2008)

common primary diagnosis in cervical spine fusion cases is cervical disk displacement (19 %).

Spinal fusion, the second most common spine procedure performed in 2004, may be done in conjunction with spinal decompression. In 2004, over 307,800 spine fusion procedures were performed (32 % of all spine procedures). Lumbar spinal fusion rates have increased more rapidly than the rates of cervical or thoracic fusion [5, 6], and in 2004, the number of lumbar fusion procedures was higher than cervical procedures, accounting for 46 % versus 41 % of all fusion procedures. It should be noted, however, that rates of lumbar fusion vary dramatically among geographic regions, hospitals, and even between surgeons in the same hospital, probably due to the variation in consensus regarding the indications for and the outcomes of lumbar fusion [7]. Decompression procedures that are presumably performed for spinal stenosis were performed in 160,000 cases during 2004 representing 17 % of spine procedures.

The population of lumbar spine stenosis represents a growing public health challenge for spine surgeons around the world. The literature showed good outcomes after elective surgical management of lumbar stenosis and stable pain relief up to 10 years [8–10]. A recent observational cohort study sought to compare the improvement in patient self-reported quality of life after lumbar spine surgery (decompression alone, or decompression and fusion) with the benchmark set by total joint arthroplasty [11]. With strict patient selection criteria and appropriate nonsurgical management, the results of this study showed excellent improvement in patient-reported quality of life after both decompression alone and decompression and fusion for lumbar stenosis. At 2 years after surgery, 85 % and 80 % of patients reported improved physical and mental quality of life questionnaires, respectively, which is comparable to that of total hip and total knee arthroplasties. Several studies have shown that the initial results of surgery, particularly regarding relief of leg symptoms, can be reasonably maintained (60–80 %) in the long term with an approximate re-operation rate of 1–2 % per year [10, 12–16].

The incidence of spinal fusion expressed as the number of procedures performed per 100,000 persons in the population has increased dramatically over the past 15 years. In 1998 the incidence was 85 per 100,000, which has risen to 122 per 100,000 in 2004. The likely explanations for this increase are advances in spinal instrumentation technology, improvements in the resolution of diagnostic imaging, and the broadening of indications for spine surgery. However, some of the increase must be attributed to the aging of the population with an accompanying increased incidence of spinal disorders as well as increased training in spinal surgery.

## Incidence of Complications After Spine Surgery

Before reviewing the literature for incidence of complications in spine surgery, it is crucial to realize that reported incidence rates vary significantly due to several factors, including: (1) Definition and classification of complications, (2) Study methodology, (3) Surgeon-related factors, (4) procedure-related factors, (5) Patient-related factors.

### Definition and Classification of Complications

Efforts to understand, report, and reduce complications in spine surgery have been hampered as a result of the lack of a meaningful and universally acceptable definition. The complex field of spine surgery has been a particularly challenging area for the development of a consensus to constructively define and classify complications. The term "complication" is typically used with an emphasis on events that occur intraoperatively or immediately after surgery. Some authors developed severity scores to better measure the severity of adverse events [17], whereas others used spine surgeon surveys that are validated through parallel assessment of patients undergoing spine surgery [18]. Several studies have graded complications as minor, moderate, or major [19–21].

Rampersaud et al. used the term "adverse events" to describe "any unexpected or undesirable event(s) occurring as a direct or indirect result of surgery," and defined a complication as a disease or disorder resulting from surgery that will change the expected outcome of the patient [22]. According to these definitions, 98 intraoperative adverse events out of 700 surgeries (14 %) were reported, but only 23 of them resulted in acute postoperative clinical complications (3 %). For example, a dural tear was reported in 58 cases, but after primary repair, only 8 patients continued to have CSF leak and headache. Therefore, a study

investigating the incidence of CSF leaks may underestimate the incidence of dural tears, leading to conflicting incidence reports, and a false sense of security that overlooks protocols that could easily minimize or prevent these typically "inconsequential" adverse events. Unfortunately, the overall strength of the evidence to establish a standardized system for grading and defining complications in spine surgery is low indicating that further exploration and standardization are needed [23].

## Study Methodology

Retrospective studies may underestimate actual complication incidence through the introduction of investigator recall bias [24, 25]. A disproportionate reliance on the memory of investigators and accuracy of medical records may lead to falsely low or high reported rates of complication. Also, the reliance on the International Classification of Diseases (ICD-9) codes to search complications and procedures compromises the quality of data. This method inherently limits the scope and therefore the incidence of complications. In addition, ICD-9 codes do not address the severity of complication. For example, Deyo et al. [26] retrospectively analyzed a statewide hospital discharge registry and compiled data on more than 18,000 hospitalizations over a 2-year period. The authors reported an overall complication rate of 10.3 % for the surgical treatment of degenerative lumbar spine disease. However, since they used ICD-9 codes for identifying complications, the most frequently listed complications were unspecified or unclassified (2.5 %); thus, it was impossible to gauge their severity. Moreover, ICD-9-CM codes were used to describe the surgical procedure, which do not provide more details about the procedures such as the number of levels, use of microsurgical techniques, or methods of arthrodesis.

One systematic review of spine surgery articles assessing complications of surgery indicated that retrospective reviews underestimate the incidence of complications. Overall, prospective studies reported a higher incidence of complications (19.9 %) than did retrospective studies (16.1 %, $p < 0.001$, OR 1.3) [19]. Moreover, Duration of follow-up correlated with complication incidence, with longer periods of follow-up associated with an increased incidence of operative complications.

## Surgeon-Related Factors

Due to the wide range of complication rates of spine surgery, some authors have questioned the effect of the surgeon's experience on complication rates. Wiese et al. compared the incidence of durotomy between surgeons who had performed 50–100 and those who performed >500 microdiskectomies and demonstrated a higher incidence of overall complications rate in the former group (10.7 % versus 2.2 %, $p < 0.001$) [27]. However, another recent retrospective study of more than 108,000 cases performed by members of the Scoliosis Research Society (SRS) did not find a difference in the incidence of durotomy depending on surgeon experience, with active members presumably having more and candidate members presumably having less experience [28]. Although not specifically assessed, the vast majority of candidate members of the SRS are fellowship-trained spine surgeons dedicated to the treatment of complex spinal conditions. This may contrast with the less experienced group described in the study of Wiese et al.

## Procedure-Related Factors

Complications also vary in severity and incidence among the different surgical approaches and anatomical regions. For example, in cervical spine surgery, the posterior approach-related complications include pain from injury to paraspinal muscles, epidural hematoma, and neurological injury, whereas dysphagia, recurrent laryngeal nerve damage, and rarely tracheal or esophageal perforation can occur with an anterior approach [29, 30]. As for the different anatomical regions of the spine, one meta-analysis indicates that thoracolumbar procedures have significantly more complications than in cervical procedures (17.8 % versus 8.9 %, $p < 0.001$) [19].

Overall complication rates in cervical spine surgery range from 0.1 to 19.3 %, and the mortality rates from 0.1 to 0.8 % [23]. Although an anterior approach is associated with a greater incidence of dysphagia and hoarseness, the posterior approach, particularly posterior fusion procedures, have been consistently associated with greater incidence of complications and perioperative morbidity, and nearly double resource utilization including hospital length of stay, inflation adjusted cost, and likelihood of discharge to an assisted-living facility [31–33]. A population-based analysis of 771,932 anterior cervical spine fusions from the National Hospital Discharge Survey (NHDS) showed an overall procedure-related complications rate of 7.23 % in the period 1990–1994, 5.05 % in 1995–1999, and 4.82 % in 2000–2004 [34]. See Fig. 2.3. A reduction was seen for all organ-specific complications between 1990 and 2004, except for cardiac and respiratory. In-hospital mortality decreased from 0.93 to 0.2 and 0.18 % in the time periods 1990–1994, 1995–1999, and 2000–2004.

In lumbar procedures, the overall complication rates range from 3.7 to 12.8 % [23]. Reoperation rates range from 0.5 to 19 %, and are highest in fusion procedures. In

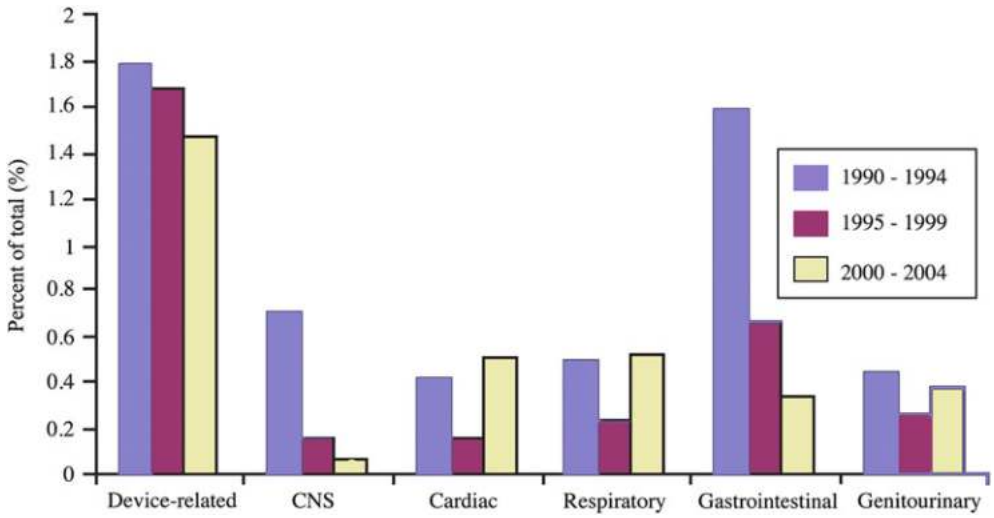


**Fig. 2.3** Prevalence of procedure-related complications following anterior cervical spine fusion, United States 1990–2005 (Used with permission from Marwar S, Girardi FP, Sama AA, et al. National trends in anterior cervical fusion procedures. Spine (Phila Pa 1976). 2010;35:1454–1459)

**Table 2.1** Prevalence of procedure-related complications after non-cervical spine fusion, USA 1998–2006

| | Non-cervical spine fusion | | | |
|---|---|---|---|---|
| Complication | Anterior, % ($N$ = 36,224) | Posterior, % ($N$ = 201,885) | Anterior/posterior, % ($N$ = 113,991) | All procedures, % ($N$ = 261,356) |
| Complications affecting specific body system | | | | |
| Central nervous system | 0.4 | 10.2 | 0.8 | 0.9 |
| Cardiopulmonary | 3.2 | 2.4 | 5.3 | 2.8 |
| Gastrointestinal | 4.8 | 2.1 | 5.6 | 2.8 |
| Genitourinary | 0.9 | 1.1 | 1.2 | 1.1 |
| Other complications of procedure | | | | |
| Postoperative shock | 0.1 | 0.1 | 0.2 | 0.1 |
| Hematoma | 1.5 | 1.6 | 2.7 | 1.6 |
| Postoperative infection | 0.8 | 0.5 | 1.2 | 0.6 |
| Thromboembolic events | 0.9 | 0.7 | 1.3 | 1.2 |
| Pulmonary embolism | 0.3 | 0.3 | 0.5 | 0.5 |
| Death | 0.5 | 0.3 | 0.4 | 0.3 |

Used with permission from Memtsoudis SG, Vougioukas VI, Ma Y, et al. Perioperative morbidity and mortality after anterior, posterior, and anterior/posterior spine fusion surgery. Spine (Phila Pa 1976). 2011;36:1867–1877
$p < 0.001$ between all approach types

general, fusion procedures appear to be associated with a higher overall rate of complication [26, 35]. In a recent study, data collected between 1998 and 2006 from the National Inpatient Sample were analyzed to assess the incidence of perioperative morbidity and mortality in anterior, posterior, and anterior/posterior non-cervical spine fusion [36]. 261,356 admissions were identified during which a primary spine fusion procedure was performed. Of those, 77 % were anterior, 14 % were posterior, and 9 % were anterior/posterior fusions. Procedure-related complications were more frequent among anterior/posterior spine fusions (23.8 %) as compared to anterior (18.7 %) and posterior (15 %) spine fusion (Table 2.1). Also, the incidence of thromboembolic events was higher among anterior/posterior spine fusion patients. While anterior procedures in the cervical regions appear to be associated with fewer complications, this study indicates that this does not hold true for thoracic and lumbar regions of the spine. Procedures involving the anterior thoracolumbar spine are associated with higher morbidity and mortality, possibly due to the entry of abdominal and thoracic cavity and the proximity of vital organs. The highest rate of morbidity and mortality was seen in the anterior/posterior fusion patients, which can be explained by longer surgical times, more blood loss, and increased surgical complexity.

Medical complications that results from spine surgery are challenging to manage. A significant number of patients undergoing orthopedic surgery are elderly, predisposing them to several medical complications. The rates of cerebrovascular, cardiopulmonary, gastrointestinal, and genitourinary complications in the National Inpatient Sample from 1998 to 2006 were 0.9 %, 2.8 %, 2.8 %, and 1.1 %, respectively (Table 2.1) [36]. In another single-center prospective study of 248 consecutive patients undergoing spine surgery in 2008, the rates of specific medical complications were reported, including myocardial infarction (1.2 %), pulmonary embolism (0.8 %), cerebrovascular accident (0.4 %), urinary tract infection (15.7 %), pneumonia (2.0 %), and death (0.8 %) [21].

In the context of surgical complications after spine fusion, there has been an appreciation in the more recent spine surgery literature that frequent and occasionally catastrophic complications are associated with the use of recombinant human bone morphogenetic protein-2 (rhBMP-2). When it was first introduced in 2002, preliminary human trials for a variety of spinal fusion techniques found no adverse events associated with rhBMP-2 use [37, 38]. As the use of BMP increased, with 25 % of all fusions utilizing BMP in 2006 [39], a series of studies reported serious complications associated with rhBMP-2 use, ranging from 10 to 50 % depending on the approach [40]. These complications were associated with swelling of neck and throat leading to compression of airways and/or neurological compromise in the cervical region, and radiculitis, ectopic bone formation, and osteolysis in the lumbar region.

Mortality rates among patients undergoing cervical and lumbar spine surgeries are <1 %. Though death events are rare in the cervical and lumbar spine, they are more common after thoracic spine surgery with rates as high as 64 % among vertebroplasty patients and 7.5 % among balloon kyphoplasty patients [23].

## Patient-Related Factors

Another factor leading to the increased variation in reported complications is the patient population. As would be expected in any surgical procedure, the risk of postoperative complications in spine surgery increases in older patients and patients with multiple comorbidities such as cardiac disease and diabetes [20, 31, 33, 41–43]. Patients with preoperative neurologic abnormalities are at higher risk of developing postoperative complications (OR, 2.88; CI, 1.42–5.83) [30, 31]. Complication rates are also affected by the primary diagnosis for the patient. Reoperation rates have been reported to be higher in patients diagnosed with herniated disk disease [44].

## Prevalence of Osteoarthritis and Related Reconstructive Surgeries of the Hip and Knee

Osteoarthritis (OA) is the most common type of arthritis, frequently affecting knees and hips, leading to progressive damage to the cartilage and other joint tissues. In a study conducted in Johnston County, NC, the prevalence of knee and hip OA among adults aged 45 years and older was 17 % and 10 %, respectively [45, 46]. The prevalence is higher in older age groups and among women, but lower in Hispanics (16.5 % versus 22 % for non-Hispanics and African Americans) [47].

Although a great variety of medications have been used to address the pain and disability associated with osteoarthritis, total joint arthroplasty remains the definitive treatment for advanced, symptomatic joint destruction. Total joint arthroplasty is indicated for arthritis and a variety of other rheumatic conditions, but osteoarthritis remains the principle diagnosis in 82.5 % of total hip replacements, and 96.8 % of all total knee replacements [2]. The hip and the knee are the most frequently replaced joints. In 2004, hip and knee replacements accounted for 95 % of the 1.07 million arthroplasty procedures performed (Fig. 2.4). Over 232,000 primary total hip arthroplasty procedures were performed (25 % of all arthroplasty procedures), and over 454,000 primary total knee arthroplasty procedures were performed (48 %). Females undergo 62 % of all total joint replacement procedures, and they undergo total knee arthroplasty twice as frequently as men reflecting the greater prevalence of knee OA in females than in males. In terms of age distribution, 60 % of primary and revision total hip and knee arthroplasty procedures are performed in patients above 65 years of age.

Data on the survival of total joint replacement implants come from several national registries. Survival rates vary depends on several factors such as patient age, implant type, and the use of cement versus cementless fixation. Analysis of the Finnish arthroplasty registry showed that for patients older than 55 years of age, the survival rates of total hip implants ranged from 92 to 98 % at 10 years, 86 to 93 % at 15 years, and 77 to 82 % at 20 years, with the end point defined as revision due to aseptic loosening of the implant [48]. Revision rates represent a crude measure of implant failure, as the need for revision operation is probably the only quantifiable event that forces the patient to return to hospital. In a systematic review, national registries were analyzed to identify revision rates after total hip and knee arthroplasties [49]. After primary hip replacement, a mean of 1.29 revisions per 100 observed component years was seen. Similarly, after total knee replacement, 1.26 revisions per 100 observed component years were seen. As for the patient's subjective measure of health-related quality of

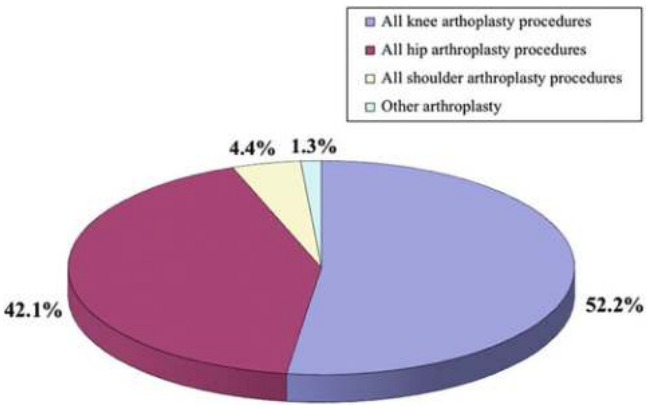


**Fig. 2.4** Arthroplasty procedures by type, USA 2004 (Used with permission from Jacobs JJ. United States Bone and Joint Initiative. The Burden of Musculoskeletal Diseases in the United States: Prevalence, Societal and Economic Cost. Rosemont, IL: © American Academy of Orthopaedic Surgeons, 2008)

life, several studies compared patients undergoing total joint replacement with a reference health group with a similar age and sex distribution [50, 51]. Patients that benefited from joint replacement had remarkably improved physical and psychosocial scores from 1 to 2 years postoperatively, and these scores were maintained up to 3–5 years.

The annual number of total joint replacement has been increasing from 1991 to 2004. There has been a threefold increase in total knee replacements, while the annual number of total hip replacements doubled. These increases in joint arthroplasty utilization outnumber the increase in incidence of OA as would be expected from an aging population. This probably represents broadening of the indications of arthroplasty procedures due to their safety and durability. There has been a parallel increase in the total estimated cost of performing total knee replacement procedures from $5.4 billion in 1998 to $14.3 billion in 2004. Projected growth model for hip and knee replacement procedures estimate that by 2030 there will be over 570,000 primary total hip replacements performed annually in the USA and nearly 3.5 million primary total knee replacements, with associated need for manpower, operating room capacity, and health care costs [1].

## The Incidence of Complications After Total Knee and Total Hip Arthroplasty

### General Trends

Despite the efficacy of total knee and total hip arthroplasty, complications can occur which result in poor functional outcomes for a subset of patients. In light of the prevalence and the increasing trends of these procedures, documenting and reviewing associated adverse events remains a priority to help optimize patient care. The National Hospital Discharge Survey (NHDS) was analyzed from 1990 to 2004 in order to elucidate temporal changes in demographics, hospital stay, in-hospital complications, and mortality of patients undergoing primary total knee [52] and total hip [53] arthroplasty during a 15-year study period in the USA. Frequencies of procedure-related complications over time were identified using ICD-9-CM diagnosis codes. In their analysis, the authors created three 5-year periods to simplify temporal changes (1990–1994, 1995–1999, and 2000–2004).

A total of 3,830,420 patients had undergone total knee arthroplasty from 1990 to 2004 based on the NHDS [52]. As expected, there was an increased utilization of primary total knee arthroplasty, increased proportion of younger patients, as well as an increased number of comorbidities among patients. Despite an increase in the rate of comorbidities, the procedure-related complication rate decreased from 12 % during the period from 1990 to 1994 to 7 % during the period from 2000 to 2004 (Table 2.2). Approximately half were categorized as organ-specific. Although mortality rate declined from 0.50 % during the period from 1990 to 1994 to 0.21 % during the period from 1995 to 1999, mortality increased slightly to 0.28 % during the period from 2000 to 2004. Despite progressive increase in the use of thromboprophylaxis during these time periods, the authors did not find a concomitant decline in mortality or pulmonary embolism during the most recent time period (2000–2004). In fact, the rate of pulmonary embolism increased from 0.29 % in the period from 1995 to 1999 to 0.52 % in the period from 2000 to 2004 (Table 2.2). An increase in patient comorbidities could explain recent trends toward increasing rates of pulmonary embolism and overall mortality.

As for total hip arthroplasty, 2,288,579 patients were identified between 1990 and 2004 [53]. The trends were generally similar to those in total knee arthroplasty. The utilization of this procedure has increased, with the highest percent of increase in the group of patients aged between 45 and 64. Also, there has been an increase in the number of comorbidities, with hypertension being the most common comorbidity occurring in nearly half of all patients in the most recent time period studied (2000–2004). Nevertheless, procedure-related complications and adverse events decreased over the study period, from 15 % in the period from 1990 to 1994 to 9 % in the period from 2000 to 2004 (Table 2.3). In-hospital mortality rate remained low and slightly decreased (0.33 % in 1990–1994 to 0.29 % in 2000–2004). Fortunately, the incidence of pulmonary embolism has decreased from 0.46 to 0.26 %, which is reassuring as much effort and creation of practice guidelines have been devoted to reduction of these thromboembolic events.

**Table 2.2** Prevalence of procedure-related complications in patients undergoing total knee arthroplasty, USA 1990–2004

| | Total knee arthroplasty | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1990–1994 ($N = 807,687$) | | 1995–1999 ($N = 1,204,109$) | | 2000–2004 ($N = 1,818,624$) | | 1990–2004 ($N = 3,830,420$) | |
| Complications | *n* | % of total | *n* | % of total | *n* | % of total | *n* | % of total |
| Complications affecting specific body system | | | | | | | | |
| Central nervous system | 143 | 0.02 | 3,180 | 0.26 | 2,405 | 0.13 | 5,758 | 0.15 |
| Cardiopulmonary | 24,923 | 3.09 | 31,041 | 2.57 | 31,888 | 1.75 | 87,852 | 2.29 |
| Gastrointestinal | 9,224 | 1.14 | 13,159 | 1.09 | 16,096 | 0.89 | 38,479 | 1.01 |
| Genitourinary | 12,188 | 1.51 | 13,554 | 1.13 | 11,611 | 0.64 | 37,353 | 0.98 |
| Other complications of procedure | | | | | | | | |
| Postoperative shock | 396 | 0.05 | 71 | 0.01 | 129 | 0.01 | 596 | 0.02 |
| Hematoma | 11,017 | 1.36 | 18,403 | 1.53 | 14,400 | 0.79 | 43,820 | 1.14 |
| Postoperative infection | 2,090 | 0.26 | 1,748 | 0.15 | 4,325 | 0.24 | 8,163 | 0.21 |
| Thromboembolic events | 6,876 | 0.85 | 6,954 | 0.58 | 10,816 | 0.59 | 24,646 | 0.64 |
| Pulmonary embolism | 2,872 | 0.36 | 3,518 | 0.29 | 9,546 | 0.52 | 15,936 | 0.42 |
| Death | 4,028 | 0.50 | 2,502 | 0.21 | 5,094 | 0.28 | 11,624 | 0.30 |

Used with permission from Memtsoudis SG, Della Valle AG, Besculides MC, et al. Trends in demographics, comorbidity profiles, in-hospital complications and mortality associated with primary knee arthroplasty. J Arthroplasty. 2009;24:518–527
$p < 0.001$ between all time periods

**Table 2.3** Prevalence of procedure-related complications in patients undergoing total hip arthroplasty, USA 1990–2004

| | Total hip arthroplasty | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1990–1994 ($N = 603,528$) | | 1995–1999 ($N = 731,921$) | | 2000–2004 ($N = 953,130$) | | 1990–2004 ($N = 2,288,579$) | |
| Complications | *n* | % of total | *n* | % of total | *n* | % of total | *n* | % of total |
| Complications affecting specific body system | | | | | | | | |
| Central nervous system | 140 | 0.02 | 1,752 | 0.24 | 2,025 | 0.21 | 3,917 | 0.17 |
| Cardiopulmonary | 13,760 | 2.28 | 16,083 | 2.19 | 18,310 | 1.92 | 48,153 | 2.11 |
| Gastrointestinal | 7,107 | 1.18 | 7,521 | 1.03 | 7,157 | 0.75 | 21,785 | 0.95 |
| Genitourinary | 9,612 | 1.59 | 6,345 | 0.87 | 8,877 | 0.93 | 24,834 | 1.09 |
| Other complications of procedure | | | | | | | | |
| Postoperative shock | 449 | 0.07 | 49 | 0.01 | 524 | 0.06 | 1,022 | 0.05 |
| Hematoma | 8,304 | 1.38 | 12,494 | 1.71 | 13,700 | 1.44 | 34,498 | 1.51 |
| Postoperative infection | 4,160 | 0.69 | 4,738 | 0.65 | 1,884 | 0.20 | 10,783 | 0.47 |
| Thromboembolic events | 3,588 | 0.60 | 1,941 | 0.27 | 3,082 | 0.32 | 8,611 | 0.38 |
| Pulmonary embolism | 2,787 | 0.46 | 2,193 | 0.30 | 2,481 | 0.26 | 7,461 | 0.33 |
| Death | 1,977 | 0.33 | 2,446 | 0.33 | 2,839 | 29.00 | 7,262 | 0.32 |

Used with permission from Liu SS, Della Valle AG, Besculides MC, et al. Trends in mortality, complications, and demographics for primary hip arthroplasty in the United States. Int Orthop. 2009;33:643–651
$p \leq 0.001$ between all time periods

## Specific Complications: Medical

As the prevalence of hip and knee osteoarthritis increases with increasing age, more of total joint replacement procedures will be performed in patients with some degree of cardiac, pulmonary, cerebral, renal, and hepatic disease. Therefore, accurate knowledge of rates of perioperative medical complications in elderly population is valuable for the decision-making process when considering elective surgeries. Prospectively collected data from the total joint registry at the Mayo clinic during a 10-year period (1986–1995) were used to identify patients with postoperative myocardial infarction, pulmonary embolism, deep venous thrombosis, or death within 30 days after total hip or knee arthroplasties [54]. Out of 10,244 patients, the overall rate of myocardial infarction, pulmonary embolism, deep venous thrombosis, and death were 2.2 %, 0.4 %, 0.7 %, 1.5 %, and 0.5 %, respectively (Fig. 2.5). Eighty-three percent of myocardial infarction occurred within 3 days, and were more frequent among males and patients aged 70 years or older. There was no difference in the overall adverse event frequency between total knee and total hip procedures, except for pulmonary embolism, which was highest in patients undergoing bilateral knee operations. A separate study investigated the incidence of perioperative stroke, and found that 36 of 18,745 patients (0.2 %) undergoing

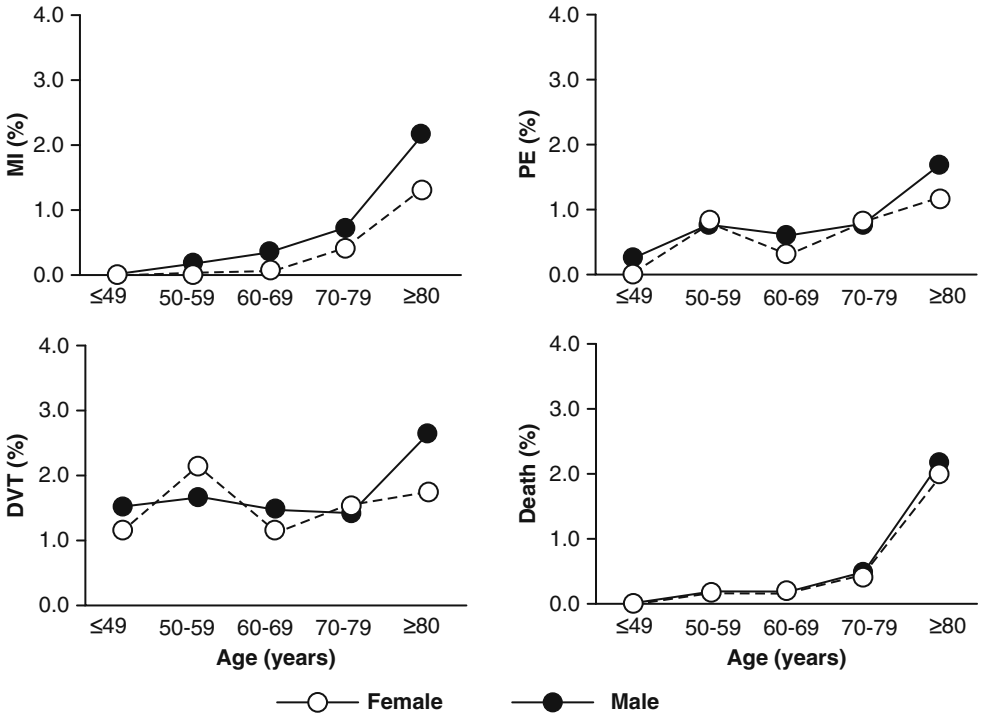


**Fig. 2.5** Frequency of myocardial infarction (MI), pulmonary embolism (PE), deep venous thrombosis (DVT), or death within 30 days after primary total hip or knee arthroplasty according to age and gender (Used with permission from Mantilla CB, Horlocker TT, Schroeder DR, et al. Frequency of myocardial infarction, pulmonary embolism, deep venous thrombosis, and death following primary hip or knee arthroplasty. Anesthesiology. 2002;96:1140–1146)

total hip and knee arthroplasties between 2000 and 2007 suffered a perioperative stroke [55]. Nine of the 36 patients died within the first year (25 %). This study indicates that perioperative stroke is a rare but devastating complication of total joint arthroplasty.

## Infection

Deep periprosthetic joint infection remains the most complex and costly complication. Even with a two-stage exchange implant-exchange protocol, failure rates in hips infected with methicillin-resistant organisms can reach as high as 21 % [56]. A retrospective review of 8,494 primary knee and hip arthroplasties reported a 0.5 % overall rate of infection (30 of 5,719 knees, and 13 of 2,775 hips) [57]. Obesity, diabetes, and younger age were identified as risk factors for infection in total joint arthroplasty. The rate of infection following total hip arthroplasty in the medicare-beneficiary population from 1995 to 1996 was around 0.2 % (137 of 58,521) for primary arthroplasty, and 0.96 % (124 of 12,956) for revision surgery [58]. A more recent review of discharge data from over 139,000 patients undergoing primary total hip arthroplasty between 1995 and 2005 reported a higher wound infection rate of 0.7 % [59]. Total knee arthroplasty appears to have a slightly higher infection rate than total hip arthroplasty [57, 60, 61]. The exact reason for knees having higher infection rates remains subject to debate. Possible explanations include differences in vascular supply, skin thickness, joint motion, the use of tourniquet, and surgical approach.

Antibiotic prophylaxis is fundamental to the reduction of primary periprosthetic infection and has been shown by meta-analysis to reduce the relative risk of wound infection by 81 % [62]. As *clostridium difficile* infections are thought to be an iatrogenic complication of antimicrobial prophylaxis [63], particularly third-generation cephalosporins, clindamycin, and ciprofloxacin, several investigators sought to identify the incidence of *Clostridium difficile* infections in patients undergoing total joint arthroplasty [64, 65]. These studies showed a very low incidence of 0.17 %.

Although the risk of infection after total joint arthroplasty is small (<1 %), considering the large number of arthroplasty procedures performed every year, and considering the mean cost of $68,053–$107,264 to treat each infection [66], this risk poses a significant economic burden.

## Dislocation

Dislocation is one of the most common complications after total hip arthroplasty [67]. Reported rates of dislocation (≤90 days postoperatively) vary and range between 1.39 [59] and 3.2 % [68] for primary arthroplasties. A comprehensive review published by Morrey in 1992 concluded that the long-term dislocation rate averaged 2.25 % in the primary

total hip arthroplasty setting [69]. As in infections, rates were higher after revision surgery reaching 8 % [58]. Dislocations are also seen following total knee arthroplasties, but to a lesser extent. A study of 2,033 total knee arthroplasties in medicare beneficiaries from 2002 to 2004 reported only four cases of dislocation (0.2 %) [70].

### Venous Thromboembolism

Venous thromboembolism is a serious complication that is used by the government and insurance payers as a performance measure of hospitals as well as surgeons. Prior research showed that 35 % of patients die within 1 year after the onset of venous thromboembolism [71]. In the Danish total hip registry from 1995 to 2006, 686 of 67,469 (1.02 %) patients were re-hospitalized due to venous thromboembolism at a median of 22 days following surgery. Ninety-three percent of the 67,469 patients received pharmacological prophylaxis with use of a low-molecular-weight heparin. The prevalence of symptomatic deep vein thrombosis was 0.7 % (499 patients), and the prevalence of nonfatal pulmonary embolism was 0.3 % (205 patients). The rate of mortality due to venous thromboembolism was 0.05 % (38 patients). However, these rates are lower than previous reports as there are differences in study populations, study design, proportion of patients receiving pharmacological prophylaxis, and type and duration of treatment [72–75].

### Periprosthetic Fractures

Periprosthetic fractures are fractures that occur in association with an orthopedic implant. These fractures are of great importance as one study has documented a higher risk of death after periprosthetic fracture as compared with a similar population of patients undergoing uncomplicated total hip arthroplasty [76]. Incidence of periprosthetic fractures about a total hip arthroplasty is variable, with multiple studies noting an incidence of 0.1–18 % [77–80]. The incidence is greater after revision arthroplasty as revision surgery is associated with problems with bone stock about the components resulting from stress shielding, osteolysis, and other factors. Data from the Mayo Clinic joint registry revealed fracture rates of 1 % after primary total hip arthroplasty and 4 % after revision total hip arthroplasty [81]. The prevalence of periprosthetic fracture about total hip arthroplasty continues to increase with time as more and more patients are undergoing total hip arthroplasty, with more surgeries being performed on older patients who may be at an increased risk of falls [76, 81, 82]. Similarly, rates of periprosthetic fractures about total knee arthroplasty are increasing as the population ages [83, 84]. The incidence is 0.3–2.5 % for primary total knee arthroplasty and up to 38 % for revision [85–87].

## Summary

As our population continues to age with a growing incidence of degenerative musculoskeletal disease, a large number of surgical procedures will be performed every year. Spine and total joint replacement procedures gained popularity with the increasing evidence of their long-term efficacy. Advances in the surgical techniques and perioperative care broadened surgical indications, which paralleled the rapid growth of the elderly population suffering from degenerative diseases. Therefore, the increasing number of older individuals with multiple comorbidities opting for surgery is not necessarily accompanied by an increase in complication rates. Nevertheless, these complications constitute a large economic burden and a major challenge for orthopedic surgeons and physicians. As such, accurate reporting of these complications and more cautious analysis of epidemiological studies are crucial to implement optimal medical and surgical management.

**Summary Bullet Points**

- As the population of the USA ages the demand for orthopedic surgery for degenerative conditions has risen. Total joint replacement and spinal reconstructive procedures are highly successful but success depends on proper surgical indications and technique.
- Complications following total joint replacement are rare. Thromboembolic events resulting in myocardial infarction, stroke, and pulmonary embolism are among the most common complications, but the incidence of these has fallen with adoption of routine prophylaxis.
- Patients of advanced age and or with poorly controlled diabetes are at the highest risk of complications following elective orthopedic surgery.

## References

1. Jacobs JJ. The burden of musculoskeletal diseases in the United States: prevalence, societal and economic cost. Rosemont, IL: The United States Bone and Joint Decade; 2008.
2. National Center for Health Statistics (2004) National hospital discharge survey 2004.
3. National Center for Health Statistics (2004) National health and nutrition examination survey data 1998–2004.
4. Agency for Healthcare Research and Quality (2004) Healthcare cost and utilization project, nationwide inpatient sample.
5. Deyo RA (2011) Epidemiology of spinal surgery, Comparative Effectiveness, Cost and Outcomes Research Center, University of Washington. http://depts.washington.edu/ccor/studies/SpineSurgEpi.shtml. Accessed on November 26, 2011.

6. Ong K, Lau E, Kurtz S, et al (2007) Cervical, thoracic, and lumbar fusion rates in the U.S.: perspective from two health databases. 53rd Annual Meeting, Orthopaedic Research Society, 2007.
7. Abraham DJ, Herkowitz HN, Katz JN. Indications for thoracic and lumbar spine fusion and trends in use. Orthop Clin North Am. 1998;29:803.
8. Amundsen T, Weber H, Nordal HJ, et al. Lumbar spinal stenosis: conservative or surgical management?: a prospective 10-year study. Spine (Phila Pa 1976). 2000;25:1424–35. discussion 1435–6.
9. Gibson JN, Waddell G. Surgery for degenerative lumbar spondylosis: updated Cochrane Review. Spine (Phila Pa 1976). 2005;30:2312–20.
10. Javid MJ, Hadar EJ. Long-term follow-up review of patients who underwent laminectomy for lumbar stenosis: a prospective study. J Neurosurg. 1998;89:1–7.
11. Rampersaud YR, Ravi B, Lewis SJ, et al. Assessment of health-related quality of life after surgical treatment of focal symptomatic spinal stenosis compared with osteoarthritis of the hip or knee. Spine J. 2008;8:296–304.
12. Atlas SJ, Keller RB, Wu YA, et al. Long-term outcomes of surgical and nonsurgical management of lumbar spinal stenosis: 8 to 10 year results from the maine lumbar spine study. Spine (Phila Pa 1976). 2005;30:936–43.
13. Chang Y, Singer DE, Wu YA, et al. The effect of surgical and nonsurgical treatment on longitudinal outcomes of lumbar spinal stenosis over 10 years. J Am Geriatr Soc. 2005;53:785–92.
14. Iguchi T, Kurihara A, Nakayama J, et al. Minimum 10-year outcome of decompressive laminectomy for degenerative lumbar spinal stenosis. Spine (Phila Pa 1976). 2000;25:1754–9.
15. Jansson KA, Nemeth G, Granath F, et al. Spinal stenosis re-operation rate in Sweden is 11 % at 10 years – A national analysis of 9,664 operations. Eur Spine J. 2005;14:659–63.
16. Kornblum MB, Fischgrund JS, Herkowitz HN, et al. Degenerative lumbar spondylolisthesis with spinal stenosis: a prospective long-term study comparing fusion and pseudarthrosis. Spine (Phila Pa 1976). 2004;29:726–33. discussion 733–4.
17. Mirza SK, Deyo RA, Heagerty PJ, et al. Towards standardized measurement of adverse events in spine surgery: conceptual model and pilot evaluation. BMC Musculoskelet Disord. 2006;7:53.
18. Ratliff JK, Lebude B, Albert T, et al. Complications in spinal surgery: comparative survey of spine surgeons and patients who underwent spinal surgery. J Neurosurg Spine. 2009;10:578–84.
19. Nasser R, Yadla S, Maltenfort MG, et al. Complications in spine surgery. J Neurosurg Spine. 2010;13:144–57.
20. Schoenfeld AJ, Ochoa LM, Bader JO, et al. Risk factors for immediate postoperative complications and mortality following spine surgery: a study of 3475 patients from the National Surgical Quality Improvement Program. J Bone Joint Surg Am. 2011;93:1577–82.
21. Yadla S, Malone J, Campbell PG, et al. Early complications in spine surgery and relation to preoperative diagnosis: a single-center prospective study. J Neurosurg Spine. 2010;13:360–6.
22. Rampersaud YR, Moro ER, Neary MA, et al. Intraoperative adverse events and related postoperative complications in spine surgery: implications for enhancing patient safety founded on evidence-based protocols. Spine (Phila Pa 1976). 2006;31:1503–10.
23. Dekutoski MB, Norvell DC, Dettori JR, et al. Surgeon perceptions and reported complications in spine surgery. Spine (Phila Pa 1976). 2010;35:S9–21.
24. Hess DR. Retrospective studies and chart reviews. Respir Care. 2004;49:1171–4.
25. Sauerland S, Lefering R, Neugebauer EA. Retrospective clinical studies in surgery: potentials and pitfalls. J Hand Surg Br. 2002;27:117–21.
26. Deyo RA, Cherkin DC, Loeser JD, et al. Morbidity and mortality in association with operations on the lumbar spine. The influence of age, diagnosis, and procedure. J Bone Joint Surg Am. 1992;74:536–43.
27. Wiese M, Kramer J, Bernsmann K, et al. The related outcome and complication rate in primary lumbar microscopic disc surgery depending on the surgeon's experience: comparative studies. Spine J. 2004;4:550–6.
28. Williams BJ, Sansur CA, Smith JS, et al. Incidence of unintended durotomy in spine surgery based on 108,478 cases. Neurosurgery. 2011;68:117–23. discussion 123–4.
29. Fountas KN, Kapsalaki EZ, Nikolakakos LG, et al. Anterior cervical discectomy and fusion associated complications. Spine (Phila Pa 1976). 2007;32:2310–7.
30. Newhouse KE, Lindsey RW, Clark CR, et al. Esophageal perforation following anterior cervical spine surgery. Spine (Phila Pa 1976). 1989;14:1051–3.
31. Boakye M, Patil CG, Santarelli J, et al. Cervical spondylotic myelopathy: complications and outcomes after spinal fusion. Neurosurgery. 2008;62:455–61. discussion 461–2.
32. Shamji MF, Cook C, Pietrobon R, et al. Impact of surgical approach on complications and resource utilization of cervical spine fusion: a nationwide perspective to the surgical treatment of diffuse cervical spondylosis. Spine J. 2009;9:31–8.
33. Wang MC, Chan L, Maiman DJ, et al. Complications and mortality associated with cervical spine surgery for degenerative disease in the United States. Spine (Phila Pa 1976). 2007;32:342–7.
34. Marawar S, Girardi FP, Sama AA, et al. National trends in anterior cervical fusion procedures. Spine (Phila Pa 1976). 2010;35:1454–9.
35. Malter AD, McNeney B, Loeser JD, et al. 5-Year reoperation rates after different types of lumbar spine surgery. Spine (Phila Pa 1976). 1998;23:814–20.
36. Memtsoudis SG, Vougioukas VI, Ma Y, et al. Perioperative morbidity and mortality after anterior, posterior, and anterior/posterior spine fusion surgery. Spine (Phila Pa 1976). 2011;36:1867–77.
37. Boden SD, Kang J, Sandhu H, et al. Use of recombinant human bone morphogenetic protein-2 to achieve posterolateral lumbar spine fusion in humans: a prospective, randomized clinical pilot trial: 2002 Volvo Award in clinical studies. Spine (Phila Pa 1976). 2002;27:2662–73.
38. Boden SD, Zdeblick TA, Sandhu HS, et al. The use of rhBMP-2 in interbody fusion cages. Definitive evidence of osteoinduction in humans: a preliminary report. Spine (Phila Pa 1976). 2000;25:376–81.
39. Cahill KS, Chi JH, Day A, et al. Prevalence, complications, and hospital charges associated with use of bone-morphogenetic proteins in spinal fusion procedures. JAMA. 2009;302:58–66.
40. Carragee EJ, Hurwitz EL, Weiner BK. A critical review of recombinant human bone morphogenetic protein-2 trials in spinal surgery: emerging safety concerns and lessons learned. Spine J. 2011;11:471–91.
41. Cook C, Tackett S, Shah A, et al. Diabetes and perioperative outcomes following cervical fusion in patients with myelopathy. Spine (Phila Pa 1976). 2008;33:E254–60.
42. Li G, Patil CG, Lad SP, et al. Effects of age and comorbidities on complication rates and adverse outcomes after lumbar laminectomy in elderly patients. Spine (Phila Pa 1976). 2008;33:1250–5.
43. Oldridge NB, Yuan Z, Stoll JE, et al. Lumbar spine surgery and mortality among Medicare beneficiaries, 1986. Am J Public Health. 1994;84:1292–8.
44. Ciol MA, Deyo RA, Kreuter W, et al. Characteristics in Medicare beneficiaries associated with reoperation after lumbar spine surgery. Spine (Phila Pa 1976). 1994;19:1329–34.
45. Jordan JM, Helmick CG, Renner JB, et al. Prevalence of hip symptoms and radiographic and symptomatic hip osteoarthritis in African Americans and Caucasians: the Johnston County Osteoarthritis Project. J Rheumatol. 2009;36:809–15.
46. Jordan JM, Helmick CG, Renner JB, et al. Prevalence of knee symptoms and radiographic and symptomatic knee osteoarthritis in African Americans and Caucasians: the Johnston County Osteoarthritis Project. J Rheumatol. 2007;34:172–80.

47. Hootman JM, Helmick CG. Projections of US prevalence of arthritis and associated activity limitations. Arthritis Rheum. 2006;54:226–9.
48. Makela KT, Eskelinen A, Pulkkinen P, et al. Total hip arthroplasty for primary osteoarthritis in patients fifty-five years of age or older. An analysis of the Finnish arthroplasty registry. J Bone Joint Surg Am. 2008;90:2160–70.
49. Labek G, Thaler M, Janda W, et al. Revision rates after total joint replacement: cumulative results from worldwide joint register datasets. J Bone Joint Surg Br. 2011;93:293–7.
50. O'Boyle CA, McGee H, Hickey A, et al. Individual quality of life in patients undergoing hip replacement. Lancet. 1992;339: 1088–91.
51. Wiklund I, Romanus B. A comparison of quality of life before and after arthroplasty in patients who had arthrosis of the hip joint. J Bone Joint Surg Am. 1991;73:765–9.
52. Memtsoudis SG, Della Valle AG, Besculides MC, et al. Trends in demographics, comorbidity profiles, in-hospital complications and mortality associated with primary knee arthroplasty. J Arthroplasty. 2009;24:518–27.
53. Liu SS, Della Valle AG, Besculides MC, et al. Trends in mortality, complications, and demographics for primary hip arthroplasty in the United States. Int Orthop. 2009;33:643–51.
54. Mantilla CB, Horlocker TT, Schroeder DR, et al. Frequency of myocardial infarction, pulmonary embolism, deep venous thrombosis, and death following primary hip or knee arthroplasty. Anesthesiology. 2002;96:1140–6.
55. Mortazavi SM, Kakli H, Bican O, et al. Perioperative stroke after total joint arthroplasty: prevalence, predictors, and outcome. J Bone Joint Surg Am. 2010;92:2095–101.
56. Leung F, Richards CJ, Garbuz DS, et al. Two-stage total hip arthroplasty: how often does it control methicillin-resistant infection? Clin Orthop Relat Res. 2011;469:1009–15.
57. Malinzak RA, Ritter MA, Berend ME, et al. Morbidly obese, diabetic, younger, and unilateral joint arthroplasty patients have elevated total joint arthroplasty infection rates. J Arthroplasty. 2009;24:84–8.
58. Katz JN, Losina E, Barrett J, et al. Association between hospital and surgeon procedure volume and outcomes of total hip replacement in the United States medicare population. J Bone Joint Surg Am. 2001;83-A:1622–9.
59. Soohoo NF, Farng E, Lieberman JR, et al. Factors that predict short-term complication rates after total hip arthroplasty. Clin Orthop Relat Res. 2010;468:2363–71.
60. Ritter MA, Olberding EM, Malinzak RA. Ultraviolet lighting during orthopaedic surgery and the rate of infection. J Bone Joint Surg Am. 2007;89:1935–40.
61. Wojkowska-Mach J, Jaje E, Romaniszyn D, et al. Comparison of SSI rates in endoarthroplasty of hip and knee in a Cracow patient population and the importance of postdischarge surveillance. Infection. 2008;36:36–40.
62. AlBuhairan B, Hind D, Hutchinson A. Antibiotic prophylaxis for wound infections in total joint arthroplasty: a systematic review. J Bone Joint Surg Br. 2008;90:915–9.
63. Harbarth S, Samore MH, Carmeli Y. Antibiotic prophylaxis and the risk of Clostridium difficile-associated diarrhoea. J Hosp Infect. 2001;48:93–7.
64. Jenkins PJ, Teoh K, Simpson PM, et al. Clostridium difficile in patients undergoing primary hip and knee replacement. J Bone Joint Surg Br. 2010;92:994–8.
65. Kurd MF, Pulido L, Joshi A, et al. Clostridium difficile infection after total joint arthroplasty: who is at risk? J Arthroplasty. 2008;23:839–42.
66. Parvizi J, Pawasarat IM, Azzam KA, et al. Periprosthetic joint infection: the economic impact of methicillin-resistant infections. J Arthroplasty. 2010;25:103–7.
67. Soong M, Rubash HE, Macaulay W. Dislocation after total hip arthroplasty. J Am Acad Orthop Surg. 2004;12:314–21.
68. Woo RY, Morrey BF. Dislocations after total hip arthroplasty. J Bone Joint Surg Am. 1982;64:1295–306.
69. Morrey BF. Instability after total hip arthroplasty. Orthop Clin North Am. 1992;23:237–48.
70. Huddleston JI, Maloney WJ, Wang Y, et al. Adverse events after total knee arthroplasty: a national Medicare study. J Arthroplasty. 2009;24:95–100.
71. Heit JA, Silverstein MD, Mohr DN, et al. Predictors of survival after deep vein thrombosis and pulmonary embolism: a population-based, cohort study. Arch Intern Med. 1999;159:445–53.
72. Eriksson BI, Dahl OE, Rosencher N, et al. Dabigatran etexilate versus enoxaparin for prevention of venous thromboembolism after total hip replacement: a randomised, double-blind, non-inferiority trial. Lancet. 2007;370:949–56.
73. Schiff RL, Kahn SR, Shrier I, et al. Identifying orthopedic patients at high risk for venous thromboembolism despite thromboprophylaxis. Chest. 2005;128:3364–71.
74. Warwick D, Friedman RJ, Agnelli G, et al. Insufficient duration of venous thromboembolism prophylaxis after total hip or knee replacement when compared with the time course of thromboembolic events: findings from the Global Orthopaedic Registry. J Bone Joint Surg Br. 2007;89:799–807.
75. White RH, Romano PS, Zhou H, et al. Incidence and time course of thromboembolic outcomes following total hip or knee arthroplasty. Arch Intern Med. 1998;158:1525–31.
76. Lindahl H, Oden A, Garellick G, et al. The excess mortality due to periprosthetic femur fracture. A study from the Swedish national hip arthroplasty register. Bone. 2007;40:1294–8.
77. Beals RK, Tower SS. Periprosthetic fractures of the femur. An analysis of 93 fractures. Clin Orthop Relat Res. 1996;327:238–46.
78. Lewallen DG, Berry DJ. Periprosthetic fracture of the femur after total hip arthroplasty: treatment and results to date. Instr Course Lect. 1998;47:243–9.
79. Lindahl H, Malchau H, Herberts P, et al. Periprosthetic femoral fractures classification and demographics of 1049 periprosthetic femoral fractures from the Swedish National Hip Arthroplasty Register. J Arthroplasty. 2005;20:857–65.
80. Schwartz Jr JT, Mayer JG, Engh CA. Femoral fracture during noncemented total hip arthroplasty. J Bone Joint Surg Am. 1989;71:1135–42.
81. Berry DJ. Epidemiology: hip and knee. Orthop Clin North Am. 1999;30:183–90.
82. Lindahl H, Garellick G, Regner H, et al. Three hundred and twenty-one periprosthetic femoral fractures. J Bone Joint Surg Am. 2006;88:1215–22.
83. Kim KI, Egol KA, Hozack WJ, et al. Periprosthetic fractures after total knee arthroplasties. Clin Orthop Relat Res. 2006;446:167–75.
84. Su ET, DeWal H, Di Cesare PE. Periprosthetic femoral fractures above total knee replacements. J Am Acad Orthop Surg. 2004;12:12–20.
85. Healy WL, Siliski JM, Incavo SJ. Operative treatment of distal femoral fractures proximal to total knee replacements. J Bone Joint Surg Am. 1993;75:27–34.
86. Inglis AE, Walker PS. Revision of failed knee replacements using fixed-axis hinges. J Bone Joint Surg Br. 1991;73:757–61.
87. Ritter MA, Faris PM, Keating EM. Anterior femoral notching and ipsilateral supracondylar femur fracture in total knee arthroplasty. J Arthroplasty. 1988;3:185–7.

# The Connective Diseases: The Rheumatologist's Perspective

3

Susan S. Kim, C. Ronald MacKenzie, and Stephen Paget

**Objectives**

- To understand the importance and impact of these conditions on society and the health care system.
- To appreciate that such patients make up a significant proportion of an orthopedic practice.
- To appreciate the protean nature of these disorders and their varied pathophysiology.
- To understand the systematic approach to the differential diagnosis of these conditions is presented.

**Key Points**

- Chronic rheumatic diseases represent a broad category of conditions that share a common feature: the destruction of cartilage and its consequences.
- While these conditions differ in their pathophysiology, the final common pathway is often the joint; hence, such patients frequently require orthopedic surgery.
- Classification of rheumatic diseases follows this organization: Osteoarthritis; Disorders of the Synovium (Rheumatoid Arthritis), Connective Tissue Diseases (Systemic Lupus Erythematosus, Systemic Sclerosis, Inflammatory Disease of the Muscle), Spondyloarthropathy (Ankylosing Spondylitis, Psoriatic Arthritis, Enteropathic Arthropathies), Vasculitides (Polymyalgia Rheumatica/Temporal Arteritis, Polyarteritis Nodosa, Microscopic Polyangiitis, Churg–Strauss, Wegener's Granulomatosis), Metabolic Bone Disease (Osteoporosis), Crystal-Induced Arthropathies (Gout, Calcium Pyrophosphate Associated Arthropathy), Infectious Arthritis.

## Introduction

Estimates of the prevalence of arthritis and the rheumatic diseases in general make evident the enormous impact that these conditions have on the US populace and the health care system in general. More than 21 % of US adults (46 million people) currently report physician-diagnosed arthritis. The National Arthritis Data Workup, an impressive collaborative effort from the Centers for Disease Control and Prevention, the National Institute of Health, the American College of Rheumatology, and the Arthritis Foundation, has published analyses that project an increase of physician-diagnosed arthritis to nearly 67 million people (an increase of 40 %) by the year 2030 [1]. While the majority of this health burden arises as a consequence of osteoarthritis, the entire span of the rheumatic diseases, such as rheumatoid arthritis, juvenile arthritis, spondlyarthropathies, systemic lupus erythematosus, systemic sclerosis, and primary Sjogren's syndrome, contributes to the impact of this class of conditions. *Already the leading cause of disability in the nation, the number of people with arthritis and arthritis-attributable limitation in activity is a serious public health issue. Such observations highlight the importance of effective interventions and programs to reduce the impact (loss of productivity, costs of therapy) of these chronic diseases.* Ultimately, orthopedic intervention is required in many of

S.S. Kim (✉)
Department of Rheumatology, Lehigh Valley Health Network, Allentown, PA, USA
e-mail: Susan.kim@luh.org

C.R. MacKenzie
Department of Medicine, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA
e-mail: mackenzier@hss.edu

S. Paget
Department of Rheumatology, Hospital for Special Surgery, Weill Cornell Medical School, New York, NY, USA
e-mail: pagets@hss.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_3, © Springer New York 2014

these individuals to address the main issues of palliation of pain, inflammation, and further structural damage and disability compromising one's quality of life. Factors such as an increased patient awareness of the benefits of surgery, improvements in surgical techniques, and the desire for an active life style have, in concert with the increasing prevalence of chronic arthritis, fueled the growth in utilization of orthopedic surgery. The orthopedic perspective and contemporary estimates concerning the rates of total joint replacement and spine surgery have been extensively reviewed in Chap. 2. This chapter introduces the broader spectrum of the rheumatic diseases as viewed by the Rheumatologist as such patients frequently require orthopedic intervention. Beginning with a review of the relevant pathobiology, a concise primer of the essential diseases is then presented.

## Pathological Considerations

The elemental pathological process leading to orthopedic surgery is damage and gradual loss of the articular cartilage. However, all structures within the joint including the bones and connective tissue are affected. Osteoarthritis involves the joint in an asymmetric, localized pattern of involvement, with focal stress across the joint. This leads to misalignment and progressive alterations in load bearing relationships of the joint, resulting in the radiographic joint space narrowing and chronic joint damage. The structural changes occur in concert with biochemical abnormalities that ensue within the cartilage component, the underlying subchondral bone, joint capsule, and synovial membrane. Microscopically, biomechanical properties of the normal cartilage contain two main components: extracellular matrix (rich in type II, IX, and XI collagens and proteoglycans) and the chondrocytes lying within the matrix, responsible for maintaining homeostatic synthesis of the extracellular matrix components. The abnormal mechanical stress that occurs in OA causes alterations in chondrocyte metabolism and incites local inflammation by inducing synthesis of proteases, such as matrix metalloproteinase (MMP)-1, MMP-8, and MMP-13, and inflammatory mediators, such as interleukin (IL)-8, IL-6, prostaglandin E2, and nitric oxide [2]. The joint damage results from the metabolic imbalance due to accelerated cartilage degradation coupled with an insufficient reparative response. These processes incite localized tissue response consisting of inflammation of the joint lining and further loss of mechanical properties of the affected joint. Owing to the synthesis of metalloproteinases, there is gradual loss of the matrix components. Alterations of the proteoglycan content and structure then follow, and with continued deterioration in the cartilage and its load bearing capacity, stiffness and pain ensue, as nociceptive and proprioceptive receptors in the periosteum are activated due to the loss of the protective layer of the articular cartilage. Bone remodeling occurs in the underlying subchondral bone, causing sclerosis of the bone, formation of bone cysts, increased subchondral plate thickness, and reactive osteophyte formation at joint margins as a result of abnormal reparative process [3, 4].

Osteoarthritis is the most common cause of end-stage arthritis. Osteoarthritis may be primary, due to biochemical changes in the cartilage, or secondary to systemic disease affecting the cartilage, joint damage from pre-existing inflammatory joint disease, or trauma. It is a heterogeneous disease with various etiologies. Mechanical overload and imbalances lead to further cartilage degradation, processes that culminate in a failure of the mechanical functioning of the surrounding normal structures. Important adaptive responses such as subchondral sclerosis and osteophyte formation occur in response to joint overload and, if chronically present, cyst formation in the sub-articular bone may also result. Over time the osteophytes or bone spurs will lead to restricted range of motion.

Inflammatory arthritis, by contrast, is a constellation of diseases that target the synovium. Included in this class of disorders are such conditions as Rheumatoid Arthritis (RA), Psoriatic Arthritis (PSa), and the Spondyloarthropathies (SpA). Common to all is the release of inflammatory mediators by the synovium leading to cartilage destruction. In contrast to osteoarthritis, mechanical overload is not a primary mechanism; as such, bone sclerosis or osteophyte formation is not seen. Rather, the inflammatory synovitis leads to a loss of cartilage matrix, marginal bony erosions, destruction of the joint capsule, and osteopenia.

Trauma is also important cause of joint destruction. Post-traumatic arthritis is initiated by cartilage damage at the time of injury or by secondary mechanical imbalances that result from fractures of juxta-articular bone. Abnormal loading conditions will subsequently lead to a wear-and-tear form of cartilage damage.

Osteonecrosis, also termed avascular necrosis, is another entity that may lead to joint arthritis. In this process the blood supply to the bone is compromised leading to necrosis of the bone supporting the articular surface. The most commonly affected joints are the hip, shoulder, and knee. As the disease progresses the necrotic bone may collapse leading to the loss of articular integrity and progressive cartilage deterioration.

Other conditions that may lead to joint damage include storage and deposition disorders (hemochromatosis,

alkaptonuria, Wilson's Disease, Gaucher's Disease), crystal deposition diseases (chondrocalcinosis, gout), tumor (synovial chondromatosis), infectious (post-septic), and bleeding disorders (hemophilia).

Owing to the prominent involvement of joints and the musculoskeletal system, patients who acquire these often multi-systemic conditions frequently require orthopedic intervention. The protean clinical manifestations of these diseases, coupled with important medication-related management considerations, present challenges encompassing the span of perioperative medical practice. Indeed such patients are amongst the most challenging encountered in the perioperative setting [5, 6].

## The Rheumatic Diseases

Table 3.1 presents a general classification of the rheumatic diseases.

**Table 3.1** Classification of the rheumatic diseases

| |
|---|
| Osteoarthritis |
| Disorders of the synovium |
| Rheumatoid arthritis |
| Connective tissue diseases |
| Systemic lupus erythematosus |
| Systemic sclerosis |
| Inflammatory disease of the muscle |
| Spondyloarthropathy |
| Ankylosing spondylitis |
| Psoriatic arthritis |
| Enteropathic arthropathies |
| Vasculitides |
| Polymyalgia rheumatica/temporal arteritis |
| Polyarteritis nodosa |
| Microscopic polyangiitis |
| Churg–Strauss |
| Wegener's granulomatosis |
| Metabolic bone disease |
| Osteoporosis |
| Crystal-induced arthropathies |
| Gout |
| Calcium pyrophosphate associated arthropathy |
| Infectious arthritis |

### Osteoarthritis (OA)

The most common form of arthritis, osteoarthritis is a heterogeneous group of common conditions that share similar pathological and radiographic features, specifically loss of articular cartilage. It should be considered, furthermore, as an organ failure of the synovial joint, driven by a primary defect in any of its supporting tissues (ligaments, meniscus, subchondral bone, periarticular muscles, synovium, nerves, or articular cartilage) [7]. Therefore, there are expectantly many pathophysiological mechanisms of OA that alter the relationship between mechanical factors and tissue response of the synovial joint; however, a common end-stage is wherein all components of the joint fail. An age-related disorder, OA is uncommon before age 40 but increases in prevalence thereafter; by age 70 most people have pathological changes of OA though they may not be symptomatic. Other risk factors include female gender, ethnicity (>blacks), genetic predisposition, obesity (especially for knee OA), and trauma. The causes for primary or idiopathic osteoarthritis remains unclear; research has focused on the intra-articular alterations involving the articular cartilage and subchondral bone, and considerable interest has arisen in the role of the neuromuscular unit involved in joint motion, stability, and proprioception as contributing to the progression and/or predisposition to the development of OA [8, 9].

Osteoarthritis is a focal disease not affecting all joints equally; even within a given joint the involvement may be patchy and asymmetric. Its pathogenesis involves an incongruence between normal cartilaginous degradative and repair mechanisms, which results in a net loss of cartilage, bony hypertrophy, and osseous outgrowths (osteophytes). Its primary symptoms are use-related joint pain and stiffness (gelling). On physical examination, some combination of joint tenderness, crepitus, bony enlargement, malalignment, decreased range of motion, and joint effusion are usually noted. Treatment is mainly symptomatic (NSAIDS, analgesics, intra-articular injections). In those with severe disease, total joint arthroplasty is a common outcome. Radiographic findings include asymmetric joint space narrowing, subchondral sclerosis and cystic change, and marginal osteophytes (bony spurs) (Figs. 3.1 and 3.2). When the spine is predominantly involved, disk degeneration and facet joint arthritis results in symptomatic stenosis, necessitating decompression (and fusion) surgery in order to alleviate symptoms and restore a functional activity (Fig. 3.3a, b).

### Disorders of the Synovium

Rheumatoid arthritis (RA) is the prototypical disorder primarily affecting the synovium. Whereas the normal synovium consists of a thin intimal lining layer, one to three cell layers thick, comprised of roughly equal proportions of different cell types (macrophage-like synviocytes or type A synoviocytes, and fibroblast-like synoviocytes or type B synoviocytes), in contrast the synovial tissue in RA is greatly hypertrophied (up to 8–10 cell layers thick) displaying

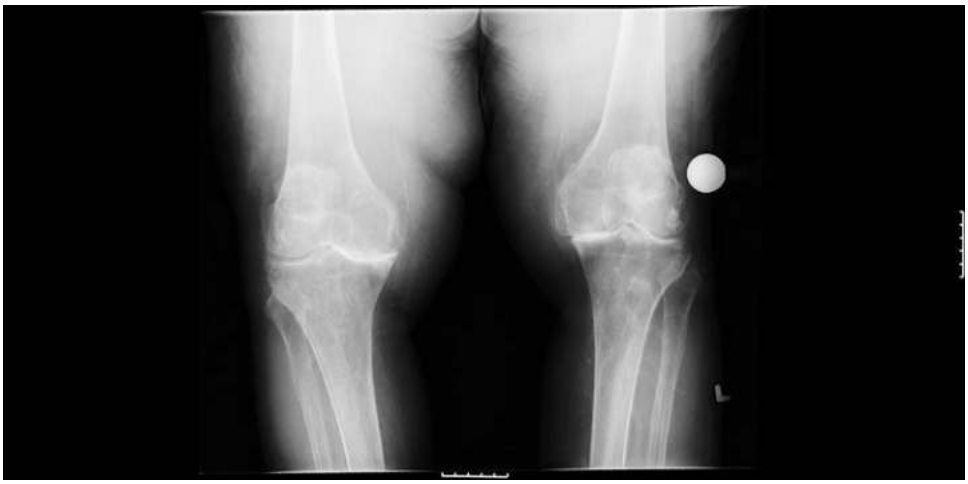

**Fig. 3.1** Radiograph of osteoarthritis in knees: varus deformity. X-ray of bilateral knees showing advanced, severe bilateral degenerative arthrosis most marked in the medial compartments bilaterally where there is bone on bone apposition. Tricompartmental osteophytosis is present. Bilateral varus deformity is noted

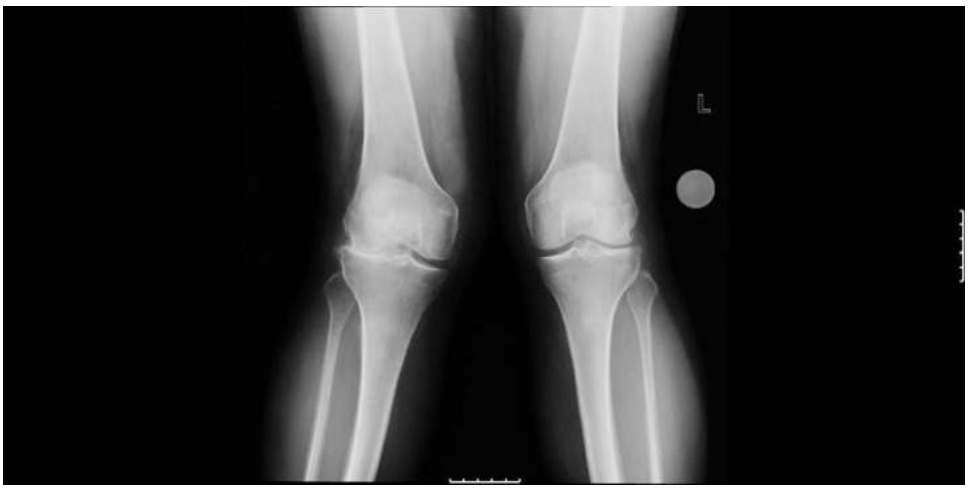

**Fig. 3.2** Radiograph of osteoarthritis in knees: valgus deformity. *Right knee* shows severe degenerative arthrosis with tricompartmental osteophytes and lateral bone-on-bone apposition with marked valgus deformity. *Left knee* shows moderate degenerative arthrosis with small joint line osteophytes and moderate lateral compartment narrowing with valgus deformity

increased numbers of both type A and B synoviocytes accompanied by mononuclear cell infiltration of the sublining below the intima transforming the milieu as the pot of inflammatory cytokines and proteases (Fig. 3.4a, b) [10, 11]. The subintimal region where the blood vessels are located become heavily infiltrated with inflammatory cells, including T and B lymphocytes, plasma cells, natural killer cells, macrophages, and mast cells. The hypertrophied synovium transforms into villous like projections, also called pannus, which protrude into the joint cavity and invade the juxtaposed articular cartilage and underlying bone, resulting in cartilage destruction bone erosions and ultimately compromising the integrity of each component of the joint (Fig. 3.5a, b). The destructive properties of the pannus are a result of: (1) increased synthesis of metalloproteinases and other proteinases by synovial fibroblasts and monocytes; (2) chrondrocyte activation by key cytokines (IL-1, TNF-α, and TGF-ß), resulting in decrease in collagen and proteogylcan synthesis; and (3) recruitment and differentiation of cells that express an osteoclast phenotype leading to focal bone erosions. It is hypothesized that the osteoclast differentiation from the macrophage lineage results in response to inflammatory mediators and cytokines (L-1, TNF-α, IL-17) produced by fibroblast-like synoviocytes in the rheumatoid synovium [12].

Rheumatoid arthritis is a chronic systemic inflammatory disease, driven by autoantibodies and immunologically overactive cells that primarily target the synovium as well as extra-articular tissues and organs. The etiopathogenesis of RA involves a complex interplay of genetic predisposition and probable environmental factors that trigger a cascade of intra-synovial immune response that perpetuates a pro-inflammatory milieu of cellular and molecular phenomena that lead to erosions of the cartilage and bone. Rheumatoid arthritis affects females more often than males (RR 3:1). Its peak onset is in the fourth to fifth decade. Usually RA presents insidiously over several weeks to months, with the initial pattern localized to inflammation of the smaller peripheral joints, typically symmetric in distribution, and often with concurrent systemic features of fatigue and generalized malaise. Uncontrolled joint inflammation, characterized by tenderness, swelling, and dysfunction,

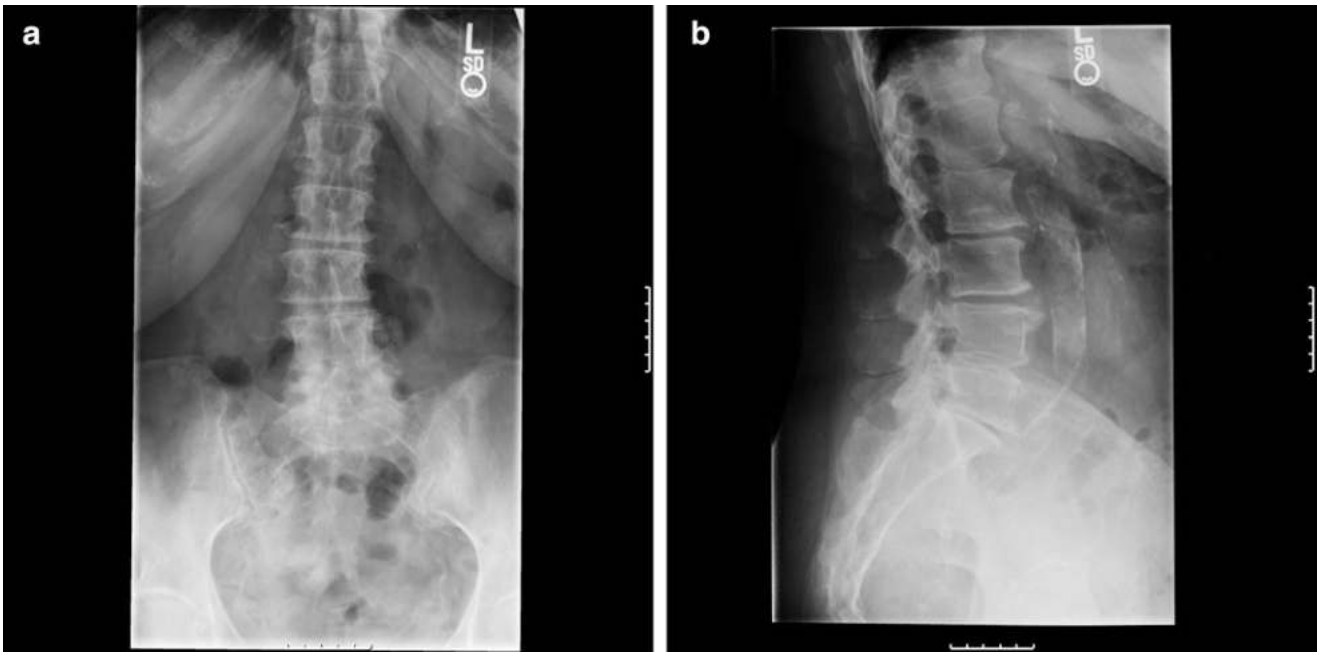


**Fig. 3.3** (**a**, **b**) Radiograph of osteoarthritis of lumbar spine. There is a mild curvature of the lumbar spine convex right with multilevel degenerative disk disease with disk space narrowing, endplate sclerosis, and osteophytes at L4-5 and L5-S1

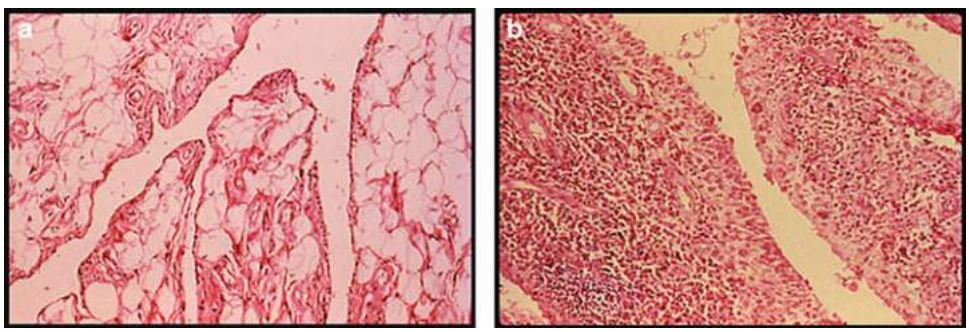


**Fig. 3.4** (**a**) Normal synovial lining: This layer is usually only 1–3 cells thick, comprised of type A macrophage-like synoviocytes and type B fibroblast-like synovicytes. (**b**) Synovial lining in rheumatoid arthritis: This lining is greatly hypertrophied (8–10 cells thick) (Both used with permission from ACR Image Bank)

may lead to larger joint involvement, destruction of synovial joints, followed by deformities and loss of joint function (Fig. 3.6a, b). Extra-articular manifestations may arise but have become less common in the modern therapeutic era.

Products of the human leukocyte antigen (HLA) region of Class II genes of the major histocompatibility complex (MHC) play an important role in the susceptibility and pathogenesis of RA. Individuals who are HLA DRB4 positive are more likely to develop severe disease, marked by erosions of the joints, deformity and disability. The concept of "shared epitope" refers to a common structural domain that consists of 5-amino acid sequence (QKRAA) found on several HLA-DR4 alleles, which has been shown to confer susceptibility to RA [13]. Early in the development of disease, T-lymphocyte infiltration occurs in the synovial tissue, followed by proliferation of the synovial lining; over time synovial infiltration by B-cells, macrophages, and fibroblasts follows and, in response to the production of various chemotactic factors, granulocytes migrate into the joint space discharging pro-inflammatory substances increasing vascular permeability and perpetuating the inflammatory response.

Relevant laboratory studies include markers of the inflammatory response (erythrocyte sedimentation rate [ESR], C-reactive protein [CRP]), rheumatoid factor (RF), and anti-cyclic citrullinated peptide (anti-CCP) antibodies. Rheumatoid factors are autoantibodies directed against the Fc portion of immunoglobulin G (IgG), and are found in 75–80 % of RA patients during the course of their illness. The immune complexes deposit into joints and tissues,

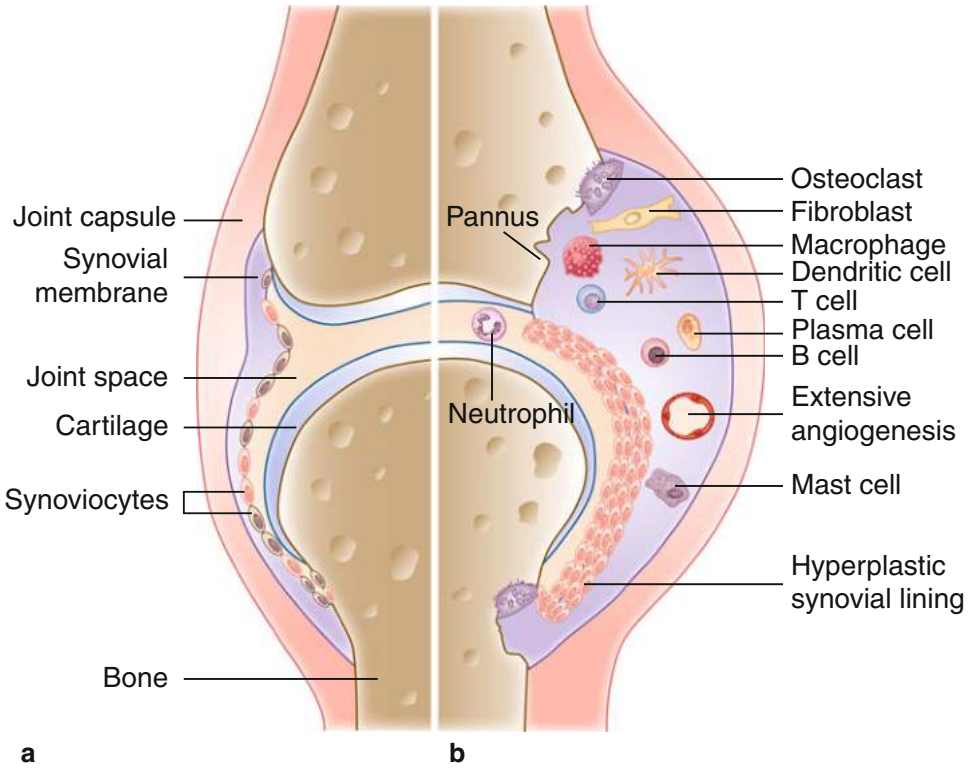


**Fig. 3.5** Pannus formation in rheumatoid arthritis. (**a**) Normal synovium with thin intimal layer. (**b**) Synovium in RA showing hypertrophied synovial layer, increase infiltration by inflammatory cells, and angiogenesis. The pannus that develops invades into the joint cavity, articular cartilage and subchondral bone (Used with permission from Strand V, Kimberly R, Isaacs JD. Biologic therapies in rheumatology: lessons learned, future directions. Nat Rev Drug Discov 2007;6:75–92)

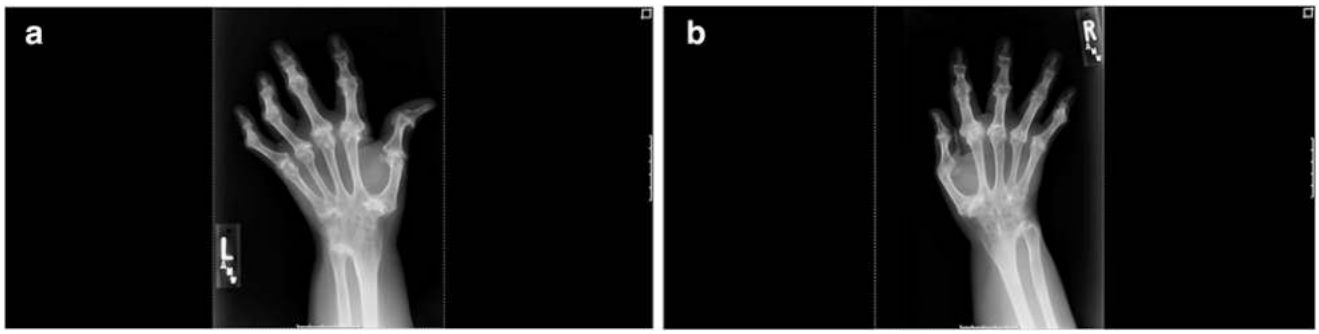


**Fig. 3.6** (**a**) Radiographic changes of advanced rheumatoid arthritis. (**b**) Rheumatoid involvement of the metacarpal and proximal interphalangeal joints bilaterally. There is fusion of the carpal joints bilaterally. The radiocarpal joints are fused. The carpal metacarpal joints are fused. Joint space narrowing, mild proliferative changes and erosions are noted in the MP and PIP joints. There is relative sparing of the DIP joints

exacting inflammation and damage. RF lacks specificity as levels may be elevated in certain infectious states (hepatitis, human immunodeficiency virus (HIV), endocarditis), malignancy (multiple myeloma), and also other connective tissue diseases (systemic lupus erythematosus (SLE), primary Sjogren's syndrome, scleroderma, myositis) [14]. Detection of anti-CCP antibodies has been shown to have greater specificity (95–97 %), with similar sensitivity to RF for the diagnosis of RA [15, 16]. More recently, Anti-citrullinated protein antibodies (ACPA) have emerged as a distinctive subset of patients with RA [17]. It has been shown to be a strong prognostic indicator for both the development of RA in the preclinical stage, as well as predictor of the extent of joint destruction [18–20]. Seropositivity for ACPA at baseline has been associated with subsequent structural damage in the setting of more persistent synovitis. ACPA status has become an important autoantibody biomarker for both diagnostic and prognostic value.

The therapeutic armamentarium of RA includes combinations of symptomatic therapies such as non-steroid inflammatory drugs (NSAIDS) and corticosteroids, nonbiologic disease modifying anti-rheumatic drugs (DMARDs) including methotrexate, leflunomide, sulfasalazine, and biological DMARDs, such as tumor necrosis factor (TNF) blockers (infliximab, etanercept, adalimumab, and more recently golimumab and certolizumab), interleukin-1 (IL-1) blockade

(with anakinra), IL-6 receptor blockade (with tocilizumab), T cell co-stimulation blockade (with abatacept), and B cell depletion (with rituximab). Non-biologic and biologic DMARDs have demonstrated major effects on inflammation as well as the tempering the pace of structural damage in the chronic course of this illness. An important consideration in the perioperative setting, however, is that many of these medications can complicate surgical interventions *increasing the risk of postoperative infection and impairing wound healing* (Chap. 22).

## Connective Tissue Diseases

The most common of these conditions is Systemic Lupus Erythematosus (SLE), a prototypical autoimmune disease driven by autoantibodies which target multiple organ systems including joints, skin, and kidneys. This condition occurs mainly in woman during their reproductive years (female to male ratio of 10:1), and disproportionately affects minorities, more commonly affecting African Americans, Asians, and Latinos (prevalence of 1:250–1:500), compared to Caucasians (1:2,000) [21, 22]. A hallmark is the diverse clinical expression and undulating course of this condition. The relapsing-remitting pattern of disease, along with the clinical heterogeneity, makes SLE one of the challenging autoimmune disorders not only to diagnose but also to treat. The most prevalent and severe manifestation of systemic involvement is renal disease (lupus nephritis), though other important manifestations involving the musculoskeletal, cutaneous, and neurologic systems frequently arise in the course of this illness. Constitutional symptoms (fever, fatigue, malaise) are the most common presenting complaints and herald the onset of disease flares. Often, the temporal sequence of organ involvement and the severity of its course are unpredictable. While its cause remains unknown, autoantibodies directed at cell nuclei and their constituents (antinuclear antibodies [ANA], anti-double stranded DNA [dsDNA] antibody) are hallmarks of this condition and are believed important to the pathogenesis of the disease. Deposition of immune complexes on a variety of target organs results in tissue injury from inflammation, thrombosis from premature infarction of blood vessels, and/or vasculitis. Multiple mechanisms are at play and lupus pathogenesis is complex due to nonlinear immune pathways. However, the formation of pathogenic autoantibodies as well as its defective clearance signals a dysregulated immune response with activation of the complement cascade, immune cell types (B cells, T cells), cytokines (type I interferon-α), and proteins involved in the inflammatory response. While hereditary and environmental susceptibility factors are believed important in the pathogenesis, pregnancy and certain drugs are also known disease precipitants.

Beyond the clinical complexity of diagnosis and tracking the course of illness, the challenge often becomes offering treatment modalities that strike the fine balance between immunosuppression and immune dysregulation. Corticosteroids and immunosuppressants remain the mainstay of therapy. Since their introduction in 1950s, corticosteroids have altered the management of most rheumatic diseases and have led to gradual improvements in the morbidity and mortality of lupus patients. However, there are major toxicities from long term corticosteroid use, which includes the infectious risks, its deleterious effects on bone health, and its disturbances to glucose homeostasis. Thus, antimalarials (plaquenil or hydroxychloroquine), nonsteroidal anti-inflammatory drugs (NSAIDs), azathioprine (Imuran®), methotrexate, cyclosporine, mycophenolate mofetil (Cellcept®), and cyclophosphamide (Cytoxan®) have been utilized for their steroid-sparing and immunosuppressive effects. In addition, a new monoclonal antibody to a soluble B-lymphocyte stimulator, known as belimumab (Benlysta®) has recently been approved by the US Food and Drug Administration (FDA) for the treatment of autoantibody (ANA and/or dsDNA) positive SLE patients who have mild to moderate disease despite standard therapy.

As will be discussed, avascular necrosis or osteonecrosis is seen relatively commonly (4–15 %) in SLE patients who have received high doses of corticosteroid therapy for serious organ involvement. Although the pathogenesis of osteonecrosis remains unclear, the final common pathway of subchondral bone destruction involves a compromise of blood flow preventing essential nutrients and normal reparative processes, leading to further osteocyte death [23]. AVN accounts for a numerically small but important indication for total joint replacement, particularly of the hip, knee, and shoulder in SLE patients (Fig. 3.7). Owing to an inherent and drug-induced immunosuppression, patients with SLE are also at increased risk for the development of septic arthritis, the acute therapy of which may require input from the orthopedic surgeon.

Another important condition of the connective tissue is that commonly known as systemic sclerosis (scleroderma). Scleroderma exits in two major and distinct forms: localized scleroderma (LSc), which is confined to the skin and subcutaneous tissues and systemic sclerosis (SSc), which almost always has internal organ involvement, but may be limited or diffuse in its cutaneous distribution on the basis of extent of skin thickening; limited disease is defined as skin thickening that affects the distal extremities below the elbows and/or below the knees, and to a lesser extent face and neck involvement, where as diffuse cutaneous disease refers to extensive skin sclerosis affecting the proximal limbs, trunk, face, and neck regions. Rarely, systemic sclerosis can also present as *SSc sine scleroderma* with the typical vascular and fibrotic features of systemic disease but without any cutaneous involvement.

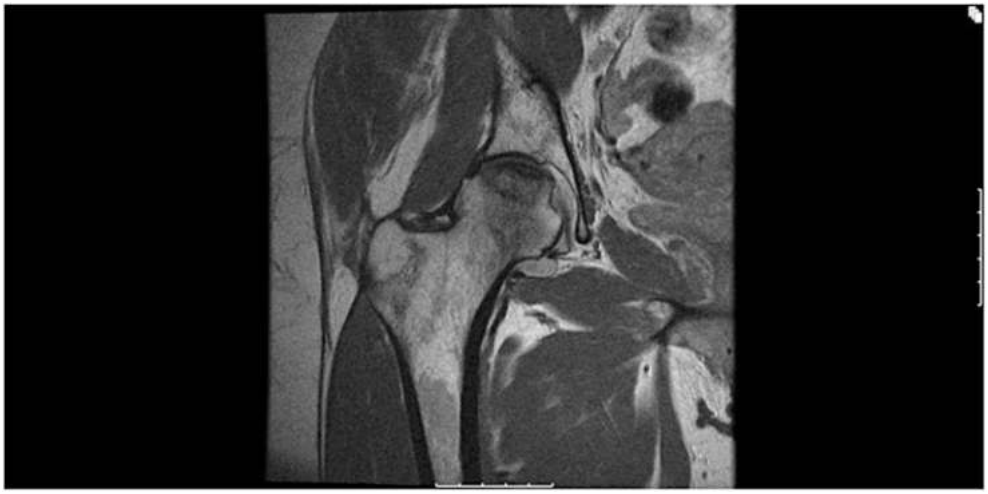

**Fig. 3.7** Avascular necrosis of the hip in systemic lupus erythematosus. The R hip reveals extensive avascular necrosis involving almost the entire articular portion of the femoral head, with mild collapse of the superior femoral head. This has elicited a moderate degree of edema within the proximal right femur as well as a joint effusion of the right hip joint. Avascular necrosis also affects the greater trochanter

Localized scleroderma, an entity that is distinct from *limited* scleroderma, includes dermatologic conditions such as morphea (circumscribed patches of thickened skin), linear scleroderma, pansclerotic morphea, or mixed scleroderma; rarely are there extracutaneous manifestations. Localized and limited scleroderma should be thought of as two distinct diseases with different clinical manifestations and prognosis (Fig. 3.8). In limited cutaneous sclerosis, formerly termed as CREST syndrome (*c*alcinosis of the digits, *R*aynaud's phenomenon, *e*sophageal dysmotility, *s*clerodactyly, and *t*elangiectasis), patient generally have prominent vasculopathic phenotype. One of the most characteristic clinical manifestation of vascular dysfunction is Raynaud's phenomenon, which is due to arterial vasoconstriction in the digits precipitated by cold or stress, manifested by the triphasic color changes (white (pallor) → blue (acrocyanosis) → red (reperfusion hyperemia)). Pulmonary vascular disease, primarily pulmonary arterial hypertension is more commonly seen in limited cutaneous disease, affecting up to 40 % of patients. In systemic sclerosis, clinical manifestations arise as a consequence of an obstructive vasculopathy involving the small vessels, the pathological accumulation of collagen in the skin and other organ systems resulting in fibrosis, and autoimmunity as evidenced by a number of associated autoantibodies. Often a severely debilitating disease, pulmonary parenchymal disease (interstitial fibrosis) has become the most common form of death for such patients [24]. There is no effective treatment for this disorder. An important complication of this condition is the ischemic digit, usually the finger, due to an obliterative vasculopathy and vasospasm in which the caliber of blood vessels narrows and irreversible tissue loss may ensue. Chronic ischemia may lead to digital ulcers, gangrene, tapering of fingers due atrophy of underlying soft tissue, and skin changes referred to as sclerodactyly (localized thickening and tightness of the digit). A consequence of the vascular obstructive and vasospastic elements of this disease, SSc manifestations in the hand may require the participation of a hand surgeon *experienced in* microsurgical revascularization, digital arterial reconstruction to improve digital vascular perfusion, and peripheral sympathectomy to relieve pain. There also may be a role of surgery for advanced SSc affecting the hand, in which chronic ischemia and fibrosis may lead to atrophy and contractures of the digits, nail deformities, and calcinosis (Fig. 3.9a, b); however, surgical benefits should be balanced with risks of impaired wound healing and the progressive course of SSc [25]. Important perioperative surveillance/screening of pulmonary disease (pulmonary arterial hypertension and/or pulmonary fibrosis) is imperative in SSc patients, especially if dyspnea is present.

A less common but important third form of the connective tissue disease include the inflammatory diseases of the muscle—dermatomyositis (DM) and polymyositis (PM). These represent another heterogeneous group of disorders, and they share the clinical features of a progressive skeletal muscle weakness and fatigue and a decrease in endurance. Disease-specific autoantibodies are also frequently found but ultimately the diagnosis is made by muscle biopsy that demonstrates an inflammatory infiltrate. Treatment includes corticosteroids, IVIG, and immunosuppressive therapy with medication such as Methotrexate. These diseases rarely require orthopedic intervention.

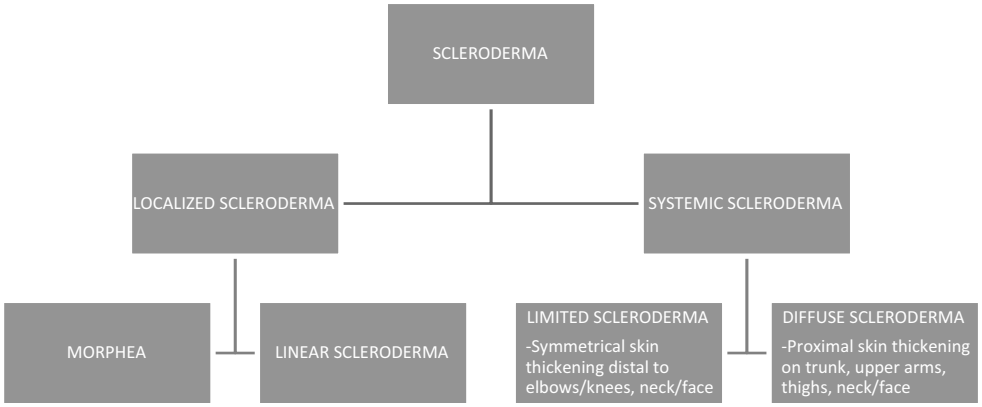


**Fig. 3.8** Schematic diagram for classification of scleroderma

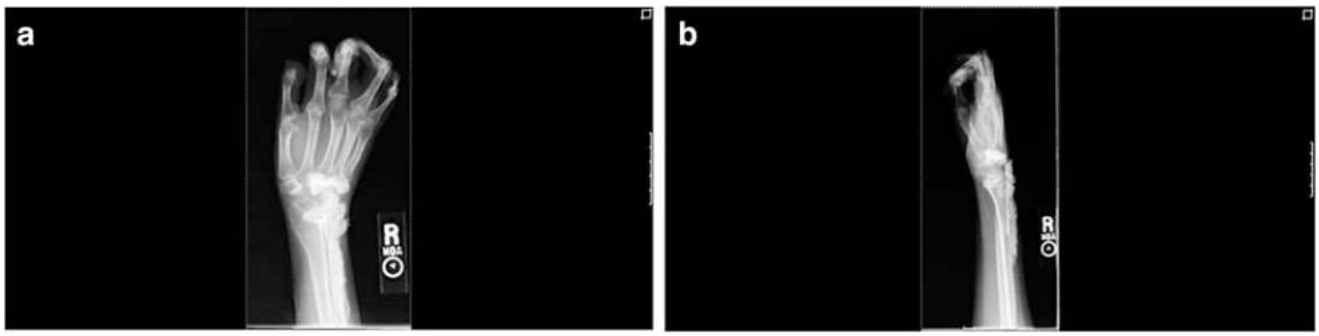


**Fig. 3.9** (**a**) Calcinosis and contracture in scleroderma. (**b**) There are flexion contractures of the PIP joints bilaterally. There are soft tissue calcifications around the wrists, hands and distal forearms bilaterally. There is acroosteolysis with loss of the terminal tufts of distal phalanges at multiple fingers

## Spondyloarthropathies

The Spondyloarthropathies (SpA) comprise a group of inflammatory disorders with overlapping clinical manifestations and a shared genetic marker (HLA-B27). Ankylosing Spondylitis (AS), with its prominent back (axial) involvement, is the protypical condition but other disorders such as Psoriatic Arthritis (PsA), the enteropathic arthropathies, and Reactive Arthritis are now categorized similarly. Patients who present with clinical features suggestive, but not diagnostic, of SpA are labeled as "undifferentiated" spondyloathropathy. In contrast, those with well defined clinical features have been referred to in the past as "seronegative" spondyloarthropathy. This designation implies the genetic, clinical, and pathophysiologic characteristics of these conditions, while making reference to the absence of rheumatoid factor. In their fullest expression, these conditions are characterized by three distinctive features: the soft tissue phenomenon of enthesitis and a true arthritis involving the axial and peripheral skeleton.

The first distinguishing feature of the spondyloarthropathies is the presence of enthesopathy, an inflammation of the boney insertion points of tendons, ligaments, or the joint capsule. *Enthesitis* is responsible for the multiple spinal and peripheral manifestations characteristic of this class of rheumatic conditions in which pain, stiffness, and restriction develops at sacroiliac and other spinal joints. Extraspinal enthesitis commonly affect the Achilles tendon insertions to the calcaneous and plantar fascia. A second trademark of these conditions is the presence of axial arthritis (i.e., sacroilitis and spondylitis). Inflammatory synovitis and capsular enthesitis at the sacroiliac joints (SI) results in sacroilitis; similarly inflammation of the entheses associated with paraspinal ligaments ultimately leads to spondylitis. Such involvement also accounts for the involvement of the intervertebral disks, symphysis pubis, manubrioclavicular and sternoclavicular joints. These conditions are brought to their fullest expression with the addition of peripheral joint involvement, an uncommon feature in AS but commonly seen in PsA or reactive arthritis. Various patterns are commonly seen and vary according to the associated disease process. For instance, in AS, the shoulder and hips are most frequently involved. In contrast, an asymmetric lower extremity oligoarthritis (knee, ankle) is more commonly seen in Reactive Arthritis while distal interphalangeal joint disease usually denotes PSa. An important feature of the

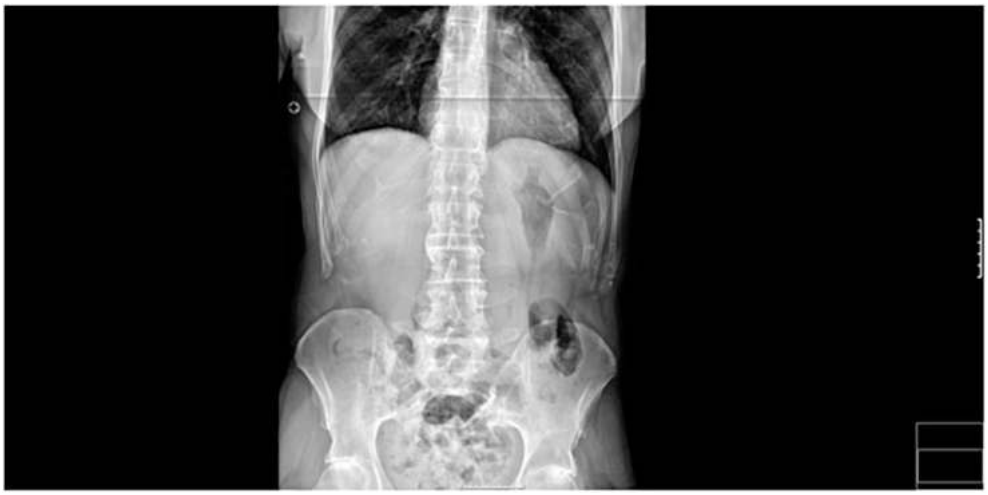

**Fig. 3.10** Spinal radiograph in severe anklyosing spondylitis. There is complete fusion of the sacroiliac joints bilaterally and axial joint space narrowing of both hip joints. In the spine, bridging syndesmophytes are noted focally at L2-3 on the *right* as well as T10-11 on the *right* and T9-10 on the *left*

SpAs is the "sausage" digit or dacyllitis, an inflammatory process involving a small joint synovitis combined with an enthesitis of the tendon sheaths, insertions and various other supporting tissues of the digit (fingers or toes). Combined, these processes produce the sausage-like swelling a finding virtually pathognomonic of the spondyloarthropathies.

As the prototypical disease among the spondyloarthropathies, the symptoms of AS usually begin in the third or fourth decade of life with the gradual onset of inflammatory back pain. It predominantly affects men at much higher frequency than women (ratio of 9:1). Signs and symptoms of spinal involvement predominate and the inflammatory (as opposed to mechanical) nature of the condition is suggested by a number of features: age $< 40$ years, insidious onset, duration of $<3$ months, marked morning stiffness, and improvement with activity. Patients often complain of back pain at nighttime. Sacroilitis, a common initial feature, presents as pain in buttocks which may radiate down the legs and/or hip pain. In a minority of patients, peripheral oligoarthritis and/or enthesitis accompany the axial involvement. Concurrent constitutional features of fatigue, weight loss, and depression often may be present. Progressive involvement of the entire spine occurs over years, resulting in spinal pain, stiffness, and severe restriction of the spine (Fig. 3.10). Family history often reveals others with early onset back pain or inflammatory problems in the eye (uveitis, iritis). Diagnosis of AS should be predominately based on the clinical presentation of a usually a young man (before the age of 40 years) who presents with chronic inflammatory back pain. The New York criteria of 1968, modified New York Criteria 1984 criteria, and the most recent European Spondyloarthropathy Study Group criteria outline important clinical and radiographic features; however, the classifications have low sensitivity in detecting early disease (Fig. 3.11; [26–28]).

In contrast, patients with Psoriatic Arthritis are also often young, but rather than spinal disease, the more typical presentation is that of an asymmetric oligoarthritis in conjunction with other characteristic features such as destructive DIP involvement, nail changes, sausage digits and the aforementioned peripheral enthesopathy (often the Achilles tendon or plantar fasciitis). For those that do have spondyloarthropathy of PsA, the asymmetric involvement of sacroilitis can distinguish that from the spondyloarthropathy of AS, which classically affects both sacroiliac joints. Also, approximately a third of patients with psoriasis will develop PsA; the majority of patients develop psoriasis years prior to inflammatory musculoskeletal features; however, there is a group of patients (15–20 %) in whom the joint disease precedes the skin disease [29]. With respect to the enteropathic disease entities, this form of inflammatory arthritis develops in patients with Crohn's Disease or Ulcerative Colitis. Sacroilitis is common and the peripheral joint arthritis tends to take the form of a large joint inflammatory process that follows the clinical activity of the underlying gastrointestinal disease. The pattern of arthritis is variable; it is commonly asymmetric but can present in a migratory or additive fashion, and tends to be non-erosive. Lastly, there is Reactive Arthritis. Formerly known as "Reiter's Syndrome," this is a clinical syndrome of arthritis coupled with extra-articular features seen in susceptible individuals following a genitourinary or gastrointestinal infection. Such individuals develop a seronegative, inflammatory arthritis arising weeks after the antecedent infection accompanied by ocular (conjunctivitis, uveitis), mucocutaneous (oral ulcers, balanitis, keratoderma blennorrhagicum), gastrointestinal

## New York Criteria (Moll and Wright, 1973)

Clinical criteria:

1) Limitation of motion lumbar spine all three planes (anterior flexion, lateral flexion, and extension)
2) History or presence of pain at the dorso-lumbar junction or in the lumbar spine
3) Limitation of chest expansion to 1in (2.5 cm) or less, measured at the level of the fourth intercostal space.

Definite AS:

1) Grade 3-4 bilateral sacroilitis with at least one clinical criterion
2) Grade 3-4 unilateral or Grade 2 bilateral sacroilitis with clinical criterion #1 or with both clinical criteria #2 and 3.

Probable AS:

1) Grade 3-4 bilateral sacroilitis with no clinical criteria

## Modified New York Criteria (Vader, 1984)

Clinical criteria:

1) Low back pain and stiffness >3 months which improves with exercise, but is not relieved by rest
2) Limitation of motion of lumbar spine in both the sagittal and frontal planes
3) Limitation of chest expansion relative to normal values corrected for age and sex

Radiologic criteria: Sacroilitis grade ≥ 2 bilaterally or sacroilitis grade 3-4 unilaterally

Definite AS: Radiologic criterion is associated with at least 1 clinical criterion

Probable AS:

1) Three clinical criteria are present
2) Radiographic criterion is present without any signs or symptoms satisfying clinical criteria

## ESSG Criteria (Dougados, 1991)

Inflammatory spinal pain OR Synovitis (1) Asymmetric; 2) Predominately in lower limbs)

AND

One or more of the following:

-Positive family history

-Psoriasis

-Inflammatory bowel disease

-Urethritis, cervicitis, or acute diarrhea within one month before arthritis

-Buttock pain alternating between right and left gluteal areas

-enthesopathy

-sacroililits (radiographic)

**Fig. 3.11** Criteria for diagnosing ankylosing spondylitis

(dysenteric), and genitourinary manifestations (urethritis, cervicitis). Infectious agents most often implicated include *Chlamydia*, *Salmonella*, *Campylobacter*, *Yersinia,* and *Shigella* species. These organisms are rarely cultured from the joint fluid or synovial tissue, and hence the designation *reactive*. The peripheral joint involvement is usually an asymmetric lower extremity oligoarthritis, though as with the other spondyloarthropathies, sausage digits (dactylitis) are also a common feature. Axial involvement is uncommon and distinguishable from AS spondyloarthropathy by its predominate asymmetric pattern of sacroilitis and paramarginal syndesmophytes. Lastly, patients may present with features suggestive (seronegative oligoarthritis and enthesitis) but not diagnostic of these conditions. In such patients the diagnostic designation is that of an undifferentiated spondyloarthropathy.

Once difficult to treat, new biologic therapies such as tumor necrosis factor (TNF) inhibitors have markedly improved the clinical course and symptomatic experience of patients suffering with these conditions. Nonetheless, given the peripheral joint involvement seen in these conditions, patients who suffer from these conditions ultimately may require total joint arthroplasty.

## Vasculitides

The term vasculitis refers to several diseases involving inflammation of the blood vessels with resultant tissue necrosis and organ-failure. The spectrum of disease is broad with overlapping features. While its classification systems had historically relied on eponyms, it is now categorized according to the size of the involved blood vessels. Polymyalgia rheumatica and temporal arteritis are amongst the best known examples but also included are such conditions as polyarteritis nodosa, granulomatosis with polyangiitis (formerly known as Wegener's granulomatosis), Churg–Strauss syndrome (also known as allergic granulomatosis and allergic angiitis) to name a few. Treatment paradigms rely on corticosteroids and immunosuppressants. Orthopedic intervention is rarely needed in the course of these conditions.

## Metabolic Bone Disease

Osteoporosis is a widely recognized disorder of skeletal muscle characterized by low bone mass and microarchitectural deterioration of bone, increasing its fragility and susceptibility to fracture. Pathophysiologically comprised of a heterogeneous group of disorders, osteoporosis is characterized by a net loss of bone (bone resorption activity dominating over bone formation activity) resulting in a decrease in the overall density of mineralized bone (Fig. 3.12). Such osteoporotic fractures that result due to the inability of the bone to absorb the traumatic load may have devastating consequences for patients and, with the aging of the population, have become so common as to constitute a threat to public health. Owing to the causal association between this condition and fracture of the hip and the importance of bone quality in osseous healing, it is one of the most important rheumatic diseases now encountered on orthopedic services.

The aim of osteoporotic screening and treatment is to prevent fractures. Presently, the dual X-ray absorptiometry (DXA) has become the diagnostic tool for osteoporosis. Adopted by the World Health Organization (WHO) and using population standards, osteoporosis is defined in a patient with a bone density measurement of the spine that is >2.5 standard deviations below the mean of the standard 35 year old population in the appropriate gender (as defined by the T score). Osteopenia is defined as a T score between 1.0 and 2.5 standard deviations the bone density of a standard 35-year old population. Additionally, the Z score provides an evaluation of bone density as it relates to age-matched controls. While bone density is a primary indicator of bone quality, there are other structural and material factors, such as bone macro- and micro-architecture, degree of mineralization and micro-damage accumulation, and bone turnover that influence overall bone quality [30]. Indeed in the orthopedic surgical setting its implications extend to such considerations as the achievement of boney fusion after spinal surgery as well as the anticipated longevity of total joint replacement.

## Crystal-Induced Arthropathies

Owing to fluid shifts and dehydration, gout (uric acid) and pseudo-gout ($Ca^{2+}$ pyrophosphate) deposition in peripheral joints occurs frequently after surgery. As such, they are common management problems in the postoperative period, as discussed in Chap. 10. The archetypal presentation of these conditions is well known to clinicians taking the form of the sudden onset of severe pain, swelling and erythema, usually of a single joint, most often the first metatarsophalangeal joint. Other joints are not uncommon, however; the tarsometatarsal joint and ankle are frequent sites as are the knee and wrist. The latter are frequently seen in $Ca^{2+}$ pyrophosphate crystal deposition (CPPD). Diagnosis is premised on the demonstration of pathognomonic crystals within the synovial fluid as seen via polarized light microscopy; that is, the negatively strongly birefringent, needle-shaped monosodium urate crystal in the case of gout versus the positively weakly birefringent, rhomboid crystal of CPPD (Fig. 3.13a, b). In the postoperative setting, treatment involves the oral administration of nonsteroidal anti-inflammatory drugs, short courses of corticosteroids

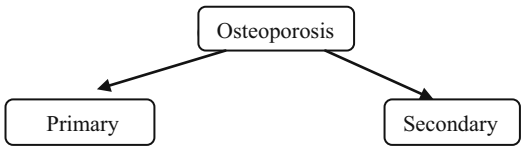


**Fig. 3.12** Common causes of osteoporosis

***Idiopathic juvenile osteoporosis**

***Involutional osteoporosis:**

*-Post menopausal*

*-Age-related*

***Drugs**:*alcohol;glucocorticoids; anticonvulsants; heparin; cyclosporine*

***Endocrinopathy:** *Hyperthyroidism; Cushing's syndrome; hypogonadism; hyperparathyroidism; type I diabetes mellitus; amenorrhea (exercise-induced, anorexia nervosa); pregnancy*

***Immobilization:** *prolonged bed rest; paralysis; weightlessness*

***Medical illnesses/neoplasm**: *systemic inflammatory disease (Rheumatoid arthritis, Systemic lupus erythematosus, inflammatory bowel disease); celiac disease; mastocytosis; multiple myeloma; leukemia/lymphoma; macroglobulinemia*

***Genetic conditions:** *osteogenesis imperfect; menkes' syndrome; Ehlers-Danlos syndrome; homocystinuria; Marfan syndrome*

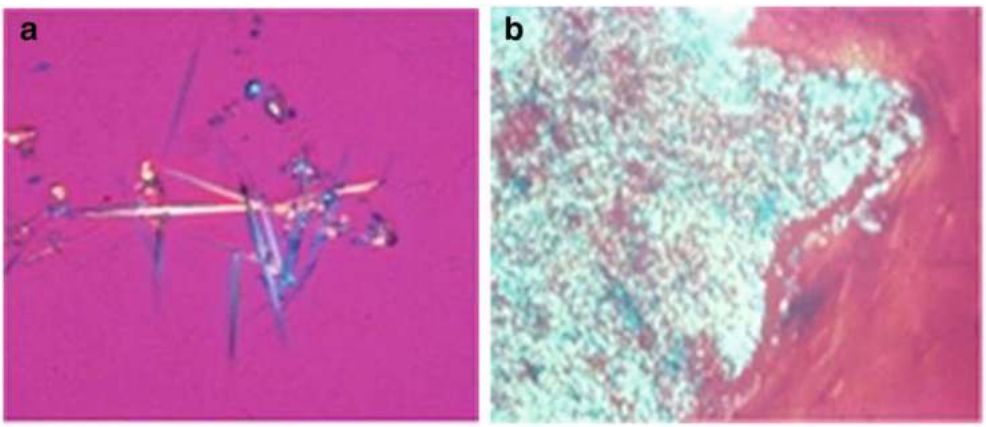


**Fig. 3.13** (**a**) Gout: monosodium urate crystals. Strongly negative birefringent, needle-shaped crystals aspirate from tophaceous deposit. Crystals are *yellow* when parallel (*blue* when perpendicular) to the long axis of the first order red compensator on polarized light microscopy consistent with gout. (**b**) Pseudo-gout: calcium pyrophosphate dehydrate (CPPD) crystals. Weakly positive birefringent, rhomboid-shaped or polymorphic crystals aspirated from joint of a patient with pseudo-gout. Crystals are typically *blue* when parallel (*yellow* when perpendicular) to the long axis of the first order red compensator on polarized light microscopy consistent with pseudo-gout (Both used with permission from ACR Image Bank)

(or ACTH), or intra-articular injections of such steroids. Because of the potential for gastrointestinal side effects, oral colchicine is a less favored medication after surgery.

Another form of crystalline disease is calcium hydroxyapatite crystal deposition disease, a common entity best characterized as "calcific tendinitis" most frequently affecting the shoulder, but also affecting other sites such as the hips, wrists, and feet. This syndrome is typically recognized by recurrent pain due to the pathologic peri- and/or intra-articular buildup of calcific material around the tendons/joints, which occurs as primary (or idiopathic) or as a secondary process due to various disease processes including renal disease, collagen vascular disease, metabolic disorders, or trauma. Hydroxyapatite crystals are small, amorphous,

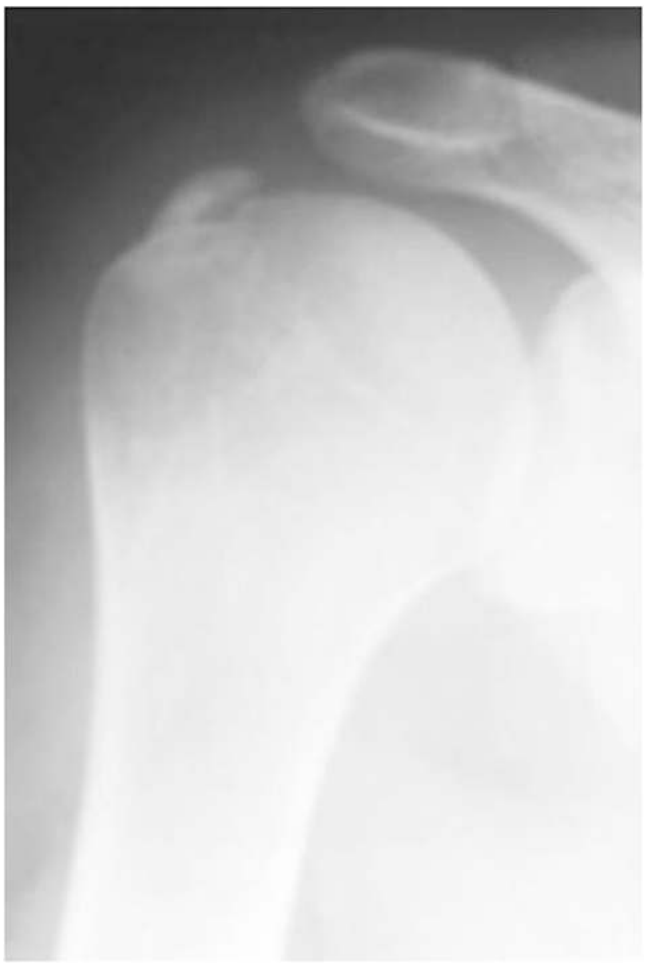

**Fig. 3.14** Calcific tendonitis of shoulder. Amorphous calcific deposit on supraspinatus tendon near its insertion site at the greater tuberosity (Used with permission from ACR Image Bank)

and nonbirefringent in polarized light, thereby making it difficult to diagnose with light microscopy; diagnosis is made on the basis of radiographic findings of calcium deposits in the typical periarticular and tendinous sites and concomitant clinical symptoms (Fig. 3.14). Rarely requiring surgical intervention, treatment of hydroxyapatite deposition disease involves conservative measures, such as nonsteroidal anti-inflammatory medications (NSAIDs), intra-articular steroid injections, and physical therapy.

## Infectious Arthritis

Invasion of a joint by pyogenic bacteria is responsible for rapidly progressive joint destruction, osteomyelitis and potentially systemic spread of the infection. The majority of such infections arise from hematogenous spread of offending bacteria to the affected joint(s). Predisposing factors include IV drug use, in-dwelling catheters, the use of immunosuppressive medication, and a host of disease processes that suppress immunity. Important examples of the latter include diabetes mellitus, chronic inflammatory arthritis, HIV infection, and alcoholism, to name a few.

The major pathogens are the gram-positive cocci (usually Staphylococcal species) accounting for >75 % of cases. *Staphylococcus aureus* is the most common offending agent, followed by streptococci and pneumococci; *Staphylococcus epidermidis* is often seen in the setting of prosthetic joint infection, rarely arising in the native joint. Gram-negative organisms, though a much less common cause of septic arthritis, are more often encountered in intravenous drug abusers. Associated with a purulent joint fluid (WBC > 50,000, predominately granulocytes), a definitive diagnosis requires the demonstration of bacteria in the joint fluid. Antibiotic therapy logically follows from culture of the synovial fluid. Prompt diagnosis and treatment is vital in order to achieve optimal recovery. Repeated joint aspiration (needle or arthroscopic) may be required serially early in the treatment process. Removal of the prosthesis is often required followed by a course (6 weeks) of intravenous antibiotic therapy and ultimately reimplantation.

## Summary

The chronic rheumatic diseases represent a broad category of conditions that share a common feature, the destruction of cartilage and its consequences. While these conditions differ in their pathophysiology, the final common pathway is often the joint hence such patients frequently require orthopedic surgery. Presented herein is a short summary of the important conditions, presenting their broad range of clinical expression the purpose of which is the education of the readership. A second chapter in this book presents the clinical approach to the assessment of such patients prior to undergoing surgery.

**Summary Bullet Points**

- The chronic rheumatic diseases are prevalent conditions with a major impact on society and the health care system.
- Given their prevalence and the involvement of the joints, such patients may make up a significant proportion of an orthopedic patient population.
- The rheumatic diseases share one central feature: the destruction of joints.
- Although a disparate group of disorders, a systematic approach to the differential diagnosis of these conditions is presented.

## References


1. Helmick CG, Felson DT, Lawrence RC, Gabriel S, Hirsch R, Kwoh CK, et al. Estimates of the prevalence of arthritis and other rheumatic conditions in the United States: Part I. Arthritis Rheum. 2008;58:15–25.
2. Abramson S, Attur M. Developments in the scientific understanding of osteoarthritis. Arth Res Ther. 2009;11:227–35.
3. Li B, Aspden RM. Mechanical and material properties of the subchondral bone plate from the femoral head of patients with osteoarthritis or osteoporosis. Ann Rheum Dis. 1997;56:247–54.
4. Goldring SR, Goldring MB. Clinical aspects, pathology and pathophysiology of osteoarthritis. J Musculoskelet Neuronal Interact. 2006;6:376–8.
5. MacKenzie CR, Paget SA. Perioperative care of the rheumatic disease patient. In: Hochberg MC, Silman AJ, Smolen MS, Weinblatt ME, Weisman MH, editors. Rheumatology. 5th ed. Philadelphia, PA: Mosby Elsevier; 2010.
6. MacKenzie CR, Sharrock NE. Perioperative medical considerations in patients with rheumatoid arthritis. Rheum Clin N Am. 1998;24:1–17.
7. Brandt KD. Defining osteoarthritis: what it is, and what it is not. J Musculoskeletal Med. 2010;27:1–12.
8. Sims KJ, Richardson CA, Brauer SG. Investigation of hip abductor activation in subjects with clinical unilateral hip osteoarthritis. Ann Rheum Dis. 2002;61:687–92.
9. Becker R, Berth A, Nehring M, Awiszus F. Neuromuscular quadriceps dysfunction prior to osteoarthritis of the knee. J Orthopaedic Res. 2004;22(4):768–73.
10. Gaston JS. Cellular immunity in rheumatoid arthritis. In: Hochberb M, Silman AJ, Smolen JS, Weinblatt ME, Weisman MH, editors. Rheumatology. 5th ed. Philadelphia, PA: Mosby; 2011. p. 897–934.
11. Hochberb M, Silman AJ, Smolen JS, Weinblatt ME, Weisman MH, editors. Rheumatology. 5th ed. Philadlephia, PA: Mosby; 2001. p. 897–934.
12. Goldring SR, Gravallese EM. Pathogenesis of bone erosions in rheumatoid arthritis. Curr Opin Rheum. 2000;12:195–9.
13. Gregersen PK, Silver J, Winchester RJ. The shared epitope hypothesis: an approach to understanding the molecular genetics of susceptibility to rheumatoid arthritis. Arthritis Rheum. 1987;30:1205–13.
14. Goodyear CS, Tighe H, McInnes IB. Rheumatoid factors and other autoantibodies in rheumatoid arthritis. In: Firestein GS, Budd RC, Harris Jr ED, et al., editors. Kelley's textbook of rheumatology. 8th ed. Philadelphia, PA: W.B. Saunders Company; 2008. Chapter 51.
15. Whiting PF, Smidt N, Sterne JA, et al. Systematic review: accuracy of anti-citrullinated peptide antibodies for diagnosis rheumatoid arthritis. Ann Intern Med. 2010;152(7):456.
16. Nishimura K, Sugiyama D, Kogata Y, et al. Meta-analysis: diagnostic accuracy of anti-cyclic citrullinated peptide antibody and rheumatoid factor for rheumatoid arthritis. Ann Intern Med. 2007;146(11):797.
17. Klareskog L, Catrina AI, Paget S. Rheumatoid arthritis. Lancet. 2009;373:659–72.
18. Syversen SW, Gaarder PI, Goll GL, et al. High anti-cyclic citrullinated peptide levels and an algorithm of four variables predict radiographic progression in patients with rheumatoid arthritis: results from a 10-year longitudinal study. Ann Rheum Dis. 2008;67:212–7.
19. Van der Helm-van Mil AH, Padyukov L, Toes RE, et al. Genome-wide single-nucleotide polymorphism studies in rheumatology: hype or hope? Arthritis Rheum. 2008;58(9):2591–7.
20. Van Gaalen FA, Linn-Rasker SP, van Venrooij WJ, et al. Autoantibodies to cyclic citrullinated peptides predict progression to rheumatoid arthritis in patients with undifferentiated arthritis: a prospective cohort study. Arthritis Rheum. 2004;50:709–15.
21. Fessel WJ. Systemic lupus erythematosus in the community: incidence, prevalence, outcome, and first symptoms; the high prevalence in black women. Arch Int Med. 1974;134:1027–35.
22. Lahita RG. Special report: adjusted lupus prevalence: results of a marketing study by the Lupus Foundation of America. Lupus. 1995;4:450–3.
23. Powell C, Chang C, Gershwin ME. Current concepts on the pathogenesis and natural history of steroid-induced osteonecrosis. Clinic Rev Allerg Immunol. 2010;41:102–13.
24. Steen VD, Medsger TA. Severe organ involvement in systemic sclerosis with diffuse scleroderma. Arthritis Rheum. 2000;43:2437–44.
25. Bogoch ER, Gross DK. Surgery of the hand in patients with systemic sclerosis: outcomes and considerations. J Rheumatol. 2005;32:642–8.
26. Moll JMH, Wright V. New York clinical criteria for ankylosing spondylitis; a statistical evaluation. Ann Rheum Dis. 1973;32:354–63.
27. Van der Linden S, Valkenburg HA, Cats A. Evaluation of diagnostic criteria for ankylosing spondylitis. A proposal for modification of the New York criteria. Arthritis Rheum. 1984;27:361–8.
28. Dougados M, van der Linden S, Juhlin R, et al. European Spondyloarthropathy Study Group (ESSG): preliminary criteria for the classification of spondyloarthropathy. Arthritis Rheum. 1991;34:1218–27.
29. Mease P. Management of psoriatic arthritis: the therapeutic interface between rheumatology and dermatology. Curr Rheum Rep. 2006;8(5):348–54.
30. Griffith JF, Engelke K, Genant HK. Looking beyond bone mineral density. Annal N Y Acad Sci. 2010;1192:45–56.

# The Pathophysiologic Events of Total Joint Replacement Surgery

4

Stavros G. Memtsoudis

**Objectives**

- To discuss issues surrounding the role of intravasation of bone, cement, and fat into the systemic circulation and its effects on various organ systems.
- To discuss the relationship of overall embolic load and end-organ reserve in the context of clinical outcomes.
- To specifically review the pathophysiology of cement and fat embolism.
- To elucidate additional pathophysiological components relevant to spine surgical interventions.
- To review interventions targeted to reduce the impact of intraoperative insults on clinical outcomes.

**Key Points**

- During reaming and insertion of a prosthesis, areas usually occupied by bone marrow are pressurized leading to intravasation of debris made up by fat, marrow cells, cement, and bone.
- Various organs are affected by this insult, including the cardiopulmonary system.
- The higher the embolic load and the lower the patient's end-organ reserve, the more likely clinical symptoms may develop.

## Introduction

A large number of insults including tissue trauma, blood loss, and activation of various neurohumoral cascades are underlying causes for perioperative complications.

While patients undergoing orthopedic procedures are not exempt from exposure to these stresses, a number of specific events associated with the nature of orthopedic surgery make this patient population unique and thus warrant special attention and discussion.

In this context, intraoperative embolization of bone, cement, and marrow material during instrumentation and manipulation of osseous structures may explain the mechanism by which perioperative complications after total joint replacement present [1, 2]. Indeed, complications which can be traced to intraoperative debris embolization have been linked to some of highest rates of associated mortality [3]. While embolic load influences the development of complications on one side of the equation, outcomes are affected by end-organ reserve of a particular patient on the other.

This chapter therefore reviews the nature and pathophysiology of the so-called "bone cement syndrome" and its effects on various organ systems. Various factors influencing the predisposition to the development of complications are presented, and approaches to ameliorate the impact are discussed.

## Pathophysiology of the Bone Cement Syndrome

Orthopedic surgery is inadvertently associated with the invasion of the bone marrow canal in order to prepare the bone for the prosthetic components. During various portions of preparation, i.e., reaming and insertion of a prosthesis, areas usually occupied by bone marrow are pressurized leading to intravasation of debris made up by fat, marrow cells, cement,

S.G. Memtsoudis (✉)
Weill Cornell Medical College, Hospital for Special Surgery, 535 East 70th Street, New York, NY 10021, USA
e-mail: memtsoudiss@hss.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_4, 

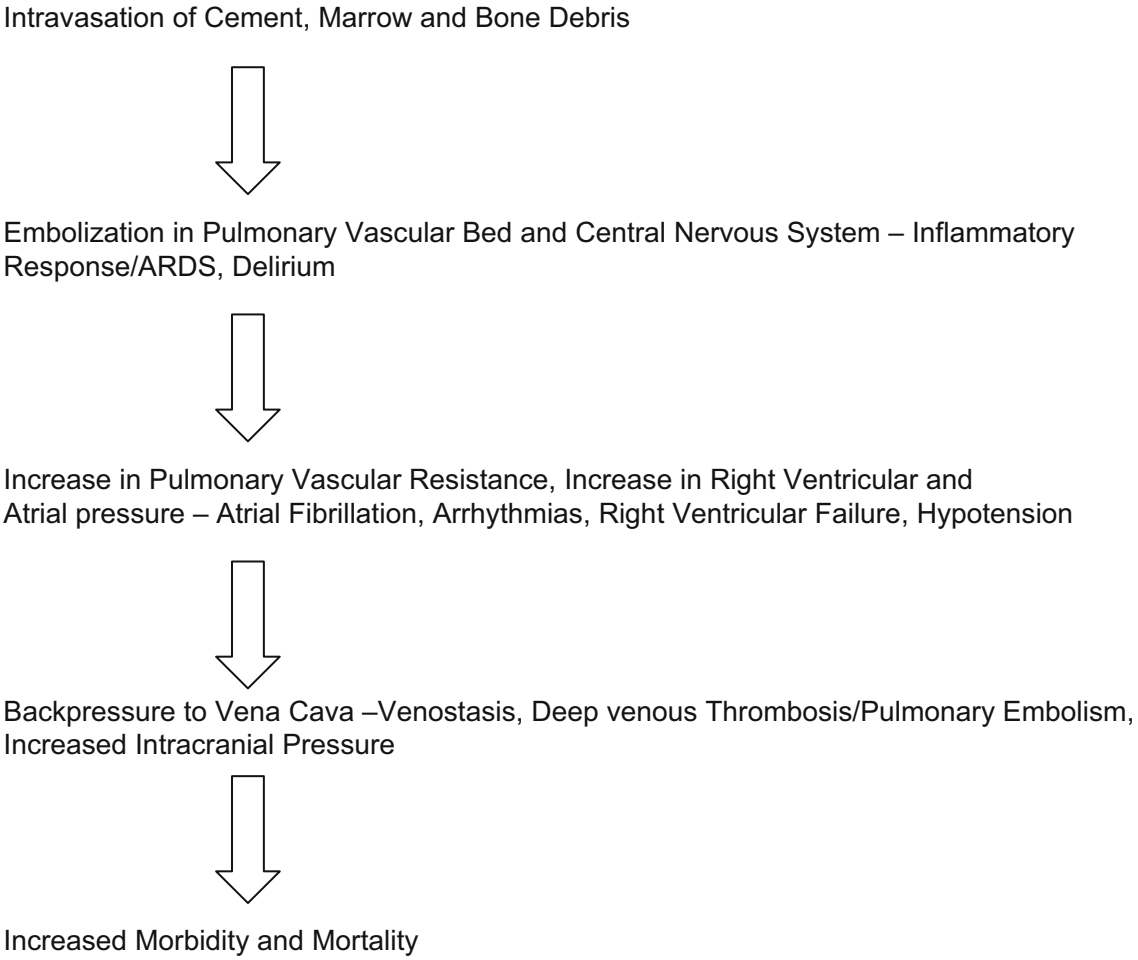


**Fig. 4.1** Process and effect of embolization of cement and bone marrow debris on organ systems

and bone. While studies suggest that these events occur in the majority of patients [4–6], the effects remain clinically insignificant and transient in the vast majority of cases [7]. However, derangements manifesting in an increase in pulmonary arterial pressures, right heart strain, cardiovascular collapse, lung injury, and death have been described [6, 8]. Mechanisms for the various degrees of presentation of these events remain speculative to date, but are thought to be related to the overall load and size of particles gaining access to the pulmonary vasculature [6, 9, 10].

Some of the proposed mechanisms include mechanical embolization of debris, toxic effects of methylmethacrylate, neuromodulation during marrow canal pressurization [11], and release of vasoactive substances promoting microthrombi [6, 12, 13].

Investigations into the toxicologic effects of methylmethacrylate monomers suggest a direct negative inotropic effect in vitro [13]. However, subsequent measurements in the clinical setting suggest that plasma concentrations in vivo are too low to account for hypotensive effects encountered during the cementation process [14]. Cement fixation of hip prosthesis has been linked to release of anaphylatoxins C3a and C5a. No such release was seen in uncemented prostheses in the same study [9].

While methylmethacrylate modulated effects may play a role in the pathophysiology of the bone implantation syndrome the impact of fat emboli has been better defined in the literature [2]. In its extreme form it presents as the "fat embolism syndrome" and is associated with pulmonary, hematologic, central nervous, and other organ system complications secondary to the effects of fat mediated embolization and inflammation [2, 15], and the details of this are discussed next.

## Physiologic Effects on Various Organ Systems

The embolization of cement and bone marrow debris is not confined to the venous and pulmonary system. Evidence suggests that smaller particles travel through the pulmonary circulation and potentially through a patent foramen ovale, facilitated via perioperatively increased pulmonary arterial pressures [6], thus leading to microembolization of various organ systems (Fig. 4.1) [1, 16].

## Cardiopulmonary Effects

Effects surrounding unilateral arthroplasty on the pulmonary vasculature have been described in the past. Most trials, however, have found little clinical significance and have described changes in pulmonary pressures and right heart function as small and relatively short-lived [17–19]. In contrast, Urban et al. found that 22 % of patients undergoing revision total hip arthroplasty showed significant decreases in right ventricular function and increases in pulmonary vascular resistance [6]. Further, increases in pulmonary vascular resistance may be more pronounced and prolonged during bilateral procedures [10, 20] stressing the role of embolic load as discussed later in this chapter.

Decreased end-organ capacity of the cardiopulmonary system has been shown to be a major factor in the patient's ability to absorb the stresses induced by intraoperative events. Thus, patients with preexisting right heart strain, as is the case with pulmonary hypertension, are at particularly high risk for morbidity and mortality [21]. In a study of nationally representative data, patients with pulmonary hypertension undergoing total hip arthroplasty experienced an approximately fourfold increased adjusted risk of mortality (2.4 % vs. 0.6 %), and those undergoing total knee arthroplasty a 4.5-fold increased adjusted risk of death (0.9 % vs. 0.2 %) compared with patients without pulmonary hypertension in a matched sample ($P < 0.001$ for each comparison). Further, the study found that the degree of pulmonary hypertension played a significant role in the risk for complications. Patients undergoing total hip arthroplasty and who suffered from primary pulmonary hypertension, which is associated with more severe disease, experienced the highest mortality rate (5 % (95 % CI, 2.3–7.7)). In support of this concept are Ramakrishna and colleagues' findings that a right ventricular systolic pressure to systemic systolic blood pressure ratio over 0.66 was a predictor for postoperative mortality [22].

Thus, it seems prudent to identify patients with potentially subclinical increases in pulmonary pressures and consider them at increased risk for complications. In this context it has been suggested that right ventricular dysfunction is more prevalent in patients with obesity, sleep apnea and patients with a history of pulmonary embolism [23, 24].

## Effects in Other Organ Systems

It has been hypothesized that intraoperative embolization of debris and increases in pulmonary pressures may represent a common pathway for complications associated with a high incidence among mortalities after hip and knee arthroplasty. In an analysis of data spanning over a 15-year time period, we were able to establish that complications that can be linked to embolic phenomena (i.e., pulmonary embolism, adult respiratory distress syndrome, and central nervous system events) had a much higher incidence among fatalities compared to patients that did not die perioperatively [3]. In the context of previous findings, it has been therefore suggested that pulmonary embolization of bone and cement debris can cause pulmonary inflammation and injury [12, 25] manifesting in adult respiratory distress syndrome in its extreme form. The hemodynamic effect is that of increased pulmonary pressures which may promote increased right heart strain leading to atrial and ventricular arrhythmias. In the setting of increased right heart pressures, venous return may promote venostasis and therefore contribute to the risk of deep venous thrombosis and pulmonary embolism. Increases in central venous pressure may further decrease venous return from the central nervous system, which in the setting of not infrequently detectable microembolization [26] of the brain by debris material during the implantation process, may negatively affect central nervous system outcomes [3] (Table 4.1).

**Table 4.1** Gurd's criteria for the diagnosis of fat embolism syndrome

| | |
|---|---|
| *Major criteria* | Petechiae |
| | Respiratory insufficiency |
| | Cerebral signs |
| *Minor criteria* | Tachycardia (HR >120) |
| | Fever |
| | Retinal signs |
| | Jaundice |
| | Renal insufficiency |
| *Laboratory findings* | Thrombocytopenia |
| | Anemia |
| | High erythrocyte sedimentation rate |
| | Fat macroglobulinemia |

One major, four minor and one laboratory finding is necessary for diagnosis

Used with permission from Gurd AR, Wilson RI. The fat embolism syndrome. J Bone Joint Surg Br. 1974; 56B:408–16

Supporting the hypothesis that a decreases in end-organ reserve plays a prominent role in the pathophysiology of complications are data suggesting that patients with decreased pulmonary vascular reserve are at increased risk for deep venous thrombosis, pulmonary embolism, and atrial fibrillation [21, 27]. The odds for patients with pulmonary hypertension to develop ARDS, PE, and DVT after total hip arthroplasty were 4.86 (95 % CI, 3.60–6.57), 4.63 (95 % CI, 3.32–6.45), and 2.35 (95 % CI, 1.78–3.10) for, respectively [21]. In an unpublished review of individuals undergoing total joint replacement with pulmonary hypertension at our institution 33 % developed atrial fibrillation. The incidence of the latter complication among total joint arthroplasty recipients has been quoted to be 3.1 % [28]. Further, the existence of dementia or cerebrovascular disease has been

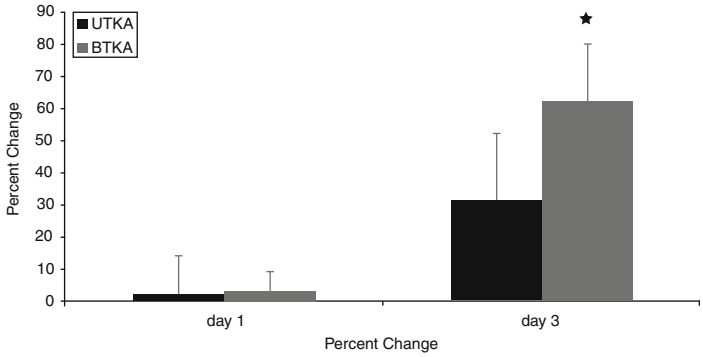


**Fig. 4.2** Percent change of urine desmosine/creatinine levels compared to baseline values. Only the rise of levels on day3 for bilateral total knee arthroplasty (*BTKA*) patients was statistically significant (see *star*). (Used with permission from Memtsoudis SG, Starcher B, Gonzalez Della Valle A, Ma Y, Jules-Elysee K, Sculco TP. Urine desmosine as a marker of lung injury following total knee arthroplasty. A pilot study. Hss J. 2009; 5:154–8)

shown to increase the risk of perioperative mortality after hip and knee arthroplasty by 7 and 4.5-fold [3].

## The Role of Embolic Load

The evaluation of the role of the overall load of embolic material on outcomes has been facilitated through the study of procedures performed on bilateral joints in which the material gaining access to the vasculature is presumably doubled. While the controversy regarding the approach to patients requiring bilateral joint replacement is ongoing, it has been accepted that simultaneously performed procedures carry a higher risk of morbidity compared to unilateral procedures [29–31]. It is likely that increased embolic load may be responsible for higher rates of ARDS and thromboembolic events seen in patients undergoing bilateral versus unilateral total knee arthroplasty [30]. Similarly, increased exposure of the central nervous system and kidneys to embolic material may at least in part explain higher rates of delirium and renal complications in bilateral versus unilateral joint arthroplasty patients [30, 31].

wIndeed, investigations on the role of bilateral versus unilateral debris exposure on the degree of lung catabolism suggest significantly higher levels of lung injury after bilateral total knee arthroplasty. Desmosine, a break down product of elastin, which is found in large amounts in lung tissue, was found at significantly higher concentrations in the urine of patients undergoing two versus one knee replacement (Fig. 4.2) [25]. This finding is consistent with the higher rates of ARDS observed in patients undergoing bilateral joint replacement [30]. When evaluating pulmonary vascular parameters in patients undergoing bilateral hip arthroplasty, an increase in pulmonary vascular resistance was observed after the second but not the first hip implantation when compared with values at incision. Pulmonary vascular resistance remained elevated 1 h after surgery and pulmonary artery pressures were significantly elevated on postoperative day 1 compared with those at baseline [10]. These findings are important in two ways: (1) they suggest that there exists a clinical injury threshold that allows individuals to absorb an insult through pulmonary capillary artery recruitment [12] and without manifesting hemodynamic changes. The exposure to an increased insult, i.e., a larger embolic load, may surpass this threshold, however, and may expose patients to increased risk of developing clinically significant complications; (2) increases in pulmonary vascular resistance and therefore right heart strain may be more prolonged than previously thought, thus exposing patients to longer periods of cardiopulmonary stress.

It may also be important to mention the at first glance "paradox" finding of decreased mortality found after revision versus primary total knee arthroplasties [3, 32]. While revision surgeries may be generally viewed as technically more difficult, the fact that the previously invaded femoral canal contains less or no medullary contents that can be forced intravascularly may explain these findings. This benefit may, however, not relate to revision hip surgeries, which are usually associated with significantly longer surgical time and higher blood loss in the absence of the possibility to use a tourniquet [3, 32].

## The Role of Cement

Further, reports have been published elucidating the role of cement on outcomes. Many investigations seem to suggest that the use of a cemented prosthesis is associated with increased risk of morbidity and mortality [32]. In a study of over 20,000 patients undergoing total knee arthroplasty, Parvizi et al. noted that all 47 mortalities observed in this cohort occurred in cases in which cement was used. In a multivariate regression the use of cement was associated with an increased adjusted risk for a fatal outcome [32].

While the cause of mortality after joint arthroplasty is almost certainly multifactorial, clinical investigations comparing surgery with the use of cement versus without it found significantly less embolic material entering the pulmonary vascular tree in those that no cement was used [33].

The use of vacuum drainage placed in the proximal femur to reduce the increase of intramedullary pressure during insertion of the prosthesis has been shown to reduce the incidence of embolization during cemented hip arthroplasty as assessed by transesophageal echocardiography [34]. Koessler et al. found that embolization of material occurred in 93.3 % of patients operated on with the conventional cementing technique, compared with only 13.3 % of patients operated on with the modified approach ($P < 0.05$).

Although it is likely that the use of cement may play a role in the severity of intraoperative embolic events it is important to consider that patients requiring cemented prostheses often present with poor bone quality, are older and therefore are burdened with comorbidities and decreased end-organ reserve. Thus, the possibility that the use of cement is a surrogate marker of demographic factors predicting adverse outcome in patients has to be kept in mind when interpreting studies of this kind.

## The Role of Fat Embolization: The Fat Embolism Syndrome

Although commonly thought to occur in patients suffering from long bone fractures, the intravasation of fat globules originating from the bone marrow can occur during the reaming and instrumentation process. Embolization of fatty material results in the occlusion of small blood vessels in the lungs, central nervous system, and other organs. Subclinical levels of embolization can be detected in over 90 % of patients undergoing total hip arthroplasties and between 46 and 65 % in those with knee replacements [27, 35]. However, serious multi-systemic manifestations termed fat embolism syndrome (FES) occur less frequently. While the true incidence of FES is unknown, it has been reported to lie between 1 and 29 %, depending on diagnostic criteria used [36–38]. Mortality associated with FES reaches 20 % and depends on the severity of end-organ involvement [39] especially that of the pulmonary and central nervous system [40].

Diagnosis requires a high level of suspicion and interpretation of clinical signs. The classic triad described by Gurd et al. includes respiratory insufficiency, neurologic changes, and upper body petechiae [41], while other nonspecific criteria include tachycardia, fever, jaundice, renal failure, and cardiovascular collapse [42]. Right heart strain pattern on ECG, anemia and coagulopathy on laboratory testing, fat globules on pulmonary artery blood aspirates on frozen section, and pulmonary edema on chest *X-ray* may be found [43–45].

A number of scoring systems have been developed in order to aid with the diagnosis of FES (Tables 4.1, 4.2). Gurd et al. originally proposed a combination of major and minor criteria and laboratory findings (Table 4.1) [41], while others have modified this approach to include further parameters (Table 4.2) [46, 47].

**Table 4.2** Schonfeld's criteria for diagnosis of fat embolism syndrome

| Clinical findings | Score |
|---|---|
| Petechiae | 5 |
| Chest *X-ray* changes | 4 |
| Hypoxemia | 3 |
| Fever | 1 |
| Tachycardia | 1 |
| Tachypnea | 1 |
| Confusion | 1 |

A total score of >5 is required for diagnosis
Used with permission from Schonfeld SA, Ploysongsang Y, DiLisio R, Crissman JD, Miller E, Hammerschmidt DE, Jacob HS. Fat embolism prophylaxis with corticosteroids. A prospective study in high-risk patients. Ann Intern Med. 1983;99:438–43

While the pathophysiology of FES is not fully understood, two major theories prevail in the literature attempting to explain its pathogenesis. The mechanical theory, suggest that lipid globules enter the bloodstream and occlude blood vessels in the lung bed and other organs, thus causing ischemia and inflammation, which in turn may lead to cerebral, renal, and other organ dysfunctions.

A biochemical theory proposes the direct effects of free fatty acids on pneumocytes, leading to hypoxia, pulmonary hypertension, and eventually to cardiopulmonary compromise. The effect of free fatty acids on various organs systems explains the other clinical sequelae of FES [16, 48, 49].

## The Pathophysiology of Spine Fusion Surgery

While the pathophysiologic principles discussed previously also apply in the setting of spine fusion surgery, this surgical entity is less homogeneous compared to joint arthroplasties. Surgical approaches, invasiveness, and length of operation vary widely to accommodate a plethora of pathologies, including traumatic, degenerative, oncologic, or those with deformity. Thus, perioperative stresses follow a more individual distribution and vary significantly from patient to patient.

Aside from the usual insults inherent to major surgery, such as massive blood loss and subsequent resuscitation, pulmonary compromise is of special concern. In a nationally representative study of patients undergoing spine fusions, the lungs were the second most commonly affected organ system by procedure related complications [50]. This is likely due to the cumulative result of a number of perioperative factors, including transfusion and ventilator associated related lung injury, direct mechanical contusion associated with a potential intrathoracic surgical approach, and the effect of pulmonary embolization of bone debris.

It is of no surprise that surgical extent and invasiveness are thus closely correlated with the risk for adverse events. It has been shown that more extensive procedures, especially those necessitating invasion of the thoracic cavity are burdened with higher rates and risk of complications [50]. Indeed, approximately 3 % of patients will develop ARDS after anterior/posterior spine surgery compared to approximately 1 % after a posterior or 1.6 % after an anterior approach only [50].

It is well established that significant lung injury does occur, especially during anterior/posterior spine surgery [51–55]. While the exact mechanism of lung injury associated spine surgery remains unclear and is likely multifactorial, Urban et al. [52] were able to demonstrate an adverse pulmonary effect of perioperative events in the form of an increase in pulmonary vascular resistance in 15 % (8/55) of patients, usually during or after posterior instrumentation. In a follow-up study, the same author analyzed bronchoalveolar specimens and linked the presence of lipid-laden macrophages to possible embolization of fat and debris entering the bloodstream during the surgical procedure. This mechanism of lung injury is supported by echocardiographic studies, in which 80 % of spine surgery patients experienced moderate to severe embolic events during instrumentation of the spine [53]. Markers of lung catabolism showed a significant increase in the postoperative period compared to baseline [55]. Roentgenographic abnormalities of the lung can be found in 64 % of patients undergoing anterior and posterior spine surgery [53].

Additional culprits contributing to pulmonary damage include ventilator associated injury [56], the effect of blood product transfusions [57], and massive resuscitation [58]. It should be mentioned that coagulopathies and pulmonary circulatory disease were identified as the two disease states with the highest predictive risk for mortality after spine fusion (Odds ratios of 5.46 (CI 4.34–6.86) and 8.37 (CI 5.95–11.78), respectively) [50]. The former may be viewed as a marker of invasiveness of the procedure and extent of blood loss while the latter is likely an indicator of reduced end-organ reserve.

## Timing of Complications

Although embolization of debris particles occur primarily intraoperatively surrounding the implantation process, most clinical complications manifest in the days following surgery [59]. Indeed, in a report published by Parvizi only 3 out of 47 mortalities undergoing total knee arthroplasty occurred intraoperatively [32]. In a study of over 30,000 hip arthroplasty patients 88 % of mortalities occurred during the patients' hospitalization. When looking at the timing of life-threatening complications, the same author concluded that 90 % occurred within the first 4 postoperative days [59].

These observations suggest that the injury following systemic embolization of debris surrounding hip and knee arthroplasty may have a stepwise effect.

The intraoperative acute phase may be marked by mechanical obstruction of blood vessels, acutely leading to vasoconstriction in the lungs and other organs. Following this initial insult, protracted cardiopulmonary strain and the evolution of an inflammatory process may explain the delayed occurrence of complications including pulmonary embolism, lung injury, and delirium [32]. Supporting this hypothesis are findings which suggest that the maximum levels of lung catabolism were found on day 3 postoperatively [25, 55] and systemic markers of inflammation peek postoperatively [60].

## Interventions

Opportunities for interventions to affect the relationship between embolic load and outcomes exist at the various perioperative stages. Careful patient selection is the cornerstone of optimizing outcomes. Therefore, it seems prudent to attempt to reduce embolic exposure in patients with decreased end-organ reserve [3, 21]. One example of such an approach would be to avoid bilateral procedures in the very old or those with significant comorbidity burden, thus increasing their chance to absorb perioperative insults [30, 31]. The use of non-cemented implantation techniques, although attractive in an attempt to reduce embolic exposure, may depend on bone quality and thus be of limited value in elderly patients [34]. However, if cement is utilized, vacuum drainage during prosthesis insertion seems to be a viable option to reduce the intramedullary pressure gradient [34]. Intensive monitoring with pulmonary artery catheters or transesophageal echocardiography may increase detection of fat emboli [34, 44], but no evidence exists that these interventions improve outcome. However, in selected cases invasive monitoring may aid to guide hemodynamic management.

Although some studies suggest that prophylactic use of steroids in patients with fractures may be beneficial in reducing markers of systemic inflammation [61] and the risk for the development of FES [62], more research is needed in this arena before clinical recommendations on routine administration of these drugs can be made. The use of intravenous alcohol, heparin, dextrans, and hypertonic dextrose is not recommended at this time. Therapy for FES remains supportive. Mortality is primarily from pulmonary sources while long term morbidity is secondary to cerebrovascular sequelae [40].

Further, the intraoperative use of epidural anesthesia may be advantageous as animal models have shown superior hemodynamics in the presence of pulmonary embolization, a situation not dissimilar to that encountered during intraoperative debris exposure [63, 64].

Interventions to reduce secondary organ injury due to stress and inflammation may be warranted. In this context, additional insults which can aggravate stress to the cardiovascular system, including pain and fluid overload, should be avoided. The use of peripheral nerve blocks has proven to positively affect levels of inflammatory markers [65].

Major blood loss remains a concern especially during major spinal surgery. While interventions such as use of antifibrinolytics, controlled hypotension, use of cell savers, and hemodilution techniques remain therapeutic options [62], the use of recombinant factor VII is being evaluated in the spinal surgery arena [66, 67].

## Summary

A large number of insults including tissue trauma, blood loss, and activation of various neurohumoral cascades may present the underlying causes for perioperative complications. While patients undergoing orthopedic procedures are not exempt from exposure to these stresses, a number of specific events, especially the embolization of cement and marrow material during instrumentation and manipulation of osseous structures, make this patient population unique and thus warrant special attention and discussion.

In this chapter we discuss issues surrounding the role of intravasations of bone, cement, and fat into the systemic circulation and its effects on various organ systems. The relationship of overall embolic load and end-organ reserve in the context of clinical outcomes is presented. Further, additional pathophysiological components relevant to spine surgical patients are reviewed. And finally, interventions to reduce the impact of intraoperative insults on clinical outcome are being presented.

We conclude that the rate and risk of perioperative complications in orthopedic patients is affected by the magnitude of intraoperative and postoperative insults and ability of various organ systems to absorb the derangements caused. The systemic embolization of debris material, extent of surgical invasiveness, and blood loss play major roles in the pathophysiology of these procedures.

Attempts should be made to find a balance between these two components and adopt management strategies including adequate patient selection, selection of surgical technique, and postoperative management.

**Summary Bullet Points**

- The intravasation of bone, cement, and marrow during the surgical process occurs frequently and may contribute to the pathophysiology of complications seen in the perioperative period.
- The risk of perioperative complications may be dependent on the level of the operative insult one hand and end-organ reserve on the other.
- Identifying interventions that can reduce perioperative insults and instituting programs to identify patients at risk may result in a decrease the odds for perioperative complications.

## Case Study

A case study for this chapter is included in Appendix A at the end of this book.

## References

1. Byrick RJ. Causes of brain injury during orthopedic surgery. Can J Anaesth. 2004;51:867–70.
2. Memtsoudis SG, Rosenberger P, Walz JM. Critical care issues in the patient after major joint replacement. J Intensive Care Med. 2007;22:92–104.
3. Memtsoudis SG, Della Valle AG, Besculides MC, Esposito M, Koulouvaris P, Salvati EA. Risk factors for perioperative mortality after lower extremity arthroplasty: a population-based study of 6,901,324 patient discharges. J Arthroplasty. 2010;25:19–26.
4. Lafont ND, Kostucki WM, Marchand PH, Michaux MN, Boogaerts JG. Embolism detected by transoesophageal echocardiography during hip arthroplasty. Can J Anaesth. 1994;41:850–3.
5. Lafont ND, Kalonji MK, Barre J, Guillaume C, Boogaerts JG. Clinical features and echocardiography of embolism during cemented hip arthroplasty. Can J Anaesth. 1997;44:112–7.
6. Urban MK, Sheppard R, Gordon MA, Urquhart BL. Right ventricular function during revision total hip arthroplasty. Anesth Analg. 1996;82:1225–9.
7. Bisignani G, Bisignani M, Pasquale GS, Greco F. Intraoperative embolism and hip arthroplasty: intraoperative transesophageal echocardiographic study. J Cardiovasc Med (Hagerstown). 2008;9:277–81.
8. Patterson BM, Healey JH, Cornell CN, Sharrock NE. Cardiac arrest during hip arthroplasty with a cemented long-stem component. A report of seven cases. J Bone Joint Surg Am. 1991;73:271–7.
9. Bengtson A, Larsson M, Gammer W, Heideman M. Anaphylatoxin release in association with methylmethacrylate fixation of hip prostheses. J Bone Joint Surg Am. 1987;69:46–9.
10. Memtsoudis SG, Salvati EA, Go G, Ma Y, Sharrock NE. Perioperative pulmonary circulatory changes during bilateral total hip arthroplasty under regional anesthesia. Reg Anesth Pain Med. 2010;35:417–21.
11. Rudigier JF, Ritter G. Pathogenesis of circulatory reactions triggered by nervous reflexes during the implantation of bone cements. Res Exp Med (Berl). 1983;183:77–94.

12. Rinecker H. New clinico-pathophysiological studies on the bone cement implantation syndrome. Arch Orthop Trauma Surg. 1980;97:263–74.
13. Mir GN, Lawrence WH, Autian J. Toxicological and pharmacological actions of methacrylate monomers. I. Effects on isolated, perfused rabbit heart. J Pharm Sci. 1973;62:778–82.
14. Wenda K, Scheuermann H, Weitzel E, Rudigier J. Pharmacokinetics of methylmethacrylate monomer during total hip replacement in man. Arch Orthop Trauma Surg. 1988;107:316–21.
15. Parisi DM, Koval K, Egol K. Fat embolism syndrome. Am J Orthop (Belle Mead NJ). 2002;31:507–12.
16. Hulman G. Pathogenesis of non-traumatic fat embolism. Lancet. 1988;1:1366–7.
17. Modig J, Malmberg P. Pulmonary and circulatory reactions during total hip replacement surgery. Acta Anaesthesiol Scand. 1975;19:219–37.
18. Dambrosio M, Tullo L, Moretti B, Patella V, Simone C, Calo MN, Dalfino L, Cinnella G. Hemodynamic and respiratory changes during hip and knee arthroplasty. An echocardiographic study. Minerva Anestesiol. 2002;68:537–47.
19. Lopez-Duran L, Garcia-Lopez A, Duran L, Hurtado J, Ruiz C, Rodrigo JL. Cardiopulmonary and haemodynamic changes during total hip arthroplasty. Int Orthop. 1997;21:253–8.
20. Stern SH, Sharrock N, Kahn R, Insall JN. Hematologic and circulatory changes associated with total knee arthroplasty surgical instrumentation. Clin Orthop Relat Res. 1994;299:179–89.
21. Memtsoudis SG, Ma Y, Chiu YL, Walz JM, Voswinckel R, Mazumdar M. Perioperative mortality in patients with pulmonary hypertension undergoing major joint replacement. Anesth Analg. 2010;111:1110–6.
22. Ramakrishna G, Sprung J, Ravi BS, Chandrasekaran K, McGoon MD. Impact of pulmonary hypertension on the outcomes of noncardiac surgery: predictors of perioperative morbidity and mortality. J Am Coll Cardiol. 2005;45:1691–9.
23. Tugcu A, Yildirimturk O, Tayyareci Y, Demiroglu C, Aytekin S. Evaluation of subclinical right ventricular dysfunction in obstructive sleep apnea patients using velocity vector imaging. Circ J. 2011;74:312–9.
24. Otero R, Oribe M, Ballaz A, Jimenez D, Uresandi F, Nauffal D, Conget F, Rodriguez C, Elias T, Jara L, Cayuela A, Blanco I, Barbera J. Echocardiographic assessment of pulmonary arterial pressure in the follow-up of patients with pulmonary embolism. Thromb Res. 2011;127:303–8.
25. Memtsoudis SG, Starcher B, Gonzalez Della Valle A, MA Y, Jules-Elysee K, Sculco TP. Urine desmosine as a marker of lung injury following total knee arthroplasty. A pilot study. HSS J. 2009;5:154–8.
26. Edmonds CR, Barbut D, Hager D, Sharrock NE. Intraoperative cerebral arterial embolization during total hip arthroplasty. Anesthesiology. 2000;93:315–8.
27. Kim YH. Incidence of fat embolism syndrome after cemented or cementless bilateral simultaneous and unilateral total knee arthroplasty. J Arthroplasty. 2001;16:730–9.
28. Kahn RL, Hargett MJ, Urquhart B, Sharrock NE, Peterson MG. Supraventricular tachyarrhythmias during total joint arthroplasty. Incidence and risk. Clin Orthop Relat Res. 1993;296:265–9.
29. Restrepo C, Parvizi J, Dietrich T, Einhorn TA. Safety of simultaneous bilateral total knee arthroplasty. A meta-analysis. J Bone Joint Surg Am. 2007;89:1220–6.
30. Memtsoudis SG, Gonzalez Della Valle A, Besculides MC, Gaber L, Sculco TP. In-hospital complications and mortality of unilateral, bilateral, and revision TKA: based on an estimate of 4,159,661 discharges. Clin Orthop Relat Res. 2008;466:2617–27.
31. Memtsoudis SG, Ma Y, Gonzalez Della Valle M, Mazumdar M, Gaber-Baylis LK, MacKenzie CR, Sculco TP. Perioperative outcomes after unilateral and bilateral total knee arthroplasty. Anesthesiology. 2009;111:1206–16.
32. Parvizi J, Sullivan TA, Trousdale RT, Lewallen DG. Thirty-day mortality after total knee arthroplasty. J Bone Joint Surg Am. 2001;83-A:1157–61.
33. Pitto RP, Koessler M, Kuehle JW. Comparison of fixation of the femoral component without cement and fixation with use of a bone-vacuum cementing technique for the prevention of fat embolism during total hip arthroplasty. A prospective, randomized clinical trial. J Bone Joint Surg Am. 1999;81:831–43.
34. Koessler MJ, Fabiani R, Hamer H, Pitto RP. The clinical relevance of embolic events detected by transesophageal echocardiography during cemented total hip arthroplasty: a randomized clinical trial. Anesth Analg. 2001;92:49–55.
35. Pitto RP, Koessler M. The risk of fat embolism during cemented total hip replacement in the elderly patient. Chir Organi Mov. 1999;84:119–28.
36. Bulger EM, Smith DG, Maier RV, Jurkovich GJ. Fat embolism syndrome. A 10-year review. Arch Surg. 1997;132:435–9.
37. Fabian TC, Hoots AV, Stanford DS, Patterson CR, Mangiante EC. Fat embolism syndrome: prospective evaluation in 92 fracture patients. Crit Care Med. 1990;18:42–6.
38. Shaikh N. Emergency management of fat embolism syndrome. J Emerg Trauma Shock. 2009;2:29–33.
39. Robert JH, Hoffmeyer P, Broquet PE, Cerutti P, Vasey H. Fat embolism syndrome. Orthop Rev. 1993;22:567–71.
40. Jacobson DM, Terrence CF, Reinmuth OM. The neurologic manifestations of fat embolism. Neurology. 1986;36:847–51.
41. Gurd AR, Wilson RI. The fat embolism syndrome. J Bone Joint Surg Br. 1974;56B:408–16.
42. Fallon KM, Fuller JG, Morley-Forster P. Fat embolization and fatal cardiac arrest during hip arthroplasty with methylmethacrylate. Can J Anaesth. 2001;48:626–9.
43. Byrick RJ. Fat embolism and postoperative coagulopathy. Can J Anaesth. 2001;48:618–21.
44. Adolph MD, Fabian HF, el-Khairi SM, Thornton JC, Oliver AM. The pulmonary artery catheter: a diagnostic adjunct for fat embolism syndrome. J Orthop Trauma. 1994;8:173–6.
45. Johnson MJ, Lucas GL. Fat embolism syndrome. Orthopedics. 1996;19:41–8. Discussion 48–9.
46. Lindeque BG, Schoeman HS, Dommisse GF, Boeyens MC, Vlok AL. Fat embolism and the fat embolism syndrome. A double-blind therapeutic study. J Bone Joint Surg Br. 1987;69:128–31.
47. Schonfeld SA, Ploysongsang Y, DiLisio R, Crissman JD, Miller E, Hammerschmidt DE, Jacob HS. Fat embolism prophylaxis with corticosteroids. A prospective study in high-risk patients. Ann Intern Med. 1983;99:438–43.
48. Gossling HR, Pellegrini Jr VD. Fat embolism syndrome: a review of the pathophysiology and physiological basis of treatment. Clin Orthop Relat Res. 1982;165:68–82.
49. Baker PL, Pazell JA, Peltier LF. Free fatty acids, catecholamines, and arterial hypoxia in patients with fat embolism. J Trauma. 1971;11:1026–30.
50. Memtsoudis SG, Vougioukas VI, Ma Y, Gaber-Baylis LK, Girardi FP. Perioperative morbidity and mortality after anterior, posterior, and anterior/posterior spine fusion surgery. Spine (Phila Pa 1976). 2010;36:1867–77.
51. Urban MK, Jules-Elysee KM, Beckman JB, Sivjee K, King T, Kelsey W, Boachie-Adjei O. Pulmonary injury in patients undergoing complex spine surgery. Spine J. 2005;5:269–76.
52. Urban MK, Urquhart B, Boachie-Adjei O. Evidence of lung injury during reconstructive surgery for adult spinal deformities with pulmonary artery pressure monitoring. Spine (Phila Pa 1976). 2001;26:387–90.

53. Jules-Elysee K, Urban MK, Urquhart BL, Susman MH, Brown AC, Kelsey WT. Pulmonary complications in anterior-posterior thoracic lumbar fusions. Spine J. 2004;4:312–6.
54. Takahashi S, Kitagawa H, Ishii T. Intraoperative pulmonary embolism during spinal instrumentation surgery. A prospective study using transoesophageal echocardiography. J Bone Joint Surg Br. 2003;85:90–4.
55. Memtsoudis SG, Starcher B, Ma Y, Buschiazzo V, Urban MK, Girardi FP. The utility of urine desmosine as a marker of lung injury in spine surgery. Hss J. 2010;6:160–3.
56. Wolthuis EK, Choi G, Dessing MC, Bresser P, Lutter R, Dzoljic M, van der Poll T, Vroom MB, Hollmann M, Schultz MJ. Mechanical ventilation with lower tidal volumes and positive end-expiratory pressure prevents pulmonary inflammation in patients without preexisting lung injury. Anesthesiology. 2008;108:46–54.
57. Triulzi DJ. Transfusion-related acute lung injury: current concepts for the clinician. Anesth Analg. 2009;108:770–6.
58. Riskin DJ, Tsai TC, Riskin L, Hernandez-Boussard T, Purtill M, Maggio PM, Spain DA, Brundage SI. Massive transfusion protocols: the role of aggressive resuscitation versus product ratio in mortality reduction. J Am Coll Surg. 2009;209:198–205.
59. Parvizi J, Mui A, Purtill JJ, Sharkey PF, Hozack WJ, Rothman RH. Total joint arthroplasty: when do fatal or near-fatal complications occur? J Bone Joint Surg Am. 2007;89:27–32.
60. Memtsoudis SG, Valle AG, Jules-Elysse K, Poultsides L, Reid S, Starcher B, Ma Y, Sculco TP. Perioperative inflammatory response in total knee arthroplasty patients: impact of limb preconditioning. Reg Anesth Pain Med. 2010;35:412–6.
61. Jules-Elysee KM, Lipnitsky JY, Patel N, Anastasian G, Wilfred SE, Urban MK, Sculco TP. Use of low-dose steroids in decreasing cytokine release during bilateral total knee replacement. Reg Anesth Pain Med. 2011;36:36–40.
62. Elgafy H, Bransford RJ, McGuire RA, Dettori JR, Fischer D. Blood loss in major spine surgery: are there effective measures to decrease massive hemorrhage in major spine fusion surgery? Spine (Phila Pa 1976). 2010;35:S47–56.
63. Jahn UR, Waurick R, Van Aken H, Hinder F, Booke M, Bone HG, Schmidt C, Meyer J. Thoracic, but not lumbar, epidural anesthesia improves cardiopulmonary function in ovine pulmonary embolism. Anesth Analg. 2001;93:1460–5. Table of contents.
64. Jahn UR, Waurick R, Van Aken H, Hinder F, Meyer J, Bone HG. Therapeutic administration of thoracic epidural anesthesia reduces cardiopulmonary deterioration in ovine pulmonary embolism. Crit Care Med. 2007;35:2582–6.
65. Bagry H, de la Cuadra Fontaine JC, Asenjo JF, Bracco D, Carli F. Effect of a continuous peripheral nerve block on the inflammatory response in knee arthroplasty. Reg Anesth Pain Med. 2008;33:17–23.
66. Kacka K, Kacki W, Merak J, Bleka A. Use of recombinant activated factor VII for reduction of perioperative blood loss during elective surgical correction of spine deformity in a Jehovah's witness. Case report. Ortop Traumatol Rehabil. 2010;12:448–58.
67. Girardi FP, Gogia J, Kotwal S, Memtsoudis SG, Pumberger M. Spinal surgery: an update. Eur Musculoskel Rev. 2011;6:105–9.

# Part II

# Anesthesiologic Management

# Anesthesia in the Orthopedic Patient

5

Shawna Dorman and Richard L. Kahn

**Objectives**

- To discuss perioperative anesthetic concerns of common orthopedic populations.
- To briefly review proper positioning for orthopedic surgery.
- To discuss how orthopedic surgery is amenable to regional anesthesia.
- To review the advantages and risks of regional anesthesia.
- To examine the use of anticoagulation in the setting of regional anesthesia.
- To discuss controlled hypotension and its use in orthopedic surgery.

**Key Points**

- A thorough preoperative evaluation should be performed evaluating for preexisting comorbidities and potential anesthetic implications.
- Orthopedic surgery is well suited for neuraxial and peripheral regional anesthetic techniques. These techniques offer many advantages including early mobilization, decreased time to discharge, and improved postoperative analgesia.
- Ultrasound guidance offers some advantages over traditional regional techniques and may allow more patients to benefit from regional anesthesia.
- Orthopedic patients are at an increased risk for thromboembolism. The anesthesiologist must be aware of the choice of pharmacologic prophylaxis in order to coordinate regional anesthetic techniques.
- Controlled hypotension is an anesthesia related blood salvage technique that can be used to safely decrease blood loss and transfusion requirements.

S. Dorman
Department of Anesthesiology, New York University Medical Center, Hospital for Joint Diseases, New York, NY 10012, USA
e-mail: Sdoherty79@yahoo.com

R.L. Kahn (✉)
Department of Anesthesiology, Hospital for Special Surgery, 535 E70th Street, New York, NY 10021, USA
e-mail: kahnr@hss.edu

## Introduction

Managing the orthopedic patient can present a wide variety of challenges to the anesthesiologist. Orthopedic patients are a heterogeneous group that varies greatly in regard to age, comorbidity profile, and surgical need. Patient outcome is affected by multiple factors including preexisting condition, type of surgery, and anesthetic management. Sharrock reported that changing from general to regional anesthesia techniques, along with changes in anesthesia personnel, resulted in a marked decrease in morbidity following orthopedic surgery [1]. Some of the anesthetic techniques that might improve patient outcome include regional anesthetic approaches and controlled hypotension. Neuraxial anesthesia has been associated with decreases in early mortality, thromboembolism, and cardiopulmonary complications when compared to general anesthesia [2–5]. Controlled hypotension is a technique that decreases blood loss and transfusion requirements as well as postoperative deep vein thrombosis [6]. Peripheral nerve blocks are associated with improved rehabilitation and reduced length of hospital stay [7, 8]. When choosing the type of anesthesia to administer, a variety of factors should be taken into account. This includes, but is not limited to, patient expectations, comorbidities, and age, as well as the plan for anticoagulation and the surgical procedure. In this chapter, we discuss various aspects of anesthesia for the

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_5, 

orthopedic patient, including unique characteristics of the orthopedic patient population, proper patient positioning, advantages and risks of regional anesthesia, regional anesthesia in the setting of anticoagulation, the utilization of ultrasound for peripheral nerve blocks, and strategies to decrease intraoperative blood loss including controlled hypotensive anesthesia and application of a pneumatic tourniquet.

## The Orthopedic Population

The orthopedic patient population encompasses a wide range of individuals and can include the elderly patient with multiple comorbidities as well as the healthy child who fell off the swing-set. Irrespective, it cannot be overemphasized that a complete preoperative evaluation of every patient is mandatory, while taking care to not focus solely on the area of injury or surgery. The elderly patient, however, may provide additional anesthetic challenges and is more likely to have perioperative complications. According to the US Department of Health and Human Services, the number of US Citizens older than 65 years is expected to reach 72.1 million by 2030 [9]. One might expect this dramatic increase to significantly increase the number of joint replacements and fracture repairs.

One of the major risk factors for perioperative mortality is advanced age, with cardiac problems being the most frequent complication. The American College of Cardiology/American Heart Association guidelines recommend preoperative cardiac testing in patients at increased cardiac risk based on clinical risk profile, functional status, and type of surgery [4]. While details on the preoperative evaluation are presented elsewhere, it should briefly be noted that orthopedic surgery is defined as an intermediate risk surgery due to the possible increase in systemic inflammatory response, potential blood loss, fluid shifts, and postoperative pain. The functional status of these patients is often difficult to assess due to the physical limitations that require them to have surgery. Extensive universal preoperative cardiac testing, however, has not shown to improve outcome. Therefore, each patient must be evaluated individually prior to surgery. In general, cardiac tests should only be ordered if the results would change treatment. Judicious use of invasive monitors and close postoperative monitoring may also affect perioperative morbidity and mortality. Further, postoperative surveillance in a monitored environment enables rapid diagnosis and treatment of abnormalities in hemodynamic and laboratory values [1].

Rheumatoid arthritis is a chronic inflammatory disease which affects 1 % of adults and poses specific anesthetic problems beyond those affecting the cardiovascular system [10]. It is characterized by persistent synovial tissue inflammation. However, it is also a systemic disease affecting multiple organ systems. The rheumatoid patient presents for orthopedic surgery throughout various stages of this progressive and disabling disease. While rheumatoid arthritis as a disease is discussed in more detail elsewhere, these patients present many anesthetic challenges. Airway management can be extremely difficult in this patient population. Patients may have atlantoaxial subluxation due to ligament destruction in which neck flexion can result in the odontoid process impinging on the spinal cord [10]. It remains controversial whether flexion and extension cervical spine *X*-rays should be performed in all rheumatoid patients. Regardless, it is prudent to thoroughly assess the patient for the presence of any symptoms and obtain radiographs if appropriate. Because of their abnormal anatomy, mask ventilation and intubation can be extremely difficult. The combination of micrognathia with protruding top teeth can make direct laryngoscopy impossible. Fifty percent of rheumatoid patients have jaw symptoms usually presenting as inability to fully open the mouth, thus further complicating airway management [10]. Additionally, patients with this disease often have laryngeal deviation and cricoarytenoid synovitis. The upper airways of individuals affected by the disease can become completely obstructed even with conscious sedation. If an airway exam is consistent with potentially difficult intubation, insertion of an endotracheal tube is best done utilizing an awake fiber-optic technique and employing a small gauge endotracheal tube. However, there is now extensive experience confirming the safety of regional anesthesia combined with careful sedation in these patients. The benefits of regional anesthesia, including avoiding instrumentation of the airway, can outweigh the rare risk of an airway emergency.

Osteoarthritis is single most common disease process seen among the orthopedic population. More than 50 million adults in the USA have physician diagnosed arthritis [11]. Osteoarthritis is a degenerative disease involving the loss of articular cartilage, leading to the loss of joint function. Women are slightly more affected than men, and the prevalence increases with age. Arthritis has a large impact on individuals as their activity is often severely limited, and it remains the most common cause of disability [12]. While osteoarthritis is not a systemic disease, the anesthesiologist should be aware of which joints are painful and/or have limited mobility [13]. Positioning these patients may be extremely difficult and if at all possible, the patient should be allowed to position himself. Airway management may also be more difficult due to the decreased range of motion of the patient's neck and decreased glottic opening. A thorough airway exam should be performed prior to surgery. Additionally, the placement of neuraxial anesthesia may be challenging due to the decreased disk height and an

increased number of osteophytes surrounding the vertebrae. Often, using a paramedian approach is more successful in these patients. Finally, these patients may require chronic NSAIDs or opioids for their arthritic pain. This should be taken into account when developing both an intraoperative and postoperative anesthetic plan.

Although other diseases are common in the orthopedic arena include ankylosing spondylosis, scoliosis, or even obstructive sleep apnea, detailing these disease processes is beyond the scope of this chapter. However, it falls upon the anesthesiologist to recognize the anesthetic challenges that each disease presents and employ the skills necessary to provide a safe and effective anesthetic.

## Positioning

Patients are placed in a variety of positions for orthopedic procedures in order to help provide better surgical exposure. However, improper positioning can lead to intraoperative and postoperative complications including bony or ligamentous injury, tissue necrosis or ischemia, neuropraxia or hemodynamic changes. Therefore, proper positioning should seek to absorb compressive forces, to prevent excessive stretching or compression by maintaining normal body alignment and to preserve hemodynamic and respiratory mechanics as much as possible [14]. The beach chair position is often used during shoulder surgery. In this position, the head, neck, and hips should be secured and remain in physiologic range. As the operative field is above the heart, the risk of an air embolism is increased. Thus, the anesthesiologist must maintain a high index of suspicion of an air embolism with any hemodynamic changes. The lateral position requires careful attention to a neutral neck alignment and an axillary roll should be placed to relieve pressure on the down shoulder, brachial plexus, and vascular structures. In the prone position, the head should remain neutral and careful attention should be paid to ensure the eyes and ears are free from excessive pressure. The chest, abdomen, breast, and genitalia should remain free to prevent traumatic injury and hemodynamic changes due to compression of large vessels. Proper positioning should be obtained prior to the surgeon preparing and draping the patient as it is difficult to adjust the position once the drapes have been applied.

## Regional Anesthesia

Regional anesthesia has a wide application in orthopedic surgery. Its components, consisting of neuraxial and peripheral nerve blocks, can be used as adjuncts to pain relief or as the primary anesthetic during surgery, and can be incorporated into many anesthetic plans. Utilizing regional anesthesia may allow the anesthesiologist to avoid instrumenting the airway and delivering positive pressure ventilation, as well as to avoid opioid-based pain medication leading to fewer side effects. Although the influence of the mode of anesthesia on outcomes remains a controversial issue, a large amount of literature has found regional anesthesia to have significant advantages over general anesthesia [4]. That said, general anesthesia can be delivered effectively and safely to the orthopedic patient and is an equivalent alternative, particularly if regional anesthesia is contraindicated. In fact, Rodgers suggests that the benefits are gained due to the presence of regional anesthesia and not the absence of general anesthesia [5].

The various regional techniques can be categorized into neuraxial anesthesia and peripheral nerve blocks. Neuraxial anesthesia has been associated with significant decreases in early mortality, fewer incidents of deep vein thrombosis and fatal pulmonary embolism, fewer myocardial infarctions, less respiratory specific morbidity, less postoperative confusion, and improved postoperative analgesia [4]. Peripheral nerve blocks are associated with improved rehabilitation and reduced length of hospital stay [3, 7]. Specific outcomes and the potential impact of regional anesthesia are discussed next.

### Mortality

Mortality following orthopedic surgery varies with the procedure performed. It is greatly dependent on the preoperative condition of the patient and his/her comorbidities. Total mortality following traumatic hip fractures can be as high as 20 % [4]. Data suggest that in-hospital mortality (1.9 % vs. 2.8 %) [5] and short-term mortality (<1 month) (6.9 % vs. 10 %) [15] seem to be lower when neuraxial anesthesia is employed versus general. This advantage, however, may not extend to long-term mortality (>3 months) [3].

### Postoperative Analgesia

Pain management following orthopedic surgery can be extremely challenging. Failure to provide adequate analgesia can prevent early mobilization and rehabilitation, which are important factors for maintaining joint range of motion and ensuring the general success of surgery. Severe pain occurs in up to 60% of patients undergoing total knee arthroplasty [7]. Patient controlled epidural analgesia, generally with a low concentration of a local anesthetic combined with a narcotic, can provide excellent pain relief for lower extremity surgery. This requires careful titration of the local anesthetic dose in order to minimize weakness and orthostatic hypotension during physical therapy. Peripheral

nerve blocks using catheters or long acting local anesthetics with or without additive may provide excellent postoperative analgesia with significantly less narcotic administration. By taking fewer narcotics, patients experience less nausea, vomiting, sedation, and urinary retention [7]. Patients who have received peripheral nerve blocks have shorter hospital stays, earlier ambulation, and improved range of motion. Orthopedic patients are also at an increase risk of developing chronic pain. A local inflammatory response to injury occurs after surgery, which sensitizes nociceptive receptors and contributes to the development of pain and hyperalgesia. Local anesthetics inhibit this response and can help prevent chronic pain syndromes. A more detailed discussion of the role of regional anesthetic techniques on pain can be found elsewhere in this book.

## Respiratory Complications

Preexisting respiratory disease and general anesthesia are significant predictors of morbidity in hip fracture patients [16]. The risk of respiratory complications including pneumonia, acute exacerbation of COPD, and respiratory failure has been found to be significantly higher when general versus regional anesthesia was used. This respiratory benefit may be related in part to superior analgesia, which may result in improved pulmonary function and decreased atelectasis, particularly in patients with limited respiratory reserve. Further explanation for this difference between the modes of anesthesia is likely attributable to the impact of mechanical ventilation on pulmonary injury.

## Postoperative Confusion

Postoperative cognitive confusion/delirium spans a large spectrum that has yet to be completely elucidated and understood. However, the incidence can be as high as 30 % and has been associated with longer hospital stays, higher costs and worse outcomes. The majority of studies report no difference in long-term postoperative confusion between regional and general anesthesia. However, a few studies have found a lower incidence of short-term confusion after regional anesthesia [15, 17, 18]. This is likely due to patients receiving fewer narcotics, benzodiazepines, and other anesthetics, leaving them more alert and cognitively aware.

## Deep Vein Thrombosis

Postoperative deep venous thrombosis is common after orthopedic surgery. It has been well established that regional anesthesia significantly reduces the incidence of deep vein thrombosis [2–5, 17, 19]. It is hypothesized that the vasodilatation caused by the regional anesthesia increases blood flow to the lower extremities, altering the coagulability and viscosity of blood. Additionally, regional anesthesia attenuates the stress response to surgery showing decreased serum catecholamine and cortisol levels versus general anesthesia [20]. This may also reduce perioperative hypercoagulability. However, regional anesthesia should not be viewed as an anticoagulation modality and standard thromboprophylaxis should still be used.

## Pulmonary Embolism

Many studies throughout the literature show a weak tendency towards a decrease in the incidence of pulmonary embolism for regional anesthesia. However, subgroup analysis demonstrates a large reduction in fatal pulmonary embolism following regional anesthesia [2–5]. Reasons for this finding may be attributable to the effects on coagulation discussed previously.

## Rehabilitation

The use of regional anesthesia facilitates patient rehabilitation after orthopedic surgery and decreases the time to readiness for discharge. While some studies have found that the use of peripheral nerve catheters improves physical therapy, no study has demonstrated a difference in long-term joint function [21]. Regional techniques do, however, result in superior postoperative analgesia and decreased opioid related side effects [3].

While regional anesthesia offers many benefits, one should also be aware of the potential adverse effects. The incidence of hypotension following regional anesthesia is increased when compared to general anesthesia. However, the impact of these hypotensive events has yet to be studied. Peripheral nerve blocks do not produce sympathectomy-induced hypotension. However, a degree of motor blockade is usually associated with the desired sensory block. This may limit the usefulness of some peripheral blocks in specific situations, especially when motor function needs to be assessed frequently.

Both neuraxial and peripheral regional techniques may be associated with neurological injury. The mechanism of this complication is often unclear and multifactorial. Contributing factors may include preexisting neuropraxias and neuropathies, diabetes mellitus, extremes of body habitus, male gender, and advanced age. Similarly, surgical factors such as direct surgical trauma, a compressive cast or sling, tourniquet inflation and improper positioning can also contribute to neurological injury [22]. The rate of

neurological complications after neuraxial blockade is estimated to be 0.04 and 3 % after peripheral nerve blockade [23]. While the injury caused by the compressive lesions of an epidural hematoma or abscess can be elucidated, other causes of injury after neuraxial anesthesia often remain elusive. Transient neurological syndrome (TNS) is one of the most common complications after spinal anesthesia and presents as pain in the buttocks and legs. The incidence of TNS is increased in outpatient surgery, lithotomy position and after a lidocaine versus a bupivacaine or mepivacaine spinal. The pain can vary from mild to severe, is usually self-limited and is best treated with nonsteroidal anti-inflammatory agents, suggesting an inflammatory component as its etiology. When neurological injury is suspected after neuraxial anesthesia, rapid diagnosis and treatment is essential. Particularly in the setting of an epidural hematoma or abscess, the likelihood of a recovery decreases after 8 h [22, 24]. Magnetic resonance imaging is the preferred diagnostic modality, but treatment should not be delayed if it is not available.

Causes of peripheral nerve injuries are assumed to be due to local anesthetic toxicity, complications of needle placement, or injury to surrounding structures by the local anesthetic or additives. However, no localization method or monitoring technique has shown to be superior and the pathophysiology of nerve injury remains unclear. It is extremely difficult to predict which patients will develop a neuropraxia. Some evidence suggests that patients with preexisting neurological deficits are more likely to develop a neuropraxia, with a suggested mechanism often referred to as the double crush theory [22, 25, 26]. Therefore, performing regional anesthesia on patients with preexisting neurological deficits is controversial and should be decided on an individual basis after fully discussing the risks with both the patient and the surgeon. Additionally, reducing the dose or concentration of local anesthetic, as well as eliminating vasoconstrictive additives may be prudent [27].

Recovery from a nerve injury depends on a number of factors, including if the axon of the affected nerve is preserved. It seems that if the axon is transected, recovery is slow and often incomplete. Similarly, if the neuronal fascicle is penetrated, neurons are exposed to injury from the local anesthetic that can be exacerbated by vasoconstrictors such as epinephrine [22]. Complete or worsening neural deficits should be immediately assessed by a neurologist, while mild symptoms often require only patient reassurance as the prognosis for improvement is excellent. If the injury does not resolve after 2–3 weeks, neurophysiologic testing can help to better define the nerve damage. Although neurophysiologic changes may not appear for a few weeks after the injury, nerve conduction studies and electromyography testing can help establish a baseline and rule out preexisting disease [22, 26]. While an exhaustive list of adverse effects of peripheral anesthetic techniques is beyond the scope of this chapter, it is essential to be knowledgeable on the limitations and risks of each block in order to properly and safely anesthetize the patient.

## Anticoagulation

As stated previously, thromboembolic prophylaxis is essential because the risk of deep vein thrombosis and pulmonary embolism is high after orthopedic surgery. Total hip arthroplasty, total knee arthroplasty, hip and pelvic fracture surgery have the highest incidence of thromboembolism. Further, a number of patients are chronically on anticoagulation and antiplatelet therapy for various conditions. However, pharmacologic anticoagulation therapy has a significant impact on the use of regional anesthesia. The potential risk of an epidural hematoma with devastating consequences makes full anticoagulation a contraindication to regional techniques, particularly neuraxial anesthesia. The actual incidence of neurologic dysfunction resulting from hemorrhagic complications associated with neuraxial blockade is unknown. However, the frequency may be as high as 1 in 3,000 in some populations [19]. The guidelines from the American Society of Regional Anesthesia and Pain Medicine (ASRA) were recently revised to reflect the ever changing treatment standards for thromboembolic prevention and the introduction of more potent antithrombotic medications. It must be mentioned, however, that the ASRA guidelines are based on expert opinion and are not evidence based. Thus, the placement of a neuraxial block should be performed based on the pharmacological profile, mainly the time required to reach maximal concentration, the half-life and the dosing regimen of each drug [28].

ASRA does not make any recommendations regarding the new oral anticoagulants, including dabigatran and rivaroxaban, other than stating extreme caution should be used. To date, no spinal hematomas have been reported with these medications. However, the lack of experience with these drugs warrants further investigation. Llau discusses these new anticoagulants and offers the following information and recommendations [29]. Currently, there are three oral anti-embolic medications undergoing investigation. Dabigatran etexilate is a direct thrombin inhibitor and the only oral agent approved in the USA. It has a half-life of 8 h after a single dose and 17 h after multiple doses. The drug is completely renally excreted, so one should expect a longer half-life in patients with renal failure. There is no known antagonist. Neuraxial anesthesia should be avoided for 5 days after the last dose and the administration should be delayed for 36 h after the removal of a catheter.

Rivaroxaban is a reversible factor Xa inhibitor. It is absorbed 100 % and has a rapid onset of action. The half-life is 9 h but may be prolonged in renal function and the elderly. The epidural catheter should be removed 18 h after the last dose and the administration should be delayed 4 h after the removal of a catheter. Apixaban is also a reversible inhibitor of X. However, much less information is available as it is still undergoing investigative studies.

The data evaluating the risk of hemorrhagic complications in anticoagulated patients undergoing peripheral nerve blocks are insufficient. ASRA recommends following the same guidelines detailed above for neuraxial techniques [19]. However, with the advent of ultrasound and the ability to visualize perivascular blocks, many anesthesiologists will apply a more liberal standard. The guidelines are based on information in the literature; however, there is no prospective-randomized study. Therefore, each decision regarding regional anesthesia in the anti-coagulated patient should be individualized to the patient taking into account all the risks and benefits.

As the options for postoperative anticoagulation continue to evolve, it is important to remain informed on the medications available, their mechanism of action and pharmacologic properties in order to make educated risk-benefit analyses and decisions regarding regional anesthesia. Additionally, many patients will be on several medications affecting various parts of the coagulation cascade. The additive effect of these medications should be considered, although no recommendations have been made to address this issue. The need for prompt diagnosis and intervention is imperative to preserve neurological function and reverse spinal cord ischemia in the event of a spinal hematoma. This requires having a high index of suspicion and diligent assessments of neurologic status after regional anesthesia.

## Ultrasound-Guided Regional Anesthesia

The use of ultrasound-guided peripheral nerve blocks has increased dramatically over the past decade. While ultrasound offers the ability to guide the needle placement and monitor the injection of local anesthetic, no study has found a reduction in complication rates [30]. It has, however, been shown that ultrasound leads to a fewer needle passes, fewer intravascular punctures and decreased time to onset of blocks versus traditional nerve stimulation [30–32]. The faster onset time is likely due to a closer approximation of the needle and nerves with use of the ultrasound. This enhanced onset of a block, however, does not reduce the number of failed blocks requiring general anesthesia. Several studies have also shown a dramatic reduction in the dose of local anesthetic necessary to achieve a successful block for surgical anesthesia or analgesia. Gautier found only 5 mL were necessary to achieve surgical anesthesia with an ultrasound-guided interscalene block for shoulder arthroscopy [33]. Similarly, Renes used an up-down method to show the minimum effective volume of local anesthetic for shoulder analgesia to be 3.6 mL [34]. These volumes are significantly lower than the traditional 40–60 mL used with paresthesia and nerve stimulator techniques. The ability to use less local anesthetic may theoretically lead to fewer systemically toxic reactions to local anesthetics. However, the incidence of local anesthetic toxicity is already extremely low (0.004 %) [35]. Other benefits of low dose blocks may be less motor blockade, leading to increase patient satisfaction and fewer adverse effects of the block. However, these advantages have yet to be elucidated.

Historically, anesthesiologists have used anatomical landmarks to elicit paresthesias or electrical nerve stimulation in order to place the needle as close to a nerve as possible. However, this approach provides no information regarding the actual position of the needle tip, raising concern that the needle may be in an intraneural or intrafascicular location. Although the consequences of injecting local anesthetic intraneurally are controversial, it is acknowledged that injecting intrafascicularly is associated with an increased risk of nerve injury and neuropraxia. With the utilization of ultrasound it has also become evident that even with a visually confirmed needle to nerve contact, a paresthesia is felt by only 38 % of patients and an electrical stimulation of $<0.5$ mA elicits a visible muscle twitch in only 75 % of patients [32]. Despite the absence of a muscle twitch, this does not affect the success rate with ultrasound. While many clinicians combine both nerve stimulation and ultrasound when performing blocks, nerve stimulation is insensitive and the addition of nerve stimulation likely offers no advantage.

Although the data does not show conclusive superiority of ultrasound, it is likely to become the preferred technique. Ultrasound allows those who are not regional anesthesia experts to feel comfortable performing a variety of blocks. This will likely increase the amount of regional anesthesia being performed and allow more patients to benefit from the technique.

## Controlled Hypotension

Blood loss during orthopedic surgeries can be significant, particularly with revision procedures. Hypotensive anesthesia is a technique that lowers the mean arterial blood pressure to 50–60 mmHg and results in a significant reduction in blood loss (503 mL reduction after total hip arthroplasty). This decrease in bleeding also correlates with a reduction in transfusion requirements [36]. By reducing interoperative blood loss, surgical exposure is improved and surgical time

is reduced. Studies have also shown that a dry surgical field facilitates the penetration of cement into cancellous bone improving the fixation during a total hip arthroplasty [6].

Prior to discussing the technique to achieve controlled hypotension, it is important to review the concept of oxygen delivery. Maintaining adequate oxygen delivery has been shown to improve prognosis [37]. Arterial oxygen delivery and consumption are dependent on cardiac output, hemoglobin and arterial and venous oxygen saturation. Accordingly, a decrease in cardiac output that occurs with a decrease in blood pressure will adversely affect oxygen delivery. Keeping this in mind, there are many ways to lower the mean arterial blood pressure. These include general anesthesia, use of antihypertensive medication and regional anesthesia. Both general anesthesia and antihypertensive medication are cardiac depressants and lead to a decrease in end organ perfusion. Neuraxial anesthesia dilates the arterioles and veins and also suppresses both the inotropic and chronotropic activity of the heart. However, it has been well described that by obtaining hypotension with a high sympathetic blockade approximating T4 and then adding an epinephrine infusion, cardiac output, and thus blood flow, is maintained despite hypotension [6]. Additionally, by utilizing neuraxial anesthesia, the negative effects of positive pressure ventilation on cardiac output and oxygen extraction are avoided.

When utilizing this technique, invasive monitoring is required. A reliable arterial line is essential with central venous access depending on a number of patient and procedure related factors. Further, the maintenance of intravascular euvolemia is essential. With neuraxial anesthesia, the patient can be kept awake to assess neurological status in high risk situations. Few studies, however, have been powered to detect harm; therefore, the technique should be used with caution in people with a history of cardiac, cerebrovascular, renal, hepatic, or severe peripheral vascular disease.

The optimal mean arterial pressure for hypotensive anesthesia is controversial. The estimated intraoperative blood loss has been found to be 179 mL when the MAP was maintained at 50 mmHg and 263 mL when the MAP was kept at 60 mmHg. This reduction may not be considered clinically significant. Cerebral blood flow is thought to be maintained constant over a range from 70 to 150 mmHg, but this assumption has recently been challenged. Some researchers suggest that during induced hypotension, the systolic blood pressure should not be reduced more than 20 % from baseline [38].

Hypotensive neuroaxial anesthesia has also been found to reduce the incidence of deep vein thrombosis. Virchow's triad describes thromboembolism occurring in the setting of venous stasis, vessel injury, and hypercoagulable state. All three of these components exist during total hip arthroplasty, but can be offset by obtaining controlled hypotension using neuraxial anesthesia and an epinephrine infusion. The neuraxial technique prevents thrombosis as previously described and the epinephrine infusion increases the skeletal muscle blood flow, reducing stasis and lessening thrombogenesis [6]. Additionally, the reduction in blood loss limits the dilution and consumption of coagulation factors, thus limiting rebound hypercoagulability.

The major cardiovascular risks with the hypotensive neuraxial technique are obtaining a high spinal or epidural level of blockade and severe bradycardia. The high spinal or epidural should be managed by assisting ventilation and supporting the circulation with epinephrine until resolution of the block. Early treatment of bradycardia with a beta agonist is essential.

Intraoperatively hypotension is also used during shoulder surgeries in the sitting position. The sitting position gives the surgeons better access to the shoulder and hypotension helps decrease the blood loss and create a dry field. Several case studies have attributed ischemic brain or spinal cord injury to hypotensive anesthesia in the sitting position. However, a recent study showed no strokes in over 4,000 patients having outpatient shoulder surgery in the sitting position with hypotensive anesthesia [38]. Most of these cases were done under brachial plexus block and sedation with spontaneous ventilation, as positive pressure ventilation can theoretically adversely affect cerebral blood flow. Although this technique appears to be safe, it should be individualized to the patient taking into account comorbidities and risks.

## Pneumatic Tourniquet

Applying a pneumatic tourniquet prior to incision is another strategy to minimize blood loss during orthopedic surgery. The tourniquet creates a bloodless field when inflated to 100 mmHg above the patient's systolic blood pressure. The tourniquet, however, is not without complications. It can cause significant pain that is often resistant to regional anesthesia and narcotics, but is relieved with the deflation of the tourniquet. Although the etiology of this pain is unclear, a significant sympathetic response occurs 60 min after the inflation of the tourniquet. Complications include postoperative swelling, compression neuropraxia, wound hematoma, vascular injury, tissue necrosis, muscle weakness, and compartment syndrome. Contributing factors are related to the height of the inflation pressure and duration of inflation [39]. Wider cuffs require lower inflation pressures to stop flow and may help to minimize these complications [39, 40]. After 2 h of tourniquet inflation, ischemic neuropraxia, edema, stiffness, pallor, and weakness, otherwise known as post-tourniquet syndrome may occur [39]. When the tourniquet is deflated, both the mean arterial pressure and central venous pressure are decreased, and there is an increase in

$PaCO_2$, $EtCO_2$, lactate, and potassium, leading to a transient metabolic acidosis. This is due to the circulation of the metabolic waste released from the ischemic extremity. Deflation is also associated with thrombolytic activity, activation of anti-thrombin III and protein C which may lead to post-tourniquet bleeding [40]. Whether these effects become significant is highly variable. Therefore, the anesthesiologist should anticipate these changes when evaluating each patient preoperatively and careful perioperative monitoring is required, particularly in patients with poor cardiopulmonary reserve.

## Summary

As the population continues to age, the volume of orthopedic surgery will continue to increase. Each orthopedic patient presents different challenges, but should be managed by the anesthesiologist with knowledge of the surgical technique, position, predicted blood loss, and associated complications. The elderly are at an increased risk for perioperative complications making a thorough preoperative evaluation and use of appropriate intraoperative invasive monitors essential. Additionally, the anesthesiologist should appreciate the anesthetic challenges each disease process presents including the airway challenges in the rheumatoid arthritis patient or the difficult neuraxial placement in individuals with osteoarthritis.

In orthopedic surgery, both general and regional anesthesia techniques are widely used in clinical practice. While the regional versus general anesthesia debate continues, regional anesthesia has some advantages over general anesthesia. These include decreased early mortality, fewer cases of deep vein thrombosis and fatal pulmonary embolism, fewer respiratory complications and improved rehabilitation. Sharrock showed a statistically significant decrease in the death rate at Hospital for Special Surgery after making several changes, including performing 96 % of all surgeries under regional anesthesia and utilizing perioperative invasive hemodynamic monitors more liberally [1]. Particularly in orthopedic surgery, regional anesthesia seems to have a strong indication. However, regional anesthesia is not a panacea and the anesthetic plan should carefully consider the operation, the patient's comorbidities and patient and surgeon preference.

Although the incidence of neurologic dysfunction following hemorrhagic complications after neuraxial blockade is likely rare, the catastrophic consequences associated with compression of the spinal cord demand attention be paid to anticoagulation in the setting of regional anesthesia. A complete review of every patient's medication list to assess for medications that affect components of the clotting cascade is essential. Currently, the recommendations regarding neuraxial anesthesia and anticoagulants are based on expert opinion and are not evidence-based. As new medications continue to emerge, the anesthesiologist must be vigilant when making decisions regarding the use of regional anesthesia based on the pharmacological profile of each drug and must weigh the risks and benefits on an individualized basis.

Although ultrasound has not been shown to reduce complication rates associated with the performance of nerve blocks, it does lead to a higher block success rate, less number of needle passes, decreased dose of local anesthetic, and decreased time to onset of blocks versus traditional techniques. Ultrasound will allow the occasional regional anesthesiologist to feel confident in the success of the blocks making regional techniques more accessible.

As orthopedic surgery is often associated with the potential for large blood loss, fluid shifts and complications such as fat and air embolism, an anesthesiologist should have a low threshold for using invasive monitors, particularly if controlled hypotension or a pneumatic tourniquet is being used. Controlled hypotension leads to less blood loss and transfusion requirements, decreased rates of thrombotic phenomena and improved fixation during total hip arthroplasty. Hypotension accomplished by neuraxial anesthesia with an epinephrine infusion results in a normal cardiac output and oxygen delivery despite low blood pressure. A pneumatic tourniquet provides a bloodless field but may lead to tissue, nerve, and blood vessel damage. Attempts to limit tourniquet time and pressure as well as to ensure proper fitting and placement of the tourniquet may help decrease these complications.

As the field of orthopedic surgery continues to evolve, there is an increased demand for joint replacements in an aging population, more procedures are being performed in an ambulatory setting and the public seems to have a decreasing tolerance for postoperative pain. The anesthesiologist should be an active participant in the entire perioperative care of these patients in order to help improve the patient's operative experience and outcome.

**Summary Bullet Points**

- Orthopedic surgical patients pose specific anesthesia related concerns that the perioperative team should be aware of.
- Many orthopedic patients are candidates for regional anesthetic techniques and the literature suggests potential benefits associated with their use.
- To avoid potential bleeding complications, perioperative physicians need to be aware of the effects of a growing number of anticoagulants and antiplatelet agents.
- The hypotensive epidural technique as utilized for hip arthroplasty patients represents an advanced anesthetic approach and may be associated with improved perioperative outcomes.

## Case Study

A case study for this chapter is included in Appendix B at the end of this book.

## References


1. Sharrock NE, Cazan MG, Hargett MJ, Williams-Russo P, Wilson Jr PD. Changes in mortality after total hip and knee arthroplasty over a ten-year period. Anesth Analg. 1995;80:242–8.
2. Fischer B. Benefits, risks, and best practice in regional anesthesia: do we have the evidence we need? Reg Anesth Pain Med. 2010;35:545–8.
3. Hanna MN, Murphy JD, Kumar K, Wu CL. Regional techniques and outcome: what is the evidence? Curr Opin Anaesthesiol. 2009;22:672–7.
4. Luger TJ, Kammerlander C, Gosch M, Luger MF, Kammerlander-Knauer U, Roth T, Kreutziger J. Neuroaxial versus general anaesthesia in geriatric patients for hip fracture surgery: does it matter? Osteoporos Int. 2010;21:S555–72.
5. Rodgers A, Walker N, Schug S, McKee A, Kehlet H, van Zundert A, Sage D, Futter M, Saville G, Clark T, MacMahon S. Reduction of postoperative mortality and morbidity with epidural or spinal anaesthesia: results from overview of randomised trials. BMJ. 2000;321:1493.
6. Sharrock NE, Salvati EA. Hypotensive epidural anesthesia for total hip arthroplasty: a review. Acta Orthop Scand. 1996;67:91–107.
7. Hebl JR, Dilger JA, Byer DE, Kopp SL, Stevens SR, Pagnano MW, Hanssen AD, Horlocker TT. A pre-emptive multimodal pathway featuring peripheral nerve block improves perioperative outcomes after major orthopedic surgery. Reg Anesth Pain Med. 2008;33:510–7.
8. Chung F, Ritchie E, Su J. Postoperative pain in ambulatory surgery. Anesth Analg. 1997;85:808–16.
9. Administration on Aging. Aging statistics. 2011. HCUP Databases. http://www.aoa.gov/aoaroot/aging_statistics/index.aspx. Accessed 25 Nov 2011.
10. Matti MV, Sharrock NE. Anesthesia on the rheumatoid patient. Rheum Dis Clin North Am. 1998;24:19–34.
11. Centers for Disease Control and Prevention. Arthritis data and statistics. 2011. http://www.cdc.gov/arthritis/data_statistics.htm. Accessed 25 Nov 2011.
12. Centers for Disease Control and Prevention. NHIS arthritis surveillance. 2011. http://www.cdc.gov/arthritis/data_statistics/national_nhis.htm#gender_specific. Accessed 25 Nov 2011.
13. Urban MK. Anesthesia for orthopedic surgery. In: Miller RD, editor. Miller's anesthesia. 7th ed. Philadelphia, PA: Elsevier Churchill Livingstone; 2009. p. 2241–59.
14. St-Arnaud D, Paquin MJ. Safe positioning for neurosurgical patients. AORN J. 2008;87:1156–68. Quiz 1169–72.
15. Parker MJ, Handoll HH, Griffiths R. Anaesthesia for hip fracture surgery in adults. Cochrane Database Syst Rev. 2004;4:CD000521.
16. Shih Y-J, Hsieh C-H, Kang T-W, Peng S-Y, Fan K-T, Wang L-M. General versus spinal anesthesia: which is a risk factor for octogenarian hip fracture repair patients? Int J Geront. 2010;4:42–7.
17. Urwin SC, Parker MJ, Griffiths R. General versus regional anaesthesia for hip fracture surgery: a meta-analysis of randomized trials. Br J Anaesth. 2000;84:450–5.
18. Papaioannou A, Fraidakis O, Michaloudis D, Balalis C, Askitopoulou H. The impact of the type of anaesthesia on cognitive status and delirium during the first postoperative days in elderly patients. Eur J Anaesthesiol. 2005;22:492–9.
19. Horlocker TT, Wedel DJ, Rowlingson JC, Enneking FK, Kopp SL, Benzon HT, Brown DL, Heit JA, Mulroy MF, Rosenquist RW, Tryba M, Yuan CS. Regional anesthesia in the patient receiving antithrombotic or thrombolytic therapy: American Society of Regional Anesthesia and Pain Medicine evidence-based guidelines (third edition). Reg Anesth Pain Med. 2010;35:64–101.
20. Davis FM, Quince M, Laurenson VG. Deep vein thrombosis and anaesthetic technique in emergency hip surgery. Br Med J. 1980;281:1528–9.
21. Ilfeld BM, Shuster JJ, Theriaque DW, Mariano ER, Girard PJ, Loland VJ, Meyer S, Donovan JF, Pugh GA, Le LT, Sessler DI, Ball ST. Long-term pain, stiffness, and functional disability after total knee arthroplasty with and without an extended ambulatory continuous femoral nerve block: a prospective, 1-year follow-up of a multicenter, randomized, triple-masked, placebo-controlled trial. Reg Anesth Pain Med. 2011;36:116–20.
22. Neal JM, Bernards CM, Hadzic A, Hebl JR, Hogan QH, Horlocker TT, Lee LA, Rathmell JP, Sorenson EJ, Suresh S, Wedel DJ. ASRA practice advisory on neurologic complications in regional anesthesia and pain medicine. Reg Anesth Pain Med. 2008;33:404–15.
23. Brull R, McCartney CJ, Chan VW, El-Beheiry H. Neurological complications after regional anesthesia: contemporary estimates of risk. Anesth Analg. 2007;104:965–74.
24. Horlocker TT, Wedel DJ, Benzon H, Brown DL, Enneking FK, Heit JA, Mulroy MF, Rosenquist RW, Rowlingson J, Tryba M, Yuan CS. Regional anesthesia in the anticoagulated patient: defining the risks (the second ASRA consensus conference on neuraxial anesthesia and anticoagulation). Reg Anesth Pain Med. 2003;28:172–97.
25. Hebl JR, Horlocker TT, Pritchard DJ. Diffuse brachial plexopathy after interscalene blockade in a patient receiving cisplatin chemotherapy: the pharmacologic double crush syndrome. Anesth Analg. 2001;92:249–51.
26. Sorenson EJ. Neurological injuries associated with regional anesthesia. Reg Anesth Pain Med. 2008;33:442–8.
27. Neal JM. Effects of epinephrine in local anesthetics on the central and peripheral nervous systems: neurotoxicity and neural blood flow. Reg Anesth Pain Med. 2003;28:124–34.
28. Rosencher N, Bonnet MP, Sessler DI. Selected new antithrombotic agents and neuraxial anaesthesia for major orthopaedic surgery: management strategies. Anaesthesia. 2007;62:1154–60.
29. Llau JV, Ferrandis R. New anticoagulants and regional anesthesia. Curr Opin Anaesthesiol. 2009;22:661–6.
30. Neal JM, Brull R, Chan VW, Grant SA, Horn JL, Liu SS, McCartney CJ, Narouze SN, Perlas A, Salinas FV, Sites BD, Tsui BC. The ASRA evidence-based medicine assessment of ultrasound-guided regional anesthesia and pain medicine: executive summary. Reg Anesth Pain Med. 2010;35:S1–9.
31. Gelfand HJ, Ouanes JP, Lesley MR, Ko PS, Murphy JD, Sumida SM, Isaac GR, Kumar K, Wu CL. Analgesic efficacy of ultrasound-guided regional anesthesia: a meta-analysis. J Clin Anesth. 2010;23:90–6.
32. Koscielniak-Nielsen ZJ. Ultrasound-guided peripheral nerve blocks: what are the benefits? Acta Anaesthesiol Scand. 2008;52:727–37.
33. Gautier P, Vandepitte C, Ramquet C, DeCoopman M, Xu D, Hadzic A. The minimum effective anesthetic volume of 0.75 % ropivacaine in ultrasound-guided interscalene brachial plexus block. Anesth Analg. 2011;113:951–5.
34. Renes SH, van Geffen GJ, Rettig HC, Gielen MJ, Scheffer GJ. Minimum effective volume of local anesthetic for shoulder analgesia by ultrasound-guided block at root C7 with assessment of pulmonary function. Reg Anesth Pain Med. 2010;35:529–34.

35. Liu SS, Ngeow JE, Yadeau JT. Ultrasound-guided regional anesthesia and analgesia: a qualitative systematic review. Reg Anesth Pain Med. 2009;34:47–59.
36. Paul JE, Ling E, Lalonde C, Thabane L. Deliberate hypotension in orthopedic surgery reduces blood loss and transfusion requirements: a meta-analysis of randomized controlled trials. Can J Anaesth. 2007;54:799–810.
37. Conte B, L'Hermite J, Ripart J, Lefrant J-Y. Perioperative optimization of oxygen delivery. Transfus Altern Transfus Med. 2010;11:22–9.
38. Yadeau JT, Casciano M, Liu SS, Edmonds CR, Gordon M, Stanton J, John R, Shaw PM, Wilfred SE, Stanton M. Stroke, regional anesthesia in the sitting position, and hypotension: a review of 4169 ambulatory surgery patients. Reg Anesth Pain Med. 2011;36:430–5.
39. Wakai A, Winter DC, Street JT, Redmond PH. Pneumatic tourniquets in extremity surgery. J Am Acad Orthop Surg. 2001;9:345–51.
40. Noordin S, McEwen JA, Kragh Jr JF, Eisen A, Masri BA. Surgical tourniquets in orthopaedics. J Bone Joint Surg Am. 2009;91:2958–67.

# Pediatric Anesthesia for Orthopedic Surgery

6

Kathryn R. DelPizzo, Naomi Dong, and Carrie R. Guheen

**Objectives**

- To highlight the unique aspects of performing regional anesthesia in children, including local anesthetic properties in the young patient.
- To review neuraxial anesthesia and the risks and benefits in children.
- To illustrate potential complications of regional and neuraxial anesthesia in the pediatric population.
- To introduce the anesthetic implications of special populations in the pediatric orthopedic setting, including Cerebral Palsy, Osteogenesis Imperfecta, Arthrogryposis, Myopathies, and patients with Ventriculoperitoneal Shunts.
- To present the perioperative considerations related to pediatric spine patients.

**Key Points**

- The anesthetic care of the pediatric orthopedic patient is challenging and differs in important ways from adults.
- Preemptive analgesia in the form of neuraxial anesthesia and peripheral nerve blockade can be utilized in the young patient on a routine basis. Practitioners of pediatric anesthesia must have in-depth knowledge of pediatric anatomy and the pharmacology of local anesthetics to prevent complications, both life-threatening and minor.
- Performing regional anesthesia on children who are sedated or under general anesthesia is the standard of care in pediatric operating rooms. Several studies in the literature support the safety of this technique.
- Patients with syndromes such as cerebral palsy frequently present for orthopedic surgery. Understanding the spectrum of these syndromes and their anesthetic implications will help the clinician tailor safe and effective perioperative care of this patient population.
- Surgery for patients undergoing scoliosis correction is a common procedure performed on both healthy and medically complex teenagers. Although the surgical procedure has become routine, rare and potentially fatal complications can occur.

## Introduction

Unlike most adult patients, children frequently require an orthopedic operation because of a congenital abnormality or syndrome. Common syndromes with orthopedic involvement include Osteogensis Imperfecta (OI), Cerebral Palsy (CP), achondroplasia, muscular dystrophies, and Charcot–Marie–Tooth. Some of these patients will present with other neurological sequelae such as seizure disorders, ventriculoperitoneal (VP) shunts, developmental delay and intrathecal baclofen pumps. Each of these entities has specific anesthetic implications.

In recent years, concern has been raised about the effects of anesthesia on the developing brain. Animal studies have shown impaired synaptogenesis and apoptotic neurodegeneration during neonatal neuronal development secondary to inhaled anesthetics, ketamine, and propofol [1–5]. In a retrospective sibling cohort study, authors found evidence of increased developmental and behavioral disorders in children who were exposed to general anesthesia under the age of 3 years [6]. However, available data are inconclusive

K.R. DelPizzo (✉) • N. Dong • C.R. Guheen
Department of Anesthesiology, Hospital for Special Surgery, Weill Cornell Medical College, 535 E70th Street, New York, NY 10021, USA
e-mail: delpizzok@hss.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_6, 

because of the obvious difficulties with conducting randomized controlled studies in humans [7]. It is in this context of uncertainty that the use of regional anesthesia is proposed as an alternative to a general anesthetic approach [8].

Children presenting for surgery at our institution have received regional anesthesia in the same fashion as adult patients for over 25 years. Led by the French-Language Society of Pediatric Anesthesiologists (ADARPEF), the quantity of articles about pediatric regional anesthesia in the literature has grown exponentially in the last two decades [9–11]. Bernard Dalens wrote the first and only edition of the textbook Pediatric Regional Anesthesia over 20 years ago [12]. More recently, The New York School of Regional Anesthesia (NYSORA) Textbook of Regional Anesthesia and Pain Management dedicated over 80 pages to this patient population [13, 14]. In addition, the development of the new, multi-institutional Pediatric Regional Anesthesia Network (PRAN) is now contributing large-scale data to the field.

Not all orthopedic procedures are amenable to regional anesthesia. Idiopathic scoliosis correction is a commonly performed surgery on healthy teenagers in the orthopedic setting. The incidence of idiopathic scoliosis has been estimated to be 1.9–3 %; females who require surgery outnumber males by at least 2:1 [15]. Neuromuscular scoliosis is less commonly seen and can be neuropathic (cerebral palsy) or myopathic (muscular dystrophy) [16]. These patients usually have associated comorbidities and warrant a comprehensive preoperative evaluation with a multidisciplinary team approach.

This chapter is not intended to be a comprehensive review or a complete reference for pediatric practitioners in an orthopedic setting; our goal is to summarize and provide a starting point for the reader interested in the field of pediatric anesthesia for orthopedic surgery. The pertinent texts and literature will be emphasized for the reader who would like more in-depth information. Here, we will highlight common anesthetic techniques and unique circumstances that are more likely to be seen in an orthopedic operating room. Although beyond the scope of this chapter, the basic premises of pediatric anesthesia—airway management, preoperative parent–child preparation, pain assessment, and physiological differences between children and adults—are of paramount significance.

This chapter will focus on the discussion of: (1) the positive impact of regional anesthesia on the perioperative care of children undergoing orthopedic surgery, (2) neuraxial anesthesia and its risks and benefits in children, (3) common anesthetic and postoperative pain management techniques used at our institution for children, (4) possible complications of these techniques, and (5) aspects surrounding specific patient populations, including the risk of life-threatening problems such as anaphylaxis.

## Regional Anesthesia

### The Impact of Regional Anesthesia in the Pediatric Patient

It is important to understand the concept of preemptive analgesia and that effective pain management begins before the child emerges from anesthesia. Preemptive analgesia can decrease morbidity and the development of chronic pain in the surgical patient of any age [17]. In the form of regional anesthesia, it may attenuate the stress response to surgery, resulting in improved postoperative outcomes [18].

Children have been highlighted as excellent candidates for using regional anesthesia to modulate the stress response to surgery for over two decades. Early publications in the literature focused on neonates and young infants undergoing cardiac surgery [19–21]. Wolf and colleagues found lower levels of stress markers and less morbidity and mortality in infants who received neuraxial anesthesia [22]. Evidence exists that shows regional anesthesia combined with general anesthesia is more effective at suppressing neuroendocrine stress responses compared to conventional general anesthetic techniques using opioids alone [18]. Although perioperative events surrounding orthopedic surgery may differ from those that activate the intense physiologic response seen with cardiac surgery, we recommend the use of neuraxial and peripheral nerve blocks as valuable components in a comprehensive approach to the perioperative management of pediatric orthopedic patients.

### Safety in Pediatric Regional Anesthesia

Pediatric regional anesthesia should not be performed without understanding key differences between adults and children. The most obvious one is the timing of block placement. Although at one time considered controversial, it is now widely accepted among anesthesiologists to perform regional anesthetics in children who are anesthetized.

In 1996 Giaufré et al. presented their findings from a multicenter study in France.

Of 24,409 regional anesthetics (60 % caudal blocks) none were associated with major complications, and minor complications were rare (0.9 %). Eighty-nine per cent of the blocks were placed under general anesthesia or heavy sedation, the majority of events occurred secondary to human error (overdose of local anesthesia or improper equipment usage) and none of the adverse events occurred

secondary to peripheral nerve blocks [10]. In a follow-up study, Ecoffey and colleagues reported a similarly low incidence of serious complications (0.12 %) with no patients having sequelae 1 year later [9]. Additionally, anesthesiologists in the UK published The National Epidural Audit in 2007. Between 2001 and 2005 they studied over 10,000 children who had an epidural catheter with a postoperative infusion in the caudal, lumbar, or thoracic areas. Of 56 incidents, they found only five to be serious (0.05 %) and only one patient suffering sequelae 1 year later [23].

In the USA, the Pediatric Regional Anesthesia Network (PRAN) was organized in 2006. This is the first system of its kind to collect prospective data from multiple institutions on regional anesthetics performed in children. In its first 2 years, PRAN reported on data from 7,500 nerve blocks in children with no permanent injuries [24]. The small number of complications reported were mostly drug reactions, (e.g., pruritus) catheter issues, (e.g., kinking or dislodgement) or inadequate analgesia. There was one temporary dysesthesia from a single-injection sciatic block and one infection from an epidural that resolved with antibiotics. The collaborators now have documentation of over 53,000 pediatric nerve blocks and will soon be publishing more reassuring results.

### Ultrasound

One cannot discuss safety of regional anesthesia in children without giving credit to the advent of portable ultrasound technologies. In the past decade this topic has dominated the pediatric regional anesthesia literature as an increasing number of providers use it routinely. Recent data in the USA demonstrate a 2.5-fold increase in its use for lower extremity single-shot blocks over the past 4 years [25].

The advance of the ultrasound technique has made the performance of blocks in children easier, safer, and more effective. By visualizing the needle and its target anatomy, local anesthetic spread can be assessed in real-time, while avoiding vital structures (blood vessels, the lungs, etc.). In addition the needle may be repositioned more effectively as needed. The literature shows clear benefits of the use of ultrasound for the performance of peripheral nerve blocks; its use for neuraxial procedures, however, is less persuasive [26, 27].

It has been advocated that ultrasound guidance be mandatory for peripheral nerve blocks in children, arguing that the following benefits outweigh the cost of purchasing the machines and training clinicians: (1) clinically relevant reduction in onset time, (2) improvement in success rate, (3) reduction in volume of local anesthesia required, and (4) potential decrease in complication rates [28].

Compared to previous conventional techniques in children, ultrasound-guided blocks provide prolonged sensory blockade with lower volume of local anesthesia [29, 30]. Because the complication rates are very low even with conventional techniques, no study has proven that ultrasound is superior; however, it is becoming the standard of care in many practices, including ours.

As with any tool, its benefit is only as good as the hands of its operator. Major complications with the ultrasound are rare but when operator error occurs, it is usually with the novice practitioner. It is imperative that providers using the ultrasound in children have an understanding of the anatomy and block technique, as well as competence using the machine and the ability to mentally construct a three dimensional image from the two dimensional one obtained on the screen. Conventional techniques should not be forgotten, as the simultaneous use of nerve stimulation can be extremely helpful in confirmation of the needle-nerve relationship [31].

## Neuraxial Anesthesia

### Neuraxial Anesthesia in Children

Neuraxial anesthesia is routinely used at the Hospital for Special Surgery. It reduces the requirements for anesthetics agents, muscle relaxants (and hence reversal agents,) and intraoperative opioids. Benefits include a faster return to a lucid mental status, appetite, bowel function, and less postoperative nausea and vomiting (PONV).

Most providers comfortable with pediatric anesthesia find the placement of a neuraxial block in a child to be easier than in an adult. Usually the patients are deeply sedated or under general anesthesia, have less adipose tissue, no osteophytes or ligament calcifications, and fewer spinal deformities. However, clinicians need to use care and understand that the depth of needle insertion is but one of many considerations. For most children, loss of resistance will be obtained more superficially than in adults. Although we do not recommend using a strict formula, some experts have developed one to assist the novice [14]. The ligamentum flavum is less tensile in children, but it can feel "tighter" and offer more resistance than expected. It can be difficult for beginners to differentiate between ligament and bone with the epidural needle. There may not be a distinctive "pop" relied upon in the loss-of-resistance technique, so clinicians need to pay attention to *any* change in resistance rather than a specific qualitative sensation they have become accustomed to with adult patients. When an epidural catheter is passed and secured, an insertion depth of no more than 3–4 cm past the epidural needle tip is recommended to increase the likelihood a midline location. This shallow placement can cause leaking at the epidural site if a postoperative infusion is used, thus requiring the education of nursing staff and parents. Securing the catheter at the

insertion site is important and if desired, there are commercial adhesive devices on the market that can be used for this purpose.

The incidences of serious or major complications after lumbar epidural analgesia in children are 1:10,000 and 1:100,000, respectively [32]. Epidural blockade in children and adolescents produces less hemodynamic disturbance than in adults. In children less than 8 years of age, hypotension is less frequently encountered for the following two reasons: (1) the combination of a lower circulatory volume in the legs and splanchnic system, and (2) an already relatively vasodilated systemic vasculature. If a significant change in the blood pressure or heart rate is observed in a child receiving neuraxial anesthesia in the operating room, other causes, including life-threatening events such as anaphylaxis or acute blood loss, must be considered.

The dosing of neuraxial anesthesia medication is different in children compared to adults. Although children require more frequent dosing in the operating room to achieve adequate anesthesia, they are at greater risk for toxicity of local anesthesia with repeated doses [33]. Infants and young children have a larger volume of cerebrospinal fluid than adults per kilogram (4 ml/kg vs. 2 ml/kg) with presumed higher daily turnover rates. They have lower epidural fat content, which facilitates the spread of local anesthetic within and out of the epidural space. Further, with the absence of restrictions to distribution, such as spinal stenosis seen with older individuals, local anesthesia diffuses out of the epidural space faster, leaving the site of action more quickly. Spinal cord myelinization is not complete until most children are 12 years of age so local anesthetics do not last as long as they do in adults due to increased endoneurium permeability [17]. For these reasons, spinal anesthesia alone is only helpful for cases that last less than 90 min [34].

The use of postoperative epidural catheters is a good solution for these challenges, as long as one follows the established dosing guidelines for children (See "Pediatrics and Local Anesthesia" section). Infusions avoid the problem of decreased latency and duration of local anesthetics in these patients, as well as the toxicity associated with repeated boluses. Because children require higher volumes of local anesthetic for neuraxial anesthesia and analgesia, it is important that the tip of the catheter is as close to the site of surgery as possible. At our institution, these catheters are used for lower extremity surgeries, so lumbar placement is our primary site of insertion, and combined spinal epidurals are used routinely. More information about thoracic or caudal epidural placement in children can be found elsewhere [14].

### Caudal Epidurals

Although considered to be the "bread and butter" of most pediatric anesthesia practices, caudal anesthesia is not widely used at our institution mainly due to the age distribution of our patient population and clinician comfort with lumbar epidural placement. The majority of our infants and toddlers having lower extremity surgery undergo club foot reconstruction and will receive ultrasound-guided popliteal and sometimes saphenous nerve blocks after induction of general anesthesia (Table 6.1). Infants undergoing surgery for congenital hip dysplasia will sometimes receive a caudal if deemed beneficial.

## Perioperative Care

### Perioperative Blocks and Postoperative Pain Management

To ensure that the benefit of the regional anesthetic is not overshadowed by intense untreated pain during block resolution, the transition period needs to be managed proactively. Parents and nurses caring for the child need to anticipate the recession of the block. If the patient has a catheter, perineural or epidural, the weaning process can be controlled gradually. If the patient received a single-injection block, the provider needs to give the caretakers a timeline for when to expect the block to recede. This can be difficult, as the recession of peripheral blockade is very unpredictable in the younger pediatric population. In general, recognizing pain in children can be challenging, and while a block recedes, this population may describe their limb as "itchy," or "cold" as opposed to "tingling" like many adults will.

The transition from epidural or perineural analgesia is best bridged with an oral narcotic offered on a regular basis, usually every 3–4 h. Barring any contraindications, acetaminophen and nonsteroidal anti-inflammatory agents should be given around-the-clock for the first few days postoperatively. We recommend beginning the non-narcotic analgesics as soon as possible in the operating or recovery room, and then begin the narcotics (either orally or intravenously) as soon as the patient reports any of the following: pain, tingling in the blocked extremity, or resumption of motor function (for example, moving toes after popliteal block, bending non-operative knee after neuraxial anesthesia, moving fingers after upper extremity block).

**Table 6.1** Common anesthetic techniques in children at HSS

| Procedure | Age | Common indications | Anesthesia | Postoperative pain | Notes |
|---|---|---|---|---|---|
| Club foot repair | Infant | Club foot | General anesthesia, U/S[a]-guided, popliteal | Acetaminophen, oxycodone | |
| Hip closed reduction, arthrogram, spica cast | Infant | Congenital hip dysplasia | General anesthesia, +/− Caudal | Acetaminophen | |
| Foot reconstruction | Predominantly school-aged, (10–15 years) | Flat foot deformity | Neuraxial anesthesia, popliteal +/− catheter, [b]saphenous at end of case | IV [c]PCA, oral oxycodone, acetaminophen | Popliteal catheters: 0.2 % ropivacaine 0.1–0.2 ml/kg/h |
| Knee<br>ACL<br>MPFL[d] | Predominantly teenagers | ACL injury, patella instability | Spinal, saphenous | Ambulatory surgery, goes home with oral narcotic, acetaminophen | |
| Hip varus rotational osteotomy, femoral osteotomy | Usually 5–10 years | Spastic hip subluxation | General anesthesia, neuraxial | Epidural PCA, 0.1 % bupivacaine, diazepam, oxycodone | Cerebral Palsy patients |
| Hip arthroscopy | Usually teens-early 40s | Labral tear, impingement | Neuraxial anesthesia | Ambulatory surgery | Majority are healthy and active |
| Hip preservation<br>PAO[e]<br>Surgical dislocation | Teens-early 40s | PAO—dysplasia, dislocation—impingement | Neuraxial anesthesia, +/− GA | Both receive [c]PCEA, diazepam, narcotics and ketorolac | Mostly women |
| Limb-lengthening, external fixator placement | Usually age 10–13 | Unequal limb length or short limbs | Combined spinal-epidural, IV sedation or general anesthesia | IV PCA, oxycodone, acetaminophen | Some patients have achondroplasia |
| Elbow, hand surgery | Varies | Fractures, cerebral palsy, elbow contractures | Infraclavicular or supraclavicular block depending on patient age and anatomy | IV PCA, oral narcotics, acetaminophen. May avoid block if risk of compartment syndrome | Surgeons may ask for infraclavicular catheter for continuous passive motion therapy (contractures) |

Unless indicated all cases are done with IV sedation unless general anesthesia required for airway control
Regional anesthesia not performed if contraindicated
[a]U/S = ultrasound
[b]Saphenous = subsartorial approach, ultrasound-guided. For foot surgery, it is often performed at the end of the case, because it benefits the patient longer in the postoperative period and the local anesthetic load at induction is already maximized
[c]Patient-controlled analgesia, patient-controlled epidural analgesia
[d]Medial patellofemoral ligament
[e]Periacetabular osteotomy

## Complications

### Neurological Injury

There are few contraindications to regional anesthesia that are specific to pediatrics. The incidence of neurological injury as a result of these techniques is difficult to quantify; in closed claims databases, perioperative nerve damage is more frequently associated with surgical factors and general anesthesia [35]. In a recent international review, the incidence reported in adults ranged from 0.04 to 0.5 % [36]. Current efforts to quantify the risks of regional anesthesia in pediatrics rely on multicenter databases such as the Pediatric Regional Anesthesia Network (PRAN).

Peripheral nerve blocks are performed on children with chemotherapy-induced and other peripheral neuropathies including Charcot–Marie–Tooth [37, 38]. Preexisting central nervous system disorders were once considered a contraindication to regional anesthesia, but in adults with these disorders, neuraxial anesthesia and analgesia does not appear to cause a worsening of preoperative neurological symptoms [39].

Some authors postulate that children may be at a lower risk for neurological injury compared to adults because of higher nerve plasticity [40]. Nevertheless, the patient with preoperative neurological disease should be approached with care and considered on a case-by-case basis. Lirk and colleagues suggest the following strategies to minimize the risk in patients with preexisting neuropathies: (1) avoid epinephrine in the local anesthetic solution, (2) use the lowest effective dose and concentration of local anesthetic, (3) use ultrasound guidance to place peripheral blocks, and (4) use lipophilic opioids to decrease the dose of local anesthetic [36]. A report from the PRAN shows that children who received blocks placed after neuromuscular blockade had a higher incidence of transient neurological complications [41].

## Neuraxial Complications

When discussing complications of neuraxial techniques, postdural puncture headaches (PDPH) and transient neurologic symptoms (TNS) are common concerns. For adults, the frequency with which PDPH occur is often quoted as less than 1 % for neuraxial anesthesia. TNS has an incidence as high as 7 % when using mepivicaine 1.5 % [42], and this risk is typically much lower with bupivacaine. For pediatric patients, these frequencies are less clear.

In general there are several risk factors that can increase one's risk for a PDPH: pregnancy, and young age, with a peak incidence in the teenage years. Patients over 50 years of age have a markedly lower incidence. The use of a small gauge (25–27), non-cutting, pencil-point spinal needles, such as a Whitacre, appears to decrease the incidence of PDPH in adults and likely pediatric patients [14]. Ascertaining the presence of a PDPH or TNS can be challenging in the pediatric population due to their age, maturity level, and presence of developmental delays. PDPH have a very characteristic positional quality to them that is not always easy to determine in the pediatric population. Other causes of postoperative headache should be considered, including sinusitis, pneumocephalus, and, of higher acuity, meningitis and subdural or subarachnoid hematoma [14]. Diagnosing and treating these complications in children are often challenging tasks.

Much of the literature associated with PDPH in children reflects those who have had lumbar puncture for either diagnostic testing or intrathecal chemotherapy, performed with large-bore needles. Studies from this population have found an incidence as high as 8 % [14]. Several studies in the past 15 years have attempted to determine the incidence and treatment of postdural puncture headaches in children undergoing spinal anesthesia with no needle larger than 25 g. See Table 6.2.

A recently completed study from the Hospital for Special Surgery examined the incidence of these complications in children age 5–14 years. Of over 300 patients, no reports of PDPH or TNS occurred with spinal, epidural, or combined spinal epidural (CSE) anesthesia. At least two patients in this age range who did not participate in the study are known to have developed PDPH. One was a healthy 12-year-old boy after an uneventful spinal anesthetic for a ligamentoplasty of the knee. The other patient was a healthy 9-year-old girl for an outpatient knee procedure. Both were successfully treated with intravenous fluids, acetaminophen, and bed rest for 2 days with complete resolution of symptoms. It should be noted that some authors maintain that children under 10 years of age do not develop PDPH [43].

**Table 6.2** Incidence PDPH and TNS in children

| Lead author | Year | Country | PDPH[a] (%) | TNS[a] (%) |
|---|---|---|---|---|
| Puncuh [73] | 2004 | Italy, Finland | 0.4 | 0.8 |
| Kokki [74] | 2005 | Finland | 4 | 2 |
| Imbelloni [75] | 2006 | Brazil | 0.9 | None |
| Llewellyn [23] | 2007 | UK | 0.06 | None |

[a]Incidence

In children, performing an epidural blood patch must be carefully considered. Unlike adults, pediatric patients often require heavy sedation for the performance of a blood patch, and at least two practitioners. Furthermore, the appropriate amount of blood to use in the pediatric population is unclear. Most authors recommend 0.2–0.3 ml/kg of blood [14, 44]. We rarely see PDPH in children, but if it is present, conservative management of bed rest, hydration, and analgesics, such as acetaminophen, is the first course of action with extraordinarily rare use of epidural blood patches.

Contraindications to neuraxial anesthesia are the same as for adults. At the Hospital for Special Surgery, a high risk of compartment syndrome is the most common reason not to use an epidural in children postoperatively. This is due to the fear that the symptoms of compartment syndrome—increasing pain in the affected limb—will be masked and therefore delay the diagnosis. Spina bifida and myelomeningocele are absolute contraindications, but the presence of a ventriculoperitoneal (VP) shunt is not, although the risks and benefits of spinal and epidural anesthesia should be carefully considered on an individual basis. The concerns with VP shunts include changes in intracranial pressure and infection. Despite these concerns, there is literature to support the use of spinal and epidural anesthesia in these patients [45–47].

## Pediatrics and Local Anesthesia

Safe doses of local anesthetics are computed based on weight in kilograms. Most children receive blocks after they are sedated or anesthetized, making the early signs of toxicity difficult or impossible to recognize. General anesthesia may modify the hemodynamic responses to epinephrine-containing test doses, leaving the methods used for adults (changes in heart rate and blood pressure) less reliable for children [48]. In children, ECG changes, specifically T-wave changes, may be the first sign of intravascular injection during a test dose [49]. Even if a child is awake, the prodromal warning signs for toxicity can be confused with irritability that can be attributed to other factors.

Unlike opioids, which may be titrated around a weight-based starting point, local anesthetics have a "maximum allowable dose" (single-injection bupivacaine/ropivacaine with epinephrine 2.5–3 mg/kg, lidocaine/mepivacaine with epinephrine 7 mg/kg). Neurologic and cardiac toxicity from local anesthetics are rare in pediatrics when providers are cautious. In a pivotal article by Berde in 1993, guidelines for local anesthetic infusions were introduced based on analysis of a series of convulsions associated with pediatric regional anesthesia and further study of pharmacokinetic data [33, 50]. The risk of toxicity with repeated doses or with continuous infusion is greater in children than in adults, even though the clearance for amide local anesthetics reaches adult maturation around 8 months of age. For infusions, the maximum amount of epidural bupivacaine should be no greater than 0.4 mg/kg/h, and in neonates, 0.2 mg/kg/h. Many pediatric hospitals use chloroprocaine, an ester instead of an amide local anesthetic, for babies younger than 3 months of age because chloroprocaine is rapidly metabolized in this age group. Additives such as opioids and clonidine are frequently used in these infusions to enhance the analgesic effect.

Prepubertal children present a unique challenge when contemplating peripheral nerve blockade, because the total volume of local anesthesia allowable is less than for adults, and the blocks recede faster. The block duration is proportional to the absolute dose given, not the dose based on body weight [51]. To the authors' knowledge, there are no human studies on duration of the analgesic effect of peripheral nerve blockade stratified by age. Berde reports evidence in animals that show when dosed proportional to body weight, infant rats have a shorter duration of blockade of the sciatic nerve compared to older rats [51, 52].

In our experience, peripheral nerve blocks for prepubertal children provide shorter duration of postoperative pain relief, compared to those performed on adults. Anecdotally, children under the age of 12 years of age tend to experience surgical pain within 6–10 h after block placement, compared to approximately 18 h in our adult population when using bupivacaine. If the patient is expected to experience considerable pain postoperatively, a perineural catheter can be placed, or clonidine (maximum 1 mcg/kg) may be added to the local anesthetic solution to extend analgesic effects.

In the past decade, cases of local anesthetic toxicity successfully treated with a 20 % lipid emulsion (Intralipid®, Fresenius Kabi AB, Uppsala, Sweden) have been reported with increasing frequency. These include a 13-year-old girl who received a posterior lumbar plexus block under general anesthesia and developed a ventricular arrhythmia 15 min later [53] and a 40-day-old baby who received a caudal epidural block under general anesthesia and immediately developed tachycardia, T-wave inversions, ST segment elevations, and hypotension [54]. Lipid emulsion and all necessary resuscitative equipment and medication should be readily available when performing these procedures.

In summary, when administering these medications to children in the operating room, it is important to (1) adhere to dosing guidelines, (2) use slow, fractionated doses with regular aspiration, (3) monitor patients for ECG changes and signs of neurological toxicity, (4) have Intralipid® readily available, and (5) consider that the risk for toxicity is increased with concomitant hypoxemia and hypercarbia.

The surgeon often relies on her anesthetist to recommend the quantity of local anesthetic she can use for infiltration. If a regional block has been performed, this step may be unnecessary. If it is deemed beneficial, the total doses of local anesthetic given are additive.

## Special Patient Groups and Considerations

See Table 6.3 for a summary of common pediatric disease entities with orthopedic involvement.

### Cerebral Palsy

Cerebral palsy (CP) is a nonprogressive disorder of motion and posture that results from an injury to the developing brain, first described in the 1860s by an English surgeon named William Little. The condition was called Little's disease for many years and is now known as spastic diplegia. In developing countries the incidence is two for every 1,000 live births, and almost half of the cases present in babies who are premature [57]. Early theories postulated that the disorder was caused by an event during birth that led to lack of oxygen delivery to the motor cortex, but in 1897 Sigmund Freud disagreed. Noting that children with cerebral palsy often had other problems such as mental retardation, visual disturbances, and seizures, Freud postulated that the disorder begins during the brain's development in the womb. "Difficult birth, in certain cases," he wrote, "is merely a symptom of deeper effects that influence the development of the fetus." [58]

However, the belief that birth complications cause cerebral palsy was widespread among physicians, families, and medical researchers until recently. It was not until the 1980s when scientists analyzed extensive data of more than 35,000 births and discovered that birth complications account for only a fraction of cases—probably less than 10 % [58]. In most cases of cerebral palsy, no etiology could be found. These findings from the National Institute of Neurological Disorders and Stroke (NINDS) perinatal study have profoundly altered medical theories about cerebral palsy and have motivated researchers to explore alternative causes.

**Table 6.3** Common pediatric disease entities with orthopedic involvement

| Disease or syndrome | Characteristics | Genetics | Orthopedic implications | Anesthetic concerns | Regional anesthesia contraindicated? |
|---|---|---|---|---|---|
| Osteogenesis imperfecta | Abnormal collagen/connective tissue disorder, fragile brittle bones that fracture easily/incidence 2.2:10,000 live births | *Type I*: Autosomal dominant, mild<br>*Type II*: Autosomal dominant (can be recessive), lethal, most severe form; can affect heart valves/aorta leading to CHF/death<br>*Type III*: Autosomal dominant (can be recessive), severe kyphoscoliosis/limb deformities<br>*Type IV*: Autosomal dominant, moderate, onset in newborn period with fractures in utero | • Surgical treatment of fractures with osteotomies, realignment of fragments, and medullary nail fixation<br>• Spinal fusion for 750° curve or to prevent progression of spinal deformity | • Risk of fracture with positioning, transfer, tourniquet, NIBP (use arterial line), and succinylcholine (fasciculations causing fractures)<br>• Difficult airway (large head, short neck, large tongue)<br>• Limited neck extension (risk of cervical spine or mandibular fracture)<br>• Spine deformity (poor respiratory function, restrictive lung disease, evaluate cardiac and respiratory function especially with Type II)<br>• Hyperpyrexia (not MH associated, thought due to elevated thyroid hormones) | No, but can be technically difficult and positioning can be fracture risk |
| Arthrogryposis multiplex congenita (multiple congenital contractures) | Non-progressive syndrome with persistent multiple limb contractures, atrophied or absent muscles, deformed /dislocated joints Incidence 0.3–3 cases:1,000 live births | Most cases sporadic | • Rigid foot deformity (club foot most common)<br>• Knee deformity (fixed flexion contracture most common)<br>• Hip deformity<br>• Upper extremities corrected after patient ambulating | • Difficult airway (micrognathia, limited TMJ mobility, atlantooccipital instability)<br>• Difficult IV access secondary to contractures<br>• Hyperpyrexia (not MH associated)<br>• Evaluate cardiac and respiratory function | No |
| Achondroplasia | Short-limbed dwarfism, macrocephaly, frontal bossing, depressed nasal bridge, midface hypoplasia, thoracolumbar kyphosis | Most cases sporadic | • Surgical treatment at 5–6 years of age if >40° localized thoracolumbar kyphosis. Surgery required anteriorly and posteriorly<br>• Limb lengthening procedures<br>• Treatment of fractures | • Airway obstruction (choanal atresia/stenosis)<br>• Macroglossia, midface hypoplasia, short neck<br>• Limited cervical mobility<br>• Possible hydrocephalus/elevated ICP and foramen magnum stenosis | Neuraxial contraindicated in presence of hydrocephalus/elevated ICP |
| Neuro-fibromatosis | Spectrum of disorders with neurofibromas of skin/nerves, café-au-lait spots, and axillary freckling/Incidence NF-I 1:4000, NF-II 1:50,000 | Usually autosomal dominant, Classified as NF type I–VII<br>*NF-I* (von Recklinghausen disease) chromosome 17q11.2<br>*NF-II* long arm of chromosome 22 (bilateral acoustic neuromas in >90 % patients, no bony involvement) | • Scoliosis most common osseous defect<br>• Must rule out presence of intraspinal lesions (pseudomeningocele, dural ectasia, or intraspinal neurofibroma) with MRI or CT myelogram due to risk of lesion compression with spine instrumentation | • Evaluate cervical spine and spinal cord for compressive neuromas<br>• Suspect pheochromocytoma (MEN IIb) with hypertension<br>• Evaluate airway for laryngeal or pharyngeal neurofibromas (possible difficult ventilation and/or intubation)<br>• Neck extension during laryngoscopy may cause cervical spine compression if intramedullary lesions present<br>• CXR to rule out mediastinal masses (especially in newborns) | Neuraxial contraindicated in presence of compressing spinal lesions |

| | | | | | |
|---|---|---|---|---|---|
| Marfan's syndrome | Connective tissue disorder associated with FNB-1 gene mutation which encodes for fibrillin, characterized by weakness, hyperextensible joints, eye lens dislocation, increased risk of valvular/aortic disease, and spontaneous pneumothorax | • Autosomal dominant with variable expression<br>• Can occur sporadically | • Severe kyphoscoliosis and thoracic deformity, scoliosis occurs in 40–60 % of Marfan's patients | • Cardiovascular assessment for presence of mitral valve disease (MVP is present in 80 % of cases) and aortic valve disease<br>• Echo, CXR, and lung function tests if severe kyphoscoliosis<br>• Intubation may be difficult, risk of TMJ subluxation/dislocation | No, however presence of dural ectasia may be cause of inadequate spinal anesthesia |
| Duchenne muscular dystrophy | Absence of dystrophin protein and destruction of muscle fibers that are replaced with scar tissue and fat, leading to pseudohypertrophy | • Sex-linked recessive<br>• 30 % occur from spontaneous mutation | • Muscle weakness, difficulty standing up<br>• Development of contractures, joint deformities, muscle retractions, and degenerations<br>• Collapse of spine leading to severe scoliosis and restrictive pulmonary disease | • Cardiovascular assessment with ECG, echocardiogram<br>• Dilated cardiomyopathy and conduction abnormalities common in adolescents<br>• Evaluate lung function with pulmonary function tests<br>• Expect difficult airway (large tongue)<br>• Avoid Succinylcholine (absolute contraindication) and halogenated agents due to hyperkalemic response<br>• Risk of severe hyperthermia with hyperkalemia and myoglobinuria secondary to rhabdomyolysis (have dantrolene available)<br>• Joint deformities and contractures can make positioning and vascular access difficult | No |
| Myotonic dystrophy | Inability of muscles to relax after contraction | • Autosomal dominant<br>• May be autosomal recessive | Possible clubfoot deformities, hip dysplasia, and scoliosis | • Evaluate muscle function, cardiac function (possible conduction abnormalities), and echocardiogram (mitral valve prolapse, cardiomyopathy), respiratory function (restrictive lung disease)<br>• CXR (silent aspiration)<br>• Pt at risk for perioperative aspiration due to dysphagia and gastric distension<br>• Avoid hypothermia to avoid shivering and myotonic crises<br>• Respiratory drive sensitive to all intravenous agents, consider reduced doses<br>• Avoid succinylcholine (risk of generalized myotonia) | No, but will not relieve myotonic contractions |

(continued)

**Table 6.3** (continued)

| Disease or syndrome | Characteristics | Genetics | Orthopedic implications | Anesthetic concerns | Regional anesthesia contraindicated? |
|---|---|---|---|---|---|
| Charcot–Marie–Tooth disease (Peroneal muscular atrophy) | Hereditary polyneuropathy, presenting with distal weakness and muscular atrophy | Inherited in different patterns (autosomal dominant, autosomal recessive, and X-linked), dominant form is most common | CMT is most common neuromuscular cause of cavovarus foot deformity | • Neurologic, cardiovascular, and respiratory evaluation preoperatively, including pulmonary function tests, CXR, EKG, and ABG if respiratory involvement suspected<br>• Echocardiogram indicated based on clinical evaluation<br>• Anesthesia may exacerbate any preexisting respiratory disease, postoperative mechanical ventilation may be required | No |
| Arnold-Chiari malformation | Herniation of cerebellar vermis and choroid plexus through foramen magnum, elongation of fourth ventricle, and noncommunicating hydrocephalus | Few reported cases of autosomal recessive inheritance associated with myelomeningocele and prenatal onset<br>Classified as Type I, II, III, IV | Type II most often in children with myelomeningocele, dysfunction of lower cranial nerves (vocal cord weakness/paralysis, difficulty feeding, crying, breathing). Ventriculoperitoneal shunt to control hydrocephalus resolves brainstem symptoms. If brainstem symptoms persist after shunting surgical decompression indicated | • Preoperative evaluation for signs of elevated ICP and brainstem and/or cervical cord compression<br>• Prone positioning with careful head positioning (risk of brainstem compression)<br>• Risk of venous air embolism depending on level of surgical field (avoid nitrous oxide) | Please refer to *Neuraxial Complications* section of text |
| Hydrocephalus/VP shunt | Caused by either overproduction or obstructed drainage of CSF from brain | 80–90 % of patients with myelomeningocele have hydrocephalus requiring shunting | Treatment to relieve obstructive hydrocephalus requires shunting, either to external ventricular drain (temporary relief) or internal shunt within brain (third ventriculostomy) to peritoneum or right atrium | Signs of shunt failure can include nausea, vomiting, severe headaches, increased irritability, increased level of paralysis (emergent neurosurgical intervention required) | Please refer to *Neuraxial Complications* section of text |

Data from [69, 76–79]

There are four different types of CP: spastic, ataxic, dyskinetic, and mixed. Spastic CP is the most common type (over 70 % of cases) and usually involves contractures in the elbows, wrists, hips, knees, and ankles. Spasticity is caused by an imbalance between inhibitory neurotransmitters like gamma-amino butyric acid (GABA) and excitatory neurotransmitters like glutamate [59]. This imbalance leads to excessive stimulation of alpha motor neurons causing contraction of agonist and antagonist muscle groups simultaneously [60].

The spectrum of severity in these patients is broad. It is important to note that the causative brain injury itself is nonprogressive, but the clinical picture can change over time and is different for each individual [60]. Some children are intellectually on par with their peers, others may understand their surroundings but be nonverbal, and some of these children will be developmentally stunted in infancy. Caring for these patients in the perioperative setting requires that all providers be sensitive to these variations and look to the caregiver for guidance on how the patient reacts to pain, separation from the caregiver, new surroundings, etc.

It is particularly important for perioperative orthopedic clinicians to understand issues associated with CP, because this patient population often presents for orthopedic surgery: lower extremity tenotomies and osteotomies are two common procedures and there is an overall incidence of 20 % for scoliosis in these children [61]. These patients require heightened attention due to their associated comorbidities. Besides developmental delays, some patients have other neurological issues such as seizure disorders, deafness, visual loss, and hydrocephalus treated with VP shunts. Many have feeding difficulties with poor nutritional status requiring gastrostomy tubes, or gastroesophageal reflux and difficulty handling oral secretions with resulting pulmonary complications such as aspiration pneumonia. Respiratory disorders are a common cause of death [60]. Patients with CP are sensitive to narcotics and anesthetics, and have a higher risk for over-sedation and respiratory depression. They often have intact sensation, with postoperative spasms being common. They often present with surgical pain that is difficult to manage. Interestingly, most patients with CP tolerate benzodiazepines well and need doses in the high-normal range to have relief from postoperative spasms, especially if they were taking them preoperatively.

The medications used to treat these comorbidities also complicate these patients' care. Antiseizure medications and anti-spasticity drugs such as baclofen and diazepam are frequently used. Anticonvulsants need to be continued throughout the perioperative period especially for children with generalized seizures. Fortunately most of these drugs have long elimination half-lives (24–36 h) and if not given for 24 h the risk of significant seizure may not be significantly increased, provided the preoperative drug levels were within the recommended range.

Balcofen acts on the GABA receptors in the dorsal horn of the spinal cord to decrease spasms and pain. It can be given orally or via the intrathecal route with a pump usually inserted subcutaneously in the anterior abdominal wall. Baclofen and benzodiazepines can potentiate central nervous system depression, contributing to a slower emergence from general anesthesia. Regardless of their medications, patients with CP have been shown to have a lower minimum alveolar concentration (MAC) compared to normal controls [62].

Baclofen pumps present a contraindication to neuraxial anesthesia. These pumps are rarely discontinued for surgery and if the patient is undergoing spine surgery, a neurosurgeon should be involved. Disruption of intrathecal baclofen administration can have life-threatening consequences. There are case reports of severe morbidity from disruption of the pump resulting in acute overdose or withdrawal [63–65]. The diagnosis of pump malfunction might be difficult unless the symptoms are placed into context and the providers have complete knowledge of the patient's medical history. Acute overdose can manifest as hypotension, bradycardia or tachycardia, hypotonia, respiratory depression, somnolence, flaccid paralysis, and coma. Acute withdrawal can manifest as generalized seizures, malaise, dysphagia, hypertonia or rigidity, hyperthermia, hypertension, tachycardia, headaches, and hallucinations.

Treating hypothermia in the perioperative period can be a challenge in these patients due to hypothalamic dysfunction and lack of adipose tissue. Patients with CP should be treated in a latex-free environment; latex allergies are more common in this patient population, likely due to having had multiple exposures during procedures in hospital-settings.

Regional anesthesia is extremely beneficial for these patients. General anesthesia is usually required for airway control, but epidurals and peripheral nerve blocks should be considered in addition, barring any contraindication. It must be noted that with these children, postoperative narcotics should be administered with caution. Postoperative epidurals using a mix of bupivacaine (0.06–0.1 %) and clonidine (1 mcg/ml) or plain bupivacaine along with oral diazepam are the mainstay of treatment at our institution, along with peripheral nerve blocks when deemed beneficial. Neuraxial opioids are rarely used. Once again it is important to note that it can be difficult to interpret pain in these patients especially if they are nonverbal, and in these cases the caregiver's input is essential.

## Surgery for Scoliosis Correction

Surgery for scoliosis correction is one of the most common operations performed on healthy teenagers. Anesthetic implications unique to this procedure include spinal cord monitoring and positioning. In general, teenagers have higher anesthetic and narcotic requirements in the operating room than adults undergoing this procedure. Some children presenting for scoliosis correction have underlying medical syndromes that add complexity to the patient's care.

It is important to elicit a complete history, including the patient's exercise tolerance. Healthy teenagers are usually still able to exercise with mild restrictive pulmonary disease and may only have respiratory symptoms at full exertion.

Identifying the location of the spinal deformity, the age of onset, and the direction and severity of the curve will provide valuable information about the patient's pulmonary function and potential associated congenital anomalies. Most curves in adolescent idiopathic scoliosis are convex to the right. A left thoracic convexity should raise ones index of suspicion to look for other underlying conditions and congenital anomalies [16].

Knowing the type or etiology of the scoliosis is essential. In many teenagers the etiology of scoliosis is unknown, or idiopathic. However, neuromuscular scoliosis may occur as a result of diseases such as cerebral palsy and muscular dystrophy [16]. This type of scoliosis is associated with significantly increased intraoperative blood loss compared with idiopathic scoliosis. These patients are also at higher risk for perioperative neurological and respiratory complications [66].

The two monitoring techniques most commonly used to monitor spinal cord function are somatosensory evoked potentials (SSEPs) and motor evoked potentials (MEPs). The functional integrity of the somatosensory pathways in the posterior column of the spinal cord can be continually assessed by SSEPs. Normal intraoperative SSEPs are good predictors of normal postoperative sensory function [16]. MEPs assess the integrity of the spinal motor pathways in the anterior columns. It is important to monitor these signals for thoracic spine surgery. The routine use of MEPs intraoperatively has virtually replaced the "wake-up test" previously relied upon to assess spinal cord insult during surgery.

All anesthetic agents affect spinal monitoring to varying degrees, and most providers at our institution use a balanced anesthetic technique that is primarily narcotic-based without nitrous oxide. Total intravenous anesthesia (TIVA) is not routinely used unless the patient has risk factors for malignant hyperthermia (MH). Of all anesthetic agents, narcotics may be least likely to adversely affect the somatosensory evoked potentials (SSEPs). Cortical SSEPs and motor evoked potentials (MEPs) are very sensitive to nitrous oxide and potent inhalational agents. Ketamine enhances MEPs and is used almost routinely at our institution for spine cases. The neurologists frequently request an infusion of a nondepolarizing neuromuscular blocker to decrease the artifacts when monitoring SSEPs, but four out of four twitches using a monitor to assess the intensity of neuromuscular blockade are still maintained for MEPs. Hypothermia, anemia, hypoxia, and significant decreases in arterial pressure below levels of cerebral autoregulation may affect both SSEPs and MEPs and should be considered when evaluating changes in these signals.

As opposed to following a prescribed technique, it is more important to provide a safe, effective anesthetic that is unchanged throughout the operation. The stability of the anesthetic makes evaluating any changes in the signals less complex. A baseline set of SSEPs and MEPs should be performed by the neuromonitoring technician as early as possible so that changes to the anesthetic and/or monitoring technique can be made before the most critical part of the operation, spine distraction and instrumentation.

Patients with coexisting diseases such as CP and muscular or myotonic dystrophy introduce special challenges. Patients with CP can have significant comorbidities and those with VP shunts or intrathecal baclofen pumps may need neurosurgical involvement. Although rare, there have been case reports of life-threatening hydrocephalus following posterior spinal fusion in children [67]. The shunt can malfunction during correction of the spinal deformity via disconnection, fracture, kinking, or inadequate length. The disruption of an intrathecal baclofen pump can also have catastrophic effects if not recognized and treated immediately.

Patients with muscular and myotonic dystrophies should be carefully evaluated preoperatively for cardiomyopathy and pulmonary insufficiencies. Patients affected by the most severe forms of the disease may succumb to cardiopulmonary problems in late adolescence or early adulthood [68]. Of note, the severity of muscle weakness does not correlate with the severity of cardiac dysfunction. These patients are at risk for nonmalignant hyperthermia and may be predisposed to malignant hyperthermia; triggering agents should be avoided [69]. Aspiration precautions must be taken, and due to preexisting muscle weakness, muscle relaxants are usually not needed. Postoperative mechanical ventilation is almost always necessary. This group of patients is sensitive to virtually all anesthetic agents including narcotics and benzodiazepines. In summary, caring for this particular patient population during spine surgery is usually more challenging than for those with idiopathic scoliosis.

## Allergic Reactions

Anaphylaxis is a severe, life-threatening, systemic hypersensitivity reaction. This is characterized by rapidly developing life-threatening airway and circulation failure usually

associated with skin and mucosal changes. The incidence of perioperative anaphylaxis is similar in children and adults, but in children, latex is more often the causative agent [70]. Sensitization mainly occurs by wound or mucosal contact with latex devices during surgery or by inhalation of airborne allergens released from powdered latex gloves.

Higher-risk patients frequent the orthopedic operating room, including those with spina bifida and cerebral palsy. Other risk factors include individuals who had neonatal surgery or multiple operations in childhood, particularly urological, spinal or rectal. Atopic individuals and those with allergies to avocado, banana, chestnut, kiwi, papaya, peach, or nectarines are also in this group.

The initial cutaneous symptoms of anaphylaxis are not always seen under surgical drapes and the first signs in the operating room may be severe hypotension and bronchospasm. Adverse latex reactions during anesthesia usually occur between 30 and 60 min after exposure. Treatment in the acute phase consists of the removal of latex from the environment and administration of intravenous epinephrine. In the late phase, histamine-blockers and corticosteroids can be helpful. Allergy-testing should be performed at least 6 weeks after the event and should include all agents used in the operating room, as neuromuscular relaxants are also frequently responsible [71]. The best method of prevention is complete avoidance of latex. In centers where a latex-free environment has been adopted, a significant decrease in the incidence has been proven [72].

## Summary

In an orthopedic setting, children often present for surgery that is amenable to regional anesthesia. Performing these techniques in children is safe and the majority of practitioners place the blocks after the patient is asleep. The ultrasound machine has made the performance of peripheral nerve blocks easier, more effective, and safer in this age group. However, utilizing these blocks in children still requires the physician to possess a thorough understanding of the basic principles of pediatric anatomy and physiology, as they relate to regional anesthesia and local anesthetics.

Neuraxial anesthesia remains a widely used technique in the pediatric population, with low complication rates. Postdural puncture headache is the most common complication and can be difficult to diagnose and treat in a child. A postoperative epidural catheter is an important component of the postoperative analgesic regimen in an orthopedic setting.

When regional anesthesia is used for postoperative analgesia in children, the transition period from limb blockade to full sensation should be managed with early initiation of oral/intravenous acetaminophen, NSAIDs, and narcotics. If a perineural or epidural catheter is in place, this process may be easier to manage. Educating the caretakers about the recession of the block is essential.

Neurological injury from regional anesthesia is rare in adults and the risk is extremely difficult to quantify in children. Multi-institutional databases, such as the Pediatric Regional Anesthesia Network (PRAN), are contributing important information regarding the safety of regional anesthesia practice to the field of pediatric anesthesia.

Patients with cerebral palsy and other syndromes are often cared for in the orthopedic setting. Understanding the sequelae of these diseases is essential. Surgery for scoliosis correction is common in these patients and in healthy teenagers. The anesthetic technique for spine surgery is unique in that it must be tailored to the spinal cord monitoring.

**Summary Bullet Points**

- Pediatric patients undergoing orthopedic procedures have their own unique considerations compared to adults. Providers should understand these differences before caring for children in the operating room.
- The use of regional anesthesia in children, particularly ultrasound-guided, is beneficial and recommended. Evidence-based data regarding the use of regional anesthesia and its safety are being compiled on a more routine basis due to the creation of the Pediatric Regional Anesthesia Network (PRAN.)
- Congenital syndromes are common in pediatric orthopedic patients and providers should be familiar with their anesthetic implications.

## Case Study

A case study for this chapter is included in Appendix C at the end of this book.

## References

1. Slikker Jr W, Zou X, Hotchkiss CE, et al. Ketamine-induced neuronal cell death in the perinatal rhesus monkey. Toxicol Sci. 2007;98:145–58.
2. Briner A, Nikonenko I, De Roo M, Dayer A, Muller D, Vutskits L. Developmental stage-dependent persistent impact of propofol anesthesia on dendritic spines in the rat medial prefrontal cortex. Anesthesiology. 2011;115:282–93.
3. Jevtovic-Todorovic V. Anesthesia and the developing brain: are we getting closer to understanding the truth? Curr Opin Anaesthesiol. 2011;24:395–9.
4. Jevtovic-Todorovic V, Hartman RE, Izumi Y, et al. Early exposure to common anesthetic agents causes widespread neurodegeneration in the developing rat brain and persistent learning deficits. J Neurosci. 2003;23:876–82.

5. Young C, Jevtovic-Todorovic V, Qin YQ, et al. Potential of ketamine and midazolam, individually or in combination, to induce apoptotic neurodegeneration in the infant mouse brain. Br J Pharmacol. 2005;146:189–97.
6. DiMaggio C, Sun LS, Li G. Early childhood exposure to anesthesia and risk of developmental and behavioral disorders in a sibling birth cohort. Anesth Analg. 2011;113:1143–51.
7. Davidson AJ. Anesthesia and neurotoxicity to the developing brain: the clinical relevance. Paediatr Anaesth. 2011;21:716–21.
8. Bosenberg A. Benefits of regional anesthesia in children. Paediatr Anaesth. 2012;22:10–8.
9. Ecoffey C, Lacroix F, Giaufre E, Orliaguet G, Courreges P. Epidemiology and morbidity of regional anesthesia in children: a follow-up one-year prospective survey of the French-Language Society of Paediatric Anaesthesiologists (ADARPEF). Paediatr Anaesth. 2010;20:1061–9.
10. Giaufre E, Dalens B, Gombert A. Epidemiology and morbidity of regional anesthesia in children: a one-year prospective survey of the French-Language Society of Pediatric Anesthesiologists. Anesth Analg. 1996;83:904–12.
11. Rochette A, Dadure C, Raux O, Troncin R, Mailhee P, Capdevila X. A review of pediatric regional anesthesia practice during a 17-year period in a single institution. Paediatr Anaesth. 2007;17:874–80.
12. Dalens BJ. Pediatric regional anesthesia. Boca Raton, FL: CRC; 1990.
13. Marhofer P, Kapral S. Ultrasound-guided peripheral nerve blocks in children. In: Hadzic A, editor. Textbook of regional anesthesia and acute pain management. New York, NY: McGraw-Hill; 2007.
14. Suresh S, Ivani G, Tsui BCH, et al. Regional anesthesia in pediatric patients. In: Hadzic A, editor. Textbook of regional anesthesia and acute pain management. New York, NY: McGraw-Hill; 2007.
15. Koumbourlis AC. Scoliosis and the respiratory system. Paediatr Respir Rev. 2006;7:152–60.
16. DelPizzo K, Zayas VM. Scoliosis. In: Yao F, Fontes ML, Malhotra V, editors. Anesthesiology: problem-oriented patient management. Philadelphia, PA: Lippincott Williams & Wilkins; 2012. p. 1245–69.
17. Hardacker DM, Tolley JA. Postoperative neuraxial pain relief in the pediatric patient. Semin Pediatr Surg. 2004;13:203–9.
18. Wolf AR. Effects of regional analgesia on stress responses to pediatric surgery. Paediatr Aanesth. 2012;22:19–24.
19. Finkel JC, Boltz MG, Conran AM. Haemodynamic changes during high spinal anaesthesia in children having open heart surgery. Paediatr Aanesth. 2003;13:48–52.
20. Humphreys N, Bays SM, Parry AJ, Pawade A, Heyderman RS, Wolf AR. Spinal anesthesia with an indwelling catheter reduces the stress response in pediatric open heart surgery. Anesthesiology. 2005;103:1113–20.
21. Lee TW, Grocott HP, Schwinn D, Jacobsohn E. High spinal anesthesia for cardiac surgery: effects on beta-adrenergic receptor function, stress response, and hemodynamics. Anesthesiology. 2003;98:499–510.
22. Wolf AR, Doyle E, Thomas E. Modifying infant stress responses to major surgery: spinal vs extradural vs opioid analgesia. Paediatr Anaesth. 1998;8:305–11.
23. Llewellyn N, Moriarty A. The national pediatric epidural audit. Paediatr Anaesth. 2007;17:520–33.
24. Polaner DM, Bosenberg AT, Cravero J, Krane E, Martin L, Suresh S, Taenzer A. The members of the Pediatric Regional Anesthesia Network: preliminary data from the Pediatric Regional Anesthesia Network (PRAN)—demographics, practice patterns and complications (abstract). 2011
25. Flack S, Anderson C. Ultrasound guided lower extremity blocks. Paediatr Aanesth. 2012;22:72–80.
26. Tsui B, Suresh S. Ultrasound imaging for regional anesthesia in infants, children, and adolescents: a review of current literature and its application in the practice of extremity and trunk blocks. Anesthesiology. 2010;112:473–92.
27. Tsui BC, Suresh S. Ultrasound imaging for regional anesthesia in infants, children, and adolescents: a review of current literature and its application in the practice of neuraxial blocks. Anesthesiology. 2010;112:719–28.
28. Lonnqvist PA. Is ultrasound guidance mandatory when performing paediatric regional anaesthesia? Curr Opin Anaesthesiol. 2010;23:337–41.
29. Ecoffey C. Safety in pediatric regional anesthesia. Paediatr Aanesth. 2012;22:25–30.
30. Rubin K, Sullivan D, Sadhasivam S. Are peripheral and neuraxial blocks with ultrasound guidance more effective and safe in children? Paediatr Anaesth. 2009;19:92–6.
31. Dillane D, Tsui BCH. Is there still a place for the use of nerve stimulation? Paediatr Aanesth. 2012;22:102–8.
32. Patel D. Epidural analgesia for children. Cont Educ Anaesth Crit Care Pain. 2006;6:63–6.
33. Berde CB. Toxicity of local anesthetics in infants and children. J Pediatr. 1993;122:S14–20.
34. Kokki H. Spinal anaesthesia in infants and children. Baillières Clin Anaesth. 2000;14:687–707.
35. Borgeat A. Peripheral nerve block in patients with preexisting neurologic disease. Periodicum Biologorum. 2011;113:147–50.
36. Lirk P, Birmingham B, Hogan Q. Regional anesthesia in patients with preexisting neuropathy. Int Anesthesiol Clin. 2011; 49:144–65.
37. Bosenberg A, Larkin K. Syndromic vignettes in anaesthesia. Anaesthesia and Charcot-Marie-Tooth disease. South Afr J Anaesth Analg. 2006;12:131–3.
38. Dhir S, Balasubramanian S, Ross D. Ultrasound-guided peripheral regional blockade in patients with Charcot-Marie-Tooth disease: a review of three cases. Can J Anaesth. 2008;55:515–20.
39. Hebl JR, Horlocker TT, Schroeder DR. Neuraxial anesthesia and analgesia in patients with preexisting central nervous system disorders. Anesth Analg. 2006;103:223–8.
40. Walco GA, Dworkin RH, Krane EJ, LeBel AA, Treede RD. Neuropathic pain in children: special considerations. Mayo Clin Proc. 2010;85:S33–41.
41. Taenzer A, Bosenberg AT, Krane E, Martin L, Polaner DM, Suresh S. The investigators of the Pediatric Regional Anesthesia Network: asleep vs. sedated vs. awake—regional anesthetic complications by patient state at the time of blockade. A report from the Pediatric Regional Anesthesia Network (PRAN) (abstract). 2011
42. YaDeau JT, Liguori GA, Zayas VM. The incidence of transient neurologic symptoms after spinal anesthesia with mepivacaine. Anesth Analg. 2005;101:661–5.
43. Wee LH, Lam F, Cranston AJ. The incidence of post dural puncture headache in children. Anaesthesia. 1996;51:1164–6.
44. Oliver A. Dural punctures in children: what should we do? Paediatr Anaesth. 2002;12:473–7.
45. Kachko L, Platis CM, Livni G, Tarabikin E, Michowiz S, Katz J. Spinal anesthesia in infants with ventriculoperitoneal shunt: report of five cases and review of literature. Paediatr Anaesth. 2006;16: 578–83.
46. Kokki H. Spinal blocks. Paediatr Aanesth. 2012;22:56–64.
47. Littleford JA, Brockhurst NJ, Bernstein EP, Georgoussis SE. Obstetrical anesthesia for a parturient with a ventriculoperitoneal shunt and third ventriculostomy. Can J Anaesth. 1999;46:1057–63.
48. Tobias JD. Caudal epidural block: a review of test dosing and recognition of systemic injection in children. Anesth Analg. 2001;93:1156–61.
49. Mossetti V, Ivani G. Controversial issues in pediatric regional anesthesia. Paediatr Aanesth. 2012;22:109–14.
50. Berde CB. Convulsions associated with pediatric regional anesthesia. Anesth Analg. 1992;75:164–6.

51. Berde C. Regional anesthesia in children: what have we learned? Anesth Analg. 1996;83:897–900.
52. Hu D, Hu R, Berde CB. Neurologic evaluation of infant and adult rats before and after sciatic nerve blockade. Anesthesiology. 1997;86:957–65.
53. Ludot H, Tharin JY, Belouadah M, Mazoit JX, Malinovsky JM. Successful resuscitation after ropivacaine and lidocaine-induced ventricular arrhythmia following posterior lumbar plexus block in a child. Anesth Analg. 2008;106:1572–4.
54. Shah S, Gopalakrishnan S, Apuya J, Shah S, Martin T. Use of Intralipid in an infant with impending cardiovascular collapse due to local anesthetic toxicity. J Anesth. 2009;23:439–41.
55. Odding E, Roebroeck ME, Stam HJ. The epidemiology of cerebral palsy: incidence, impairments and risk factors. Disabil Rehabil. 2006;28:183–91.
56. Cerebral Palsy: facts & figures. 2012. Available at http://affnet.ucp.org/ucp_generaldoc.cfm/1/9/37/37-37/447. Accessed 28 Feb 2012
57. Albright AL. Intrathecal baclofen in cerebral palsy movement disorders. J Child Neurol. 1996;11 Suppl 1:S29–35.
58. Nolan J, Chalkiadis GA, Low J, Olesch CA, Brown TC. Anaesthesia and pain management in cerebral palsy. Anaesthesia. 2000;55:32–41.
59. McCarthy JJ, D'Andrea LP, Betz RR, Clements DH. Scoliosis in the child with cerebral palsy. J Am Acad Orthop Surg. 2006;14:367–75.
60. Frei FJ, Haemmerle MH, Brunner R, Kern C. Minimum alveolar concentration for halothane in children with cerebral palsy and severe mental retardation. Anaesthesia. 1997;52:1056–60.
61. Shirley KW, Kothare S, Piatt Jr JH, Adirim TA. Intrathecal baclofen overdose and withdrawal. Pediatr Emerg Care. 2006;22:258–61.
62. Specchio N, Carotenuto A, Trivisano M, Cappelletti S, Vigevano F, Fusco L. Prolonged episode of dystonia and dyskinesia resembling status epilepticus following acute intrathecal baclofen withdrawal. Epilepsy Behav. 2011;21:321–3.
63. Watve SV, Sivan M, Raza WA, Jamil FF. Management of acute overdose or withdrawal state in intrathecal baclofen therapy. Spinal Cord. 2011;50:107–11.
64. Mohamad F, Parent S, Pawelek J, et al. Perioperative complications after surgical correction in neuromuscular scoliosis. J Pediatr Orthop. 2007;27:392–7.
65. Abu-Sneineh K, Lipton GE, Gabos PG, Miller F. Dysfunction of a ventriculoperitoneal shunt after posterior spinal fusion in children with cerebral palsy: a report of two cases. J Bone Joint Surg Am. 2003;85-A:1119–24.
66. Hahn F, Hauser D, Espinosa N, Blumenthal S, Min K. Scoliosis correction with pedicle screws in Duchenne muscular dystrophy. Eur Spine J. 2008;17:255–61.
67. Bissonnette B. Syndromes: rapid recognition and perioperative implications. New York, NY: McGraw-Hill; 2006.
68. Murat I. Latex allergy: where are we? Paediatr Anaesth. 2000;10:577–9.
69. Karila C, Brunet-Langot D, Labbez F, et al. Anaphylaxis during anesthesia: results of a 12-year survey at a French pediatric center. Allergy. 2005;60:828–34.
70. De Queiroz M, Combet S, Berard J, et al. Latex allergy in children: modalities and prevention. Paediatr Aanesth. 2009;19:313–9.
71. Puncuh F, Lampugnani E, Kokki H. Use of spinal anaesthesia in paediatric patients: a single centre experience with 1132 cases. Paediatr Anaesth. 2004;14:564–7.
72. Kokki H, Turunen M, Heikkinen M, Reinikainen M, Laisalmi M. High success rate and low incidence of headache and neurological symptoms with two spinal needle designs in children. Acta Anaesthesiol Scand. 2005;49:1367–72.
73. Imbelloni LE, Vieira EM, Sperni F, Guizellini RH, Tolentino AP. Spinal anesthesia in children with isobaric local anesthetics: report on 307 patients under 13 years of age. Paediatr Anaesth. 2006;16:43–8.
74. Canale ST. Osteochondrosis or epiphysitis and other miscellaneous affections. In: Canale ST, editor. Campbell's operative orthopaedics. 10th ed. Philadelphia, PA: Elsevier; 2003.
75. Freeman III BL. Scoliosis and kyphosis. In: Canale ST, editor. Campbell's operative orthopaedics. 10th ed. Philadelphia, PA: Elsevier; 2003.
76. Warner Jr WC. Paralytic disorders. In: Canale ST, editor. Campbell's operative orthopaedics. 10th ed. Philadelphia, PA: Elsevier; 2003.
77. Warner Jr WC. Neuromuscular disorders. In: Canale ST, editor. Campbell's operative orthopaedics. 10th ed. Philadelphia, PA: Elsevier; 2003.

# Anesthetic Techniques and Their Clinical Application for Specific Orthopedic Procedures

7

Ottokar Stundner and Cephas P. Swamidoss

**Objectives**

- To introduce the rational for the choice of specific anesthetics and techniques.
- To discuss frequently encountered contraindications and complications of regional anesthesia.
- To describe techniques used to perform various regional anesthetics.
- To provide an overview of the use of anesthetics for specific orthopedic procedures.

**Key Points**

- Many different local anesthetics with various effect profiles are available for the practice of regional anesthesia, as well as a number of additives. Main considerations in choosing the appropriate agent are dosage/volume, speed of onset, duration, and side effects.
- Absolute or relative contraindications include infection, coagulation disorders and preexisting neurologic deficits. Among the potential hazards of regional anesthesia are local anesthetic systemic toxicity and neuropathy.
- Four methods to determine the right injection sites have been developed over time: anatomic landmarks, the paresthesia technique, electric nerve stimulation, and ultrasound guidance. The insertion of catheters allows for a prolonged period of regional anesthesia or analgesia.
- Numerous block techniques can be carried out to provide anesthesia to different body parts. For the upper extremity, several approaches to anesthetize the brachial plexus have been described, including interscalene, supraclavicular, infraclavicular, and axillary blocks. Apart from neuraxial anesthesia, lumbar plexus block, femoral nerve block, saphenous nerve block, popliteal nerve block, and ankle block are among the techniques available for the lower extremity.

## Introduction

The practice of anesthesia at the Hospital for Special Surgery is primarily one of regional anesthesia (RA) techniques. Regional anesthesia—whether neuraxial (spinal, epidural) or peripheral nerve blocks—can decrease the stress response to surgery and, as such, is considered beneficial in the perioperative period. Neuraxial anesthesia is associated with decreases in (early) mortality, deep vein thrombosis/pulmonary embolism, myocardial infarctions, respiratory morbidity, and postoperative confusion. Peripheral nerve blocks (PNB) are associated with improved rehabilitation and reduced length of hospital stay. The safe and successful practice of regional anesthesia relies on anesthetizing nerves without damaging their structure. Disruption of the nerve structure or the surrounding tissue architecture with the needle can cause undesirable neurological consequences. Anesthesiologists trained in regional anesthesia achieve this goal by relying on anatomical landmarks, the patient's feedback, and the use of nerve stimulators or ultrasonography to locate the targeted nerves. This chapter introduces the reader to the practice of regional anesthesia at a single

O. Stundner
Department of Anesthesiology, Perioperative Medicine, and Intensive Care Medicine, Paracelsus Medical University, Salzburg, Austria

C.P. Swamidoss (✉)
Department of Anesthesiology, Hospital for Special Surgery, Weill Cornell Medical College, 535 E70th Street, New York, NY 10021, USA
e-mail: swamidossc@hss.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_7, © Springer New York 2014

institution—it is neither meant to be all inclusive or to provide a detailed "cookbook" approach to regional anesthesia—rather it is meant to provide an overview of its use at the Hospital for Special Surgery. Specific attention will be paid to the presentation of various techniques used for a variety of orthopedic procedures while discussing: (1) the choice of local anesthetic, (2) contraindications for the use of regional anesthesia, (3) the complications and side effects associated with regional anesthetics, (4) the performance and indications for various peripheral nerve blocks and neuraxial techniques, and (5) the utilization of techniques in the setting of specific orthopedic surgeries as practiced at the Hospital for Special Surgery.

## Local Anesthetics

### Choice of Local Anesthetic

Medium-acting and long acting amide local anesthetics (LA) are most frequently used to achieve peripheral nerve blockade, whether for surgical anesthesia or for postoperative analgesia. The choice of LA is dependent upon a number of factors, including speed of onset, duration of surgery, toxicity profile, and patient comorbidities. In general, at our institution, medium acting LAs, such as mepivacaine, are used for cases of relatively short duration (<2 h) and long-acting LAs, such as bupivacaine, are used for cases of longer duration (>2 h). In the case of peripheral nerve blockade, the choice to use longer acting LAs depends on the desired prolonged length of postoperative analgesia. Please refer to Table 7.1 for a summary on characteristics of different local anesthetics in peripheral nerve blocks, epidural and spinal anesthesia.

### Drug Dosage

Depending on age and comorbidities, in general, a volume of 30–50 ml of a number of commercially available LAs can be used to anesthetize peripheral nerves close to the trunk in an average sized adult. The doses of different types of anesthetics are shown in Table 7.1 [1].

### Latency

The latency to block onset can be decreased by (1) carbonization of the local anesthetic, (2) alkalinization of the LA, and (3) warming of the LA. A fourth option to hasten block onset of shorter acting LA includes the use of higher volumes and has become common practice at the Hospital for Special Surgery, where anesthetic blocks are performed in the operating room with surgery following in short order, allowing limited time for block onset.

### Adjuvants

Different medications have been used as adjuvants to LA in peripheral nerve blocks with the goal to either enhance or prolong the effect of a block. Possible adjuvants include: epinephrine, dexamethasone, ketamine, neostigmine, opioids, and clonidine. In general, the practice at HSS includes the use of epinephrine, clonidine, or dexamethasone to increase the duration of peripheral nerve blocks.

## Contraindications for the Use of Regional Anesthesia

### Infection

Infection at the needle puncture site is an absolute contraindication to the use of any type of regional anesthetic [2]. Bacteremia or infection in the region to be blocked is not absolute, but rather relative contraindications to the use of regional anesthesia or peripheral nerve blocks—after weighing the overall risks and benefits of the use of either neuraxial or peripheral nerve block. Conservative practice dictates that in-dwelling catheters should be avoided in the setting of infection, unless the patient has begun a course of antibiotics. It should be noted that, in the case of neuraxial anesthesia without indwelling catheter, where infection without signs of systemic involvement is present, the risk of bacterial spread to the neuraxial space is probably low [3]. Indeed, in a series of almost 500 patients presenting for surgical treatment of an infected joint and in whom a neuraxial anesthetic was performed, no cases of meningitis or epidural abscess were encountered at our institution [4].

### Coagulation Disorders

Problems with coagulation, whether iatrogenic or pathologic, remain a relative contraindication to the use of regional anesthesia or peripheral nerve blockade. The American Society of Regional Anesthesia (ASRA) provides recommendations and practice guidelines on this topic [5]. This is especially important in the setting of newer anticoagulants which carry broad indications for use (atrial fibrillation, DVT, etc.). Details on regional anesthesia in the

**Table 7.1** Local anesthetics

| Agent | Nerve block | | | | Epidural anesthesia | | | | Spinal anesthesia | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lidocaine | 1–2 % | 30–50 | 10–20 | 120–240 | 1–2 % | 15–30 | 5–15 | 60–180 | 1.5–5 % | 1–2 | 1–4 | 30-90 |
| Mepivacaine | 1–1.5 % | 30–50 | 10–20 | 180–300 | 1–2 % | 15–30 | 5–15 | 60–180 | 4 % | 1–2 | 1–4 | 30–90 |
| Prilocaine | 1–2 % | 30–50 | 10–20 | 180–300 | 1–3 % | 15–30 | 5–15 | 60–180 | 1–2 % | 2–4 | 2–7 | 60–130 |
| Bupivacaine | 0.25–0.5 % | 30–50 | 20–30 | 360–720 | 0.25–0.5 % | 15–30 | 15–20 | 180–350 | 0.5–0.75 % | 2–4 | 3–9 | 90-200 |
| Levo-bupivacaine | 0.25–0.5 % | 30–50 | 20–30 | 360–720 | 0.25–0.75 % | 15–30 | 15–20 | 180–350 | 0.5–0.75 % | 2–4 | 3–9 | 90-200 |
| Ropivacaine | 0.2–0.5 % | 30–50 | 20–30 | 360–720 | 0.2–0.75 % | 15–30 | 15–20 | 180–350 | 0.5–0.75 % | 2–4 | 3–9 | 90-200 |

Data from: References [39–41]
*Subject to hypobaricity, isobaricity, or hyperbaricity

setting of anticoagulant are frequently updated and should be followed closely [6].

### Preexisting Neurological Deficits

Previous neurological disease or peripheral nerve injuries of either acute or chronic nature are not absolute contraindications to the use of regional anesthesia or peripheral nerve blockade. Some evidence suggests, however, that preexisting neurologic abnormalities may increase the risk of anesthesia related neuropathies after neuraxial anesthesia [7]. Therefore, given the obvious advantages of regional anesthesia, the risks and benefits should be carefully weighed and thorough documentation should be performed before an anesthetic is performed. In general, due to the conservative nature of the practice of regional anesthesia at HSS, we do not perform peripheral nerve blocks in the setting of preexisting neurological deficits.

## Complications and Side Effects Associated with Regional Anesthesia

### Local Anesthetic Systemic Toxicity

Local anesthetic systemic toxicity (LAST) is a relatively rare but a potentially life threatening complication of regional anesthesia. It can range from neurological symptoms to cardiovascular collapse. While the pathophysiology of LAST is not fully clear, there is evidence that some of its mechanisms relate to the drugs' sodium channel blocking activity. Local anesthetic agents readily bind to voltage-gated sodium channels and decrease transmembrane sodium flux, thus impairing depolarization and producing the desired anesthetic action when applied to peripheral nerves. Depending on concentration they also interact with a multitude of other ion channels, drug receptors and enzymes. In the central nervous and cardiac tissues, where the local anesthetic is redistributed to in a dose-dependent manner after adsorption, a number of unfavorable side effects can occur. In the brain, disruptions of inhibitory and excitatory circuits evoke either seizure activity or cerebral depression and coma. Cardiac toxicity comprises mainly impairment of contractility and generation of arrhythmias, for which different mechanisms are thought to play a role [8]. In general, LA agents have variable side effect profiles. Longer acting LAs like bupivacaine and ropivacaine are reportedly more prone to produce cardiac toxicity even at low doses; further, they rather affect conductance than myocyte contractility, resulting in sustained arrhythmias. On the contrary, shorter acting LAs like lidocaine and prilocaine have a higher central nervous system to cardiac toxicity ratio and in the latter organ predominantly affect cardiac contractility. The optimal treatment for LAST might therefore not only depend on the predominant site of toxicity but also on the type of LA involved [9]. According to the ASRA practice advisory, airway management and prevention of hypoxia and acidosis are among the most crucial first steps to treatment [10]. Both cardiac and central nervous system toxicity have been successfully treated with the use of Intralipid® (Fresenius Kabi AB, Uppsala, Sweden) [11]. It is the currently recommended treatment for all cases of LAST except minor central nervous system toxicity [12]. It is thought that Intralipid will extract lipophilic LA from the plasma, thus reducing concentrations and its effect on neurons and cardiac cells. Other treatment options include benzodiazepines to terminate seizures, positive inotropic support with epinephrine, which is believed to be particularly beneficial where LAs are causing myocardial depression, or, as a last resort, intermittent maintenance on cardiac bypass. At the Hospital for Special Surgery, Intralipid® (and an algorithm for its use) is easily accessible at all anesthetizing locations where regional anesthesia is performed.

### Neuropathy/Neurological Injury

Prevention and education are the keys to management of neurologic injury. Nerve injury from anesthetic sources is very rare and often multifactorial [13]. A careful and considered discussion of the risks and benefits relating to neurological injury and their incidence should involve every patient to be anesthetized [14]. There are often situations (i.e., professional athletes and dancers) in which even the

potential for risk of injury makes regional anesthesia an unacceptable choice.

## Regional Anesthesia Techniques

### Anatomical Landmarks

Anatomic landmarks were the original means of guiding the location of injections for regional anesthesia. They are still used with marked success in certain situations (placement of spinals and epidurals, axillary nerve blocks, etc.). Increasingly, they are an adjunct to newer technologies for identification of neural structures (i.e., femoral artery palpation to guide placement of ultrasound probe), especially in situations involving the teaching of residents and fellows.

### Paresthesia Techniques

Eliciting a paresthesia from probing of the needle is a time-tested technique—and hence the dictum "no paresthesia, no anesthesia." It is thought that the paresthesia develops when the tip of the needle comes in contact with the nerve. Theoretically, there is an increased risk of nerve damage (decreased margin of safety) when attempting to elicit paresthesias and, as a result, its use has somewhat fallen out of favor. Further, utilizing a paresthesia technique requires the patient's cooperation, which limits the level of sedation provided during block performance.

### Nerve Stimulator

The nerve stimulator works on the principles of electrostimulation. A nerve stimulator discharges an electrical current that is transmitted through tissue structures via a needle. When the needle tip approaches the nerve, the electrical current causes a twitch of the muscle that is innervated by a particular nerve, providing localizing information to the anesthesiologist. Using this technique, the anesthesiologist can target specific nerves and deliver a dose of local anesthetic to anesthetize the surgical site. Nerve stimulation has been used to locate nerves for many years and is currently the most commonly utilized technique [15]. However, there are drawbacks to this technique, one of which is the inability to directly visualize the path of the needle as it passes through tissue.

### Ultrasound-Guidance

Ultrasound guided techniques were historically used to either diagnose side effects or avoid vascular puncture. They have more recently become the technique of choice for identifying nerves and their surrounding anatomy [16]. Ultrasonography helps visualize the targeted nerves and the needle as it moves through tissues and associated vital structures. It can also help determine the adequacy of spread of the local anesthetics around the nerves. Ultrasound imaging relies on the ability of tissue to reflect sound waves. Sound waves are emitted from the ultrasound probe into the tissue over which it is applied. These sound waves then reflect back towards the probe as they cross different areas of the body. The probe receives the reflected waves and an image is created on the screen of the ultrasound machine. The angle and intensity of the reflected sound waves transmitted through tissues determines the clarity of the picture. When using this technique, the anesthesiologist can visualize, in real time, the structures that he/she is looking for, pass the needle toward the targeted nerves, and avoid vital structures that may be in the way and avoid for example vascular puncture [17]. This ensures success of the block by confirming an adequate spread of the local anesthetic solution around the nerve. However, it must be noted that no data are available to suggest that using ultrasound decreases the risk of neuropraxias [18].

### Catheter Techniques

Continuous nerve catheter techniques can be used for either intraoperative management (depending on surgical duration and postoperative pain plan) or postoperative pain management (severe postoperative pain, posttraumatic pain states, sympathetic blockade, amputation/stump pain, etc.). Different types of administration are available—intermittent bolus administration, continuous administration, or patient-controlled administration [19]. The method of choice for a given institution most often depends on organizational factors. Continuous peripheral catheters are frequently used at our institution for patients who cannot receive epidural analgesia when undergoing lower extremity arthroplasty. Further, patients with extensive foot reconstructions benefit from this approach, as the location of pain is difficult to control with neuraxial techniques.

## Upper Extremity Nerve Blocks

### The Brachial Plexus

There are four commonly used primary approaches to regional anesthesia of the brachial plexus: interscalene, supraclavicular, infraclavicular/coracoid, and axillary. Nerve stimulator and/or ultrasound approaches can be used for each of these blocks; however, at the Hospital for Special Surgery, ultrasound techniques are used primarily for interscalene, supraclavicular, and infraclavicular approaches, while nerve stimulator

techniques are most commonly reserved as adjuncts and for teaching purposes.

## Review of Anatomy

The brachial plexus is formed by the anterior rami of the C5–C8 and T1 spinal nerves. It contains a contribution from C4 in 60 % and from T2 in nearly 30 % of individuals. The roots of the spinal nerves exit from the spinal canal behind the vertebral artery and cross the transverse process of the corresponding vertebrae. They join to form three trunks and run together toward the first rib. The upper trunk arises from the union of the roots of C5/6, while the middle is comprised of the root of C7 and the lower of the roots of C8/T1. The trunks (which lie on top of each other) pass between the scalenus anterior and scalenus medius muscles in the interscalene groove. Just above the clavicle, the trunks divide into an anterior and posterior division. The three posterior divisions join to form the posterior cord, the anterior divisions of the upper and middle trunks form the lateral cord and the medial cord is the continuation of the anterior division of the lower trunk. The cords lie close together in the infraclavicular region, surrounding the subclavian artery [20].

## Interscalene Nerve Block

The interscalene nerve block (ISB) was first introduced by Winnie as a puncture site in the interscalene groove at the level of the cricoid cartilage and the sixth cervical vertebra, with the needle directed perpendicular to the skin [21]. It has been modified and revised multiple times since then. The block provides anesthesia and analgesia for both arthroscopic and open procedures of the shoulder and proximal upper arm. Its use can also be indicated for closed reduction of shoulder dislocations, physical therapy or as a diagnostic tool in the evaluation or therapy of certain chronic pain syndromes (e.g., complex regional pain syndrome (CRPS)). Interscalene nerve blocks are contraindicated in certain situations, including contralateral phrenic nerve paresis, contralateral recurrent laryngeal nerve paresis, and severe chronic pulmonary obstructive disease. The reason for this is a high rate of temporary paralysis of the phrenic and/or recurrent nerve on the side of the block, thus exposing the patient to respiratory failure and upper airway obstruction [22–24]. Interscalene nerve blocks can also be associated with a number of complications, including vertebral artery injection (resulting in immediate seizure), local anesthetic toxicity, direct intrathecal or epidural injection (with subsequent high or total epidural or spinal), and even permanent quadriplegia [25]. Interscalene nerve blockade is achieved by injecting 15–40 ml of LA solution into the interscalene groove at the level of a line drawn laterally from the transverse process of C6 (the external jugular vein often overlies the intersection site). The site of injection can be localized via paresthesia, nerve stimulator, and/or ultrasound technique. If a paresthesia approach is used, sensory signs should be elicited before injection of LA solutions. The site can be superficial in many people. One should aim for a paresthesia of the hand or forearm, although a paresthesia of the shoulder—which does not necessarily reflect direct stimulation of the brachial plexus—may be sufficient for anesthesia needed for shoulder surgery. If a nerve stimulator technique is used, the brachial plexus in the interscalene groove should ideally contract the biceps (flexion at the elbow) before local anesthesia is deposited. If the brachial plexus is localized by using an ultrasound technique, one is classically looking for the "stop light" configuration of the C4, C5, and C6 nerve roots. Deposition of local anesthesia around these roots will achieve the desired surgical anesthesia. Smaller amounts (5 ml) of local anesthesia deposited around each nerve root have been found equally efficacious in achieving surgical anesthesia [26]. Regardless of the technique used, when the interscalene block is achieved, a catheter may be placed for those situations in which a prolonged block of the brachial plexus is desired (i.e., reanastomosis of digits). The interscalene block of the brachial plexus can be performed with the arm at the patient's side, and the risk of pneumothorax is remote. However, a pneumothorax should be considered if cough or chest pain is produced while exploring for the location of the brachial plexus. Phrenic nerve and/or recurrent laryngeal nerve block with associated ipsilateral hemiparesis of the diaphragm and laryngeal musculature are common side effects of the interscalene approach to the brachial plexus, but remain clinically irrelevant in the majority of cases [27]. Accidental epidural anesthesia and spinal anesthesia are also possible using this approach, and if local anesthesia is accidentally injected into the vertebral artery, convulsions are likely to follow. At HSS, the interscalene nerve block is used in conjunction with sedation for most arthroscopic and open procedures of the shoulder.

## Supraclavicular Nerve Block

The Supraclavicular Nerve Block (SNB) is used to provide anesthesia for surgery on the shoulder, arm, and even forearm. It is approached by paresthesia, nerve stimulator, or ultrasound techniques. This block's popularity has increased with the recent introduction of ultrasound. Classically, a SNB is achieved by injecting 15–40 ml of LA at a point just behind the midpoint of the clavicle where the nerves cross the first rib. The midpoint of the clavicle can be

confirmed by palpating the subclavian artery in thin individuals or by extending an imaginary straight line from the end of the external jugular vein. Paresthesias of the forearm or hand should be elicited before the injection of LA. Pneumothorax is the most common complication of SNB (about 1 % incidence) [28], initially manifesting as cough, dyspnea, and pleuritic chest pain. Block of the phrenic nerve occurs frequently but generally does not cause clinically significant symptoms. Advantages of SNB are rapid onset and ability to perform the block with the arm in any position. Historically, the high risk of pneumothorax limited the use of SNB. The use of ultrasound has theoretically reduced the incidence of pneumothorax by allowing visualization of the supraclavicular artery and nerve, and just as importantly, visualization of the first rib, clavicle, and apex of the lung [29]. This permits localization of the nerves while avoiding needle puncture of the lung. Ultrasound approaches either use hydrodissection (advancement of the needle while injecting) of the classic "cluster of grapes" lying next to the artery or deposition of all local anesthesia at a "12 o'clock" position above and adjacent to the neural structures [30]. Nerve stimulation can be used as an adjunct to ultrasonography to confirm needle position by eliciting an appropriate contraction of the muscles supplied by the brachial plexus. SNB is used for most closed procedures of the shoulder in conjunction with sedation.

### Infraclavicular Nerve (Coracoid) Block

Coracoid blocks are often used to provide anesthesia for surgery involving the arm, elbow, wrist, and hand. The introduction of ultrasonography has made blocking of the brachial plexus in this location relatively risk free in comparison to earlier approaches [31]. Using the ultrasound probe, the subclavian artery is visualized medially to the coracoid process and 5–7 ml of LA is deposited next to the medial, lateral and posterior cords of the brachial plexus, which lie circumferential to the artery. Alternatively, a single injection of 20–30 ml LA posterior to the artery may be equally effective [32]. Appropriate visualization of surrounding tissues and control to where the needle is directed are keys to the success of this block.

### Axillary Nerve Block

Use of the axillary nerve block for upper extremity surgery has decreased at the Hospital for Special Surgery concomitant with the increased use of ultrasound-guided infraclavicular nerve blocks. Both nerve blocks remain useful for operations involving the hand, wrist, forearm, and/or elbow; however, the newer ultrasonographic technology allows direct visualization of the nerve structures while avoiding the theoretical complications associated with the axillary nerve block. There remain two primary techniques—the perivascular "single-injection" technique and the transarterial technique [33]. The axillary block of the brachial plexus is achieved by injecting 25–40 ml of LA in the axillary sheath of the axilla. The nerves are anesthetized around the axillary artery. The primary "problem" with the axillary block is that significant anatomic variation exists. Individual septa may surround different nerves, necessitating multiple injections when compared to single injection approaches. In order to perform the block, the upper extremity is abducted to 90° and externally rotated, the axillary artery is palpated and traced back toward the axilla and the needle is inserted just anterior to the vessel. Entrance of the needle into the axillary sheath transmits a "popping" sensation to the anesthesiologist's fingers, and the needle transmits the pulsation of the artery. Paresthesias are useful but not mandatory for confirming correct placement of the needle. Digital pressure applied distal to the needle during and after injection should promote proximal flow of LA solutions, within the sheath towards the side, where the musculocutaneous nerve exits. Alternatively, one can transfix the axillary artery (aspirating on both sides of the artery before placement of local anesthesia) with the needle and deposit 10–15 ml of local anesthesia on either side of the vessel, theoretically within the confines of the axillary sheath.

Typically, a small cuff of LA is deposited in the subcutaneous tissues over the proximal medial aspect of the axilla during withdrawal of the needle to block the intercostobrachial nerve. The musculocutaneous nerve is sometimes not blocked because it leaves the sheath proximal to the point of injection. This nerve is important because it provides sensory innervations from the radial side of the forearm to the thenar eminence. It should be blocked as it emerges from between the elbow crease with 5–10 ml of LA. The axillary approach carries the lowest risk of pneumothorax, making it useful for outpatients undergoing surgery on the forearm and hand.

## Lower Extremity Nerve Blocks

### The Lumbosacral Plexus

The lumbosacral plexus (lumbar, sacral, and pudendal plexus) is formed by a set of conjoining nerve roots that arise from the lower lumbar and sacral spinal nerves (T12–S5), passing communicating branches between each other. Together, they account for the sensory and motor support of the lower extremity.

Unlike in the upper extremity, it is not easily possible to provide anesthesia to the entirety of the lower extremity via one single injection or block. Combinations of various peripheral nerve blocks with or with neuraxial anesthesia are therefore frequently utilized.

## Review of Anatomy

After assembling lateral to the intervertebral foramina, the lumbar plexus proceeds downwards in the psoas compartment between the psoas major and quatratus lumborum muscles. Aside from short, direct muscular branches, five major nerves branch off: the iliohypogastric, ilioinguinal, genitofemoral, lateral femoral cutaneous, obturator and femoral nerves. While the former three pierce the abdominal wall or psoas muscle, the latter exit the pelvis through the obturator foramen (obturator nerve) and the muscular lacuna underneath the inguinal ligament (femoral nerve), respectively. The lumbar plexus provides innervations to the anterior portions of the hip joint, groin, most regions of the anterior and medial thigh as well as parts of the knee joint and medial lower leg.

The adjacent sacral plexus innervates posterior and lower portions of the leg through nerves and direct branches. Two branches are most relevant for blockade, the posterior cutaneous femoral and sciatic (containing common fibular and tibial) nerves, which leave the pelvis together through the greater sciatic foramen.

## Lumbar Plexus Block

Different ways to anesthetize parts of the lumbar plexus have been described, including the psoas compartment and perivascular (3-in-1) blocks. For the psoas compartment block, a nerve stimulator needle is inserted 3 cm inferior and 5 cm lateral to the fourth lumbar spine, which is commonly located at the height of an imaginary line between the iliac crests. After contact with the fifth lumbar transverse process, the needle should be advanced in cephalad direction, sliding off the transverse process, until a quadriceps motor response can be seen. Complications of this technique include risk of intravascular, epidural, or subarachnoid injection and nerve damage [34]. The 3-in-1 block, in contrast, is based on the assumption that a large volume of local anesthetic injected into the femoral perineural sheath will migrate in lateral and cephalad directions, towards the lumbar plexus or at least towards its terminal branches femoral, obturator and lateral femoral cutaneous nerve, providing anesthesia to three peripheral nerves with only one injection (hence, 3-in-1 block). The reliability of this block is subject to controversy [35].

However, the nerves of the lumbar plexus do not fully cover the posterior hip, so neither of these blocks will provide full anesthesia for hip surgery; rather, they are often used in conjunction with either a spinal or epidural approach. A lumbar plexus block is sometimes performed at the Hospital for Special Surgery to help alleviate hip pain. It can be used alone or in combination with epidural anesthesia for postoperative pain control in patients after hip replacement surgery, open reduction and fixation of the femur, and closed reduction of the hip joint.

## Femoral Nerve Block

At the Hospital for Special Surgery, the femoral block is used as an effective tool against pain after knee surgery. Patients undergoing total knee replacement or anterior cruciate ligament reconstruction benefit from femoral nerve blocks [36]. The femoral nerve is blocked by the injection of 20–30 ml of LA immediately laterally to the femoral artery, just below the midpoint of the inguinal ligament. A line drawn from the anterior superior iliac spine to the symphysis pubis will approximate the ligament. The block itself can be performed by using anatomic landmarks with either nerve stimulator or ultrasonography. With a nerve stimulator, electrical stimulation resulting in contraction of the quadriceps in the prepatellar groove at 0.5 mA is considered sufficient to block the femoral nerve. As with other nerve blocks, the concentration of LA determines the clinical effect. A lower concentration is associated with analgesia of the surgical site while a higher concentration is associated with both surgical anesthesia and motor blockade in the femoral distribution.

## Saphenous Nerve Block

At the Hospital for Special Surgery, a saphenous nerve block is often used for pain control after surgery of the knee and medial foot. The saphenous nerve is a sensory branch of the femoral nerve, responsible for sensation from the inner aspect of the knee to the inner aspect of the lower leg and foot. As a purely sensory nerve, its blockade is not associated with motor blockade. As such, it is often used in the outpatient setting when early rehabilitation/motor control of the knee (i.e., knee ligamentoplasty) is requested. The Saphenous nerve can be localized in the subsartorial region with the ultrasound probe 7–10 cm above the medial epicondyle of the femur. It is located between the vastus medialis and the gracilis muscles, on the inner aspect of the thigh [37]. Ten to fifteen milliliters of LA is deposited in this space to achieve blockade.

### Popliteal Nerve Block

Sciatic nerve blocks in the popliteal fossa are used at the Hospital for Special Surgery to help alleviate pain after foot and ankle surgery, whether reconstructive or arthroscopic. Occasionally, they are used as the primary surgical anesthetic. Patients who have a popliteal block will usually have analgesia to approximately 85 % of surface area of the foot. Because the sciatic nerve does not supply sensation to the entire foot, this block is often used in combination with a saphenous nerve block for postoperative pain control. The popliteal nerve is blocked in the popliteal fossa, an anatomical site that is bordered laterally by the biceps femoris muscle and medially by the semimembranosus muscle. This is also where the sciatic nerve splits into its two major components, the tibial and common peroneal nerves. Needle entry for the popliteal nerve block should be proximal to the splitting of these two nerves to avoid a partial block. With a nerve stimulator, electrical stimulation resulting in dorsiflexion of the foot at 0.5 mA is considered sufficient to block the popliteal nerve. When this is achieved, 30–40 ml of LA is injected—a large volume is required to ensure adequate anesthesia of both branches of the sciatic nerve. As with other nerve blocks, the concentration of LA determines the clinical effect. A lower concentration is associated primarily with analgesia of the surgical site while a higher concentration is associated with both surgical anesthesia and motor blockade in the popliteal distribution.

### Ankle Block

The ankle block is often used at the Hospital for Special Surgery to either provide surgical anesthesia and/or postoperative analgesia for surgeries of the forefoot. It is a combination of multiple injections around the foot and ankle area. All five nerves of the foot can be blocked at the level of a line connecting the medial and lateral malleoli. The posterior tibial nerve is the major contributor of sensation to the sole of the foot. To block this nerve, the needle is introduced just behind the posterior tibial artery and advanced until a paresthesia to the sole of the foot is elicited or bone is encountered, at which point the needle is slightly withdrawn and 5 ml of LA is injected. The sural nerve is blocked by injecting 5 ml of LA between the lateral malleolus and calcaneus. Infiltration of 5 ml of LA anterior to the medial malleolus blocks the saphenous nerve. The deep peroneal nerve is the major nerve to the dorsum of the foot and is blocked by injecting 5 ml of local anesthesia just lateral to the anterior tibial artery. Superficial branches of the peroneal nerve are blocked by a subcutaneous ridge of local anesthesia injected between the anterior tibial artery and lateral malleolus.

### Neuraxial Anesthesia

Spinals, epidurals, and continuous spinal epidurals (CSE) are the mainstay of anesthesia for surgery of the lower limb at the Hospital for Special Surgery. Their techniques are well described elsewhere. As with peripheral nerve blocks, the choice of LA depends upon many factors, including availability, practitioner comfort, duration of surgery, positioning, and patient comorbidities. At our institution, epidurals facilitate the practice of controlled hypotension and are sometimes used to ensure patient comfort in settings where the use of a tourniquet is required. As a generalization, combined spinal/epidural techniques allow for continuous infusions of opioids and LAs for postoperative pain in the postoperative period.

## Regional Anesthesia for Specific Procedures

As mentioned previously, regional anesthesia is used for most procedures performed at the Hospital for Special Surgery except spine surgical interventions, which require general anesthetics and are not discussed here.

Following is a brief description of the anesthetic techniques routinely used for various procedures commonly performed. Variations of the techniques described will depend on details of the surgery and patient comorbidities. A summary of anesthetic techniques used by procedure type is presented in Table 7.2.

### Anesthetic Techniques: Upper Extremity

#### Total Shoulder Arthroplasty

As regional techniques, interscalene or supraclavicular nerve blocks are possible approaches for total shoulder arthroplasty, both for surgical anesthesia and postoperative pain control. Additionally, deep sedation or general anesthesia and airway management by laryngeal mask should be considered, given that the patient position and proximity of the surgical intervention to the airway can be very discomforting. An arterial line attached to a continuous blood pressure monitoring device is commonly utilized to duly detect and counteract blood pressure variations, which commonly appear in the sitting (beach chair) position.

#### Shoulder Arthroscopy

Similar to total shoulder arthroplasty, an interscalene or supraclavicular block in conjunction with sedation is used for diagnostic or interventional shoulder arthroscopy, providing adequate surgical anesthesia and postoperative analgesia to the shoulder region. Longer procedures or those requiring relaxation of the shoulder musculature,

**Table 7.2** Anesthetic techniques for common procedures carried out at HSS

| *Total knee arthroplasty* | *Total hip arthroplasty* |
|---|---|
| • Femoral nerve block<br>• Combined spinal and epidural<br>• Arterial blood pressure monitoring (if ASA $\geq$ 3) | • Combined spinal and epidural<br>• Controlled hypotension<br>• $\pm$ Lumbar plexus block<br>• Arterial blood pressure monitoring<br>• $\pm$ Central line |
| *Total shoulder arthroplasty* | *Foot and ankle surgery* |
| • Interscalene/supraclavicular block<br>• $\pm$ General with laryngeal mask<br>• Arterial blood pressure monitoring | • Spinal<br>• Popliteal block $\pm$ catheter |
| *Knee arthroscopies* | *Shoulder arthroscopies* |
| • Spinal or general with laryngeal mask<br>• Sedation | • Interscalene block<br>• Sedation |
| *Hand and forearm surgery* | |
| • Infraclavicular block<br>• Sedation | |

including shoulder stabilizations, may require the addition of a general anesthetic.

### Elbow, Forearm and Hand Surgery

Depending on the exact location of surgical intervention, a supraclavicular, infraclavicular, or axillary block can be taken into consideration. At HSS, the supraclavicular block is predominantly used for proximal, and an infraclavicular block for distal procedures, while the axillary block decreases in importance.

## Anesthetic Techniques: Lower Extremity

### Total Hip Arthroplasty

For total hip arthroplasty, combined spinal and epidural anesthesia has proven beneficial. On the one hand, given the complex nerve supply to the hip joint, surrounding tissue and muscles, neuraxial anesthesia provides advantages compared to peripheral nerve blocks in practicality and ease of use. On the other hand, controlled hypotensive epidural anesthesia can reduce bleeding. Further, a lumbar plexus block can contribute to excellent postoperative analgesia, especially in cases where anticoagulation requires removal of the epidural catheter shortly after the procedure. Arterial blood pressure monitoring is obligatory with the use of controlled hypotension and with regard to invasiveness of the surgery and potential blood loss.

### Total Knee Arthroplasty

The knee joint is supplied by both the femoral and sciatic nerves. Pain often extends to the thigh, for instance when a tourniquet is used to reduce bleeding. Complete surgical anesthesia and postoperative pain control is most easily achieved by combination of neuraxial anesthesia (spinal and epidural) and peripheral (femoral or saphenous) nerve block. Catheters make prolonged postoperative application of local anesthetic possible. Arterial blood pressure monitoring is applied in patients classified as American Society of Anesthesiologists Class 3 or above.

### Knee Arthroscopy

Outpatient knee arthroscopy can, as a minor painful procedure, will most frequently be managed by spinal anesthesia alone at the Hospital for special Surgery. Advantages are fast recovery and low incidence of complications. However, depending on patient preference or comorbidity profile, general anesthetics with a laryngeal mask airway may be used.

### Foot and Ankle Surgery

Nerve supply to the lower leg, ankle and foot is provided by the saphenous nerve (medial side), the sciatic nerve and its branches, respectively. Blockade of one or more of these nerves is sufficient for complete surgical anesthesia, as long as no thigh tourniquet is applied. Depending on the location of the surgery, a popliteal block, an ankle block or a saphenous block is chosen. For more extensive procedures a spinal or combined spinal and epidural is added.

## Summary

Orthopedic surgery is undoubtedly one of the specialties where regional anesthesia is used most frequently and most successfully. Not only does the practice of selectively anesthetizing specific regions of the body mitigate the systemic stress associated with surgery, it also allows for more focused and sustained postoperative analgesia. Especially the elderly and people suffering from comorbidities like cardiovascular or respiratory disease benefit most. Furthermore, many studies demonstrated reductions in demand for analgesics and other systemically administered drugs,

exerting a positive influence on perioperative wellbeing and diminishing associated side effects like nausea, vomiting, or constipation [38]. However, in order to achieve optimal acuity, duration and minimal side effects, it is essential for the anesthesiologist to gain knowledge about a number of influencing factors: selection of appropriate block technique; choice of the right local anesthetic agent, concentration and dosage; locating injection sites by use of anatomical landmarks, paresthesia technique, ultrasound, or a combination of these methods; determining block success and, if in doubt, resorting to another method of regional or even general anesthesia; ensuring sustained analgesia; and, last but not least, awareness of side effects associated with injection and/or drugs. The most cumbersome immediate complication of regional anesthesia is LAST. LAST can rapidly lead to catastrophic situations, only manageable by means of the full-scale application of intensive care services. The mainstay of treatment is Intralipid, and its availability is mandatory in areas where regional anesthesia is administered. Moreover, although infrequently occurring, permanent nerve damage is a matter of concern and potentially disqualifies some patients from receiving regional anesthesia.

Comprehensive unilateral anesthesia to the whole limb can more easily be achieved in the upper extremity. Possible approaches include the interscalene, supraclavicular, infraclavicular, and axillary plexus block, and should be chosen according to type of surgery and desired distribution of anesthesia. In the lower limb, several techniques are available for the lumbosacral plexus as well as for peripheral nerves. However, a multimodal approach combining one or more of these peripheral blocks with neuraxial anesthesia is applied frequently.

In conclusion, regional techniques are cornerstones of orthopedic anesthesia; their development and advancement establish new possibilities and make orthopedic surgery available to more patients. While widely used at the Hospital for Special Surgery, variations of these approaches have to be tailored to individual patient comorbidities, preferences, anatomic variations as well as to surgical cofactors like patient positioning.

**Summary Bullet Points**

- Regional anesthesia provides focused and sustained pain relief for patients undergoing orthopedic surgery.
- Choice of specific anesthetics and techniques is the key to successful regional anesthesia.
- Complications and contraindications must be kept in mind in order to minimize potential harm.

## Case Study

A case study for this chapter is included in Appendix D at the end of this book.

## References


1. Rosenberg PH, Veering BT, Urmey WF. Maximum recommended doses of local anesthetics: a multifactorial concept. Reg Anesth Pain Med. 2004;29:564–75. discussion 524.
2. Wedel DJ, Horlocker TT. Regional anesthesia in the febrile or infected patient. Reg Anesth Pain Med. 2006;31:324–33.
3. Hebl JR, Niesen AD. Infectious complications of regional anesthesia. Curr Opin Anaesthesiol. 2011;24:573–80.
4. Gritsenko K, Marcello D, Liguori GA, Jules-Elysee K, Memtsoudis SG. Meningitis or epidural abscesses after neuraxial block for removal of infected hip or knee prostheses. Br J Anaesth. 2011; 108:485–90.
5. Horlocker TT, Wedel DJ, Rowlingson JC, Enneking FK, Kopp SL, Benzon HT, Brown DL, Heit JA, Mulroy MF, Rosenquist RW, Tryba M, Yuan CS. Regional anesthesia in the patient receiving antithrombotic or thrombolytic therapy: American society of regional anesthesia and pain medicine evidence-based guidelines (third edition). Reg Anesth Pain Med. 2010;35:64–101.
6. Horlocker TT. Regional anaesthesia in the patient receiving antithrombotic and antiplatelet therapy. Br J Anaesth. 2011;107 Suppl 1:96–106.
7. Hebl JR, Horlocker TT, Kopp SL, Schroeder DR. Neuraxial blockade in patients with preexisting spinal stenosis, lumbar disk disease, or prior spine surgery: efficacy and neurologic complications. Anesth Analg. 2010;111:1511–9.
8. Wolfe JW, Butterworth JF. Local anesthetic systemic toxicity: update on mechanisms and treatment. Curr Opin Anaesthesiol. 2011;24:561–6.
9. Weinberg GL. Treatment of local anesthetic systemic toxicity (LAST). Reg Anesth Pain Med. 2010;35:188–93.
10. Neal JM, Bernards CM, Butterworth 4th JF, Di Gregorio G, Drasner K, Hejtmanek MR, Mulroy MF, Rosenquist RW, Weinberg GL. ASRA practice advisory on local anesthetic systemic toxicity. Reg Anesth Pain Med. 2010;35:152–61.
11. Corman SL, Skledar SJ. Use of lipid emulsion to reverse local anesthetic-induced toxicity. Ann Pharmacother. 2007;41:1873–7.
12. Picard J, Ward SC, Zumpe R, Meek T, Barlow J, Harrop-Griffiths W. Guidelines and the adoption of 'lipid rescue' therapy for local anaesthetic toxicity. Anaesthesia. 2009;64:122–5.
13. Jacob AK, Mantilla CB, Sviggum HP, Schroeder DR, Pagnano MW, Hebl JR. Perioperative nerve injury after total hip arthroplasty: regional anesthesia risk during a 20-year cohort study. Anesthesiology. 2011;115:1172–8.
14. Brull R, McCartney CJ, Chan VW, El-Beheiry H. Neurological complications after regional anesthesia: contemporary estimates of risk. Anesth Analg. 2007;104:965–74.
15. Urmey WF. Using the nerve stimulator for peripheral or plexus nerve blocks. Minerva Anestesiol. 2006;72:467–71.
16. Antonakakis JG, Ting PH, Sites B. Ultrasound-guided regional anesthesia for peripheral nerve blocks: an evidence-based outcome review. Anesthesiol Clin. 2011;29:179–91.
17. Bigeleisen P, Wilson M. A comparison of two techniques for ultrasound guided infraclavicular block. Br J Anaesth. 2006;96:502–7.

18. Barrington MJ, Snyder GL. Neurologic complications of regional anesthesia. Curr Opin Anaesthesiol. 2011;24:554–60.
19. Ilfeld BM. Continuous peripheral nerve blocks: a review of the published evidence. Anesth Analg. 2011;113:904–25.
20. Partridge BL, Katz J, Benirschke K. Functional anatomy of the brachial plexus sheath: implications for anesthesia. Anesthesiology. 1987;66:743–7.
21. Winnie AP. Interscalene brachial plexus block. Anesth Analg. 1970;49:455–66.
22. Urmey WF, Gloeggler PJ. Pulmonary function changes during interscalene brachial plexus block: effects of decreasing local anesthetic injection volume. Reg Anesth. 1993;18:244–9.
23. Plit ML, Chhajed PN, Macdonald P, Cole IE, Harrison GA. Bilateral vocal cord palsy following interscalene brachial plexus nerve block. Anaesth Intensive Care. 2002;30:499–501.
24. Sinha SK, Abrams JH, Barnett JT, Muller JG, Lahiri B, Bernstein BA, Weller RS. Decreasing the local anesthetic volume from 20 to 10 ml for ultrasound-guided interscalene block at the cricoid level does not reduce the incidence of hemidiaphragmatic paresis. Reg Anesth Pain Med. 2011;36:17–20.
25. Benumof JL. Permanent loss of cervical spinal cord function associated with interscalene block performed under general anesthesia. Anesthesiology. 2000;93:1541–4.
26. Gautier P, Vandepitte C, Ramquet C, DeCoopman M, Xu D, Hadzic A. The minimum effective anesthetic volume of 0.75 % ropivacaine in ultrasound-guided interscalene brachial plexus block. Anesth Analg. 2011;113:951–5.
27. Liu SS, Gordon MA, Shaw PM, Wilfred S, Shetty T, Yadeau JT. A prospective clinical registry of ultrasound-guided regional anesthesia for ambulatory shoulder surgery. Anesth Analg. 2010; 111: 617–23.
28. Guzeldemir ME. Pneumothorax and supraclavicular block. Anesth Analg. 1993;76:685.
29. Perlas A, Lobo G, Lo N, Brull R, Chan VW, Karkhanis R. Ultrasound-guided supraclavicular block: outcome of 510 consecutive cases. Reg Anesth Pain Med. 2009;34:171–6.
30. Chan VW, Perlas A, Rawson R, Odukoya O. Ultrasound-guided supraclavicular brachial plexus block. Anesth Analg. 2003; 97: 1514–7.
31. Chin KJ, Singh M, Velayutham V, Chee V. Infraclavicular brachial plexus block for regional anaesthesia of the lower arm. Anesth Analg. 2010;111:1072.
32. Fredrickson MJ, Wolstencroft P, Kejriwal R, Yoon A, Boland MR, Chinchanwala S. Single versus triple injection ultrasound-guided infraclavicular block: confirmation of the effectiveness of the single injection technique. Anesth Analg. 2010; 111: 1325–7.
33. Chin KJ, Handoll HH. Single, double or multiple-injection techniques for axillary brachial plexus block for hand, wrist or forearm surgery in adults. Cochrane Database Syst Rev. 2011;7: CD003842.
34. De Tran QH, Clemente A, Finlayson RJ. A review of approaches and techniques for lower extremity nerve blocks. Can J Anaesth. 2007;54:922–34.
35. Atanassoff PG, Weiss BM, Brull SJ, Horst A, Kulling D, Stein R, Theiler I. Electromyographic comparison of obturator nerve block to three-in-one block. Anesth Analg. 1995;81:529–33.
36. Paul JE, Arya A, Hurlburt L, Cheng J, Thabane L, Tidy A, Murthy Y. Femoral nerve block improves analgesia outcomes after total knee arthroplasty: a meta-analysis of randomized controlled trials. Anesthesiology. 2010;113:1144–62.
37. Saranteas T, Anagnostis G, Paraskeuopoulos T, Koulalis D, Kokkalis Z, Nakou M, Anagnostopoulou S, Kostopanagiotou G. Anatomy and clinical implications of the ultrasound-guided subsartorial saphenous nerve block. Reg Anesth Pain Med. 2011; 36:399–402.
38. Richman JM, Liu SS, Courpas G, Wong R, Rowlingson AJ, McGready J, Cohen SR, Wu CL. Does continuous peripheral nerve block provide superior pain control to opioids? A meta-analysis. Anesth Analg. 2006;102:248–57.
39. Heavner JE. Local anesthetics. Curr Opin Anaesthesiol. 2007; 20: 336–42.
40. Berde C, Strichartz G. Local anesthetics. In: Miller R, editor. Miller's anesthesia. 7th ed. Philadelphia, PA: Churchill Livingstone; 2009. p. 913–39.
41. Forster JG, Rosenberg PH. Revival of old local anesthetics for spinal anesthesia in ambulatory surgery. Curr Opin Anaesthesiol. 2011;24:633–7.

# The Role of the Post-anesthesia Care Unit in the Perioperative Care of the Orthopedic Patient

8

Michael K. Urban

**Objectives**

- To provide an overview of the goals of postoperative care and discuss commonly encountered challenges in the care of postoperative orthopedic patients
- To discuss common perioperative complications and the care of specific patient populations as approached at the Hospital for Special Surgery
- To introduce the concept of the model of postoperative care unique to the Hospital for Special Surgery

**Key Points**

- The traditional role of the post-anesthesia care unit (PACU) is to provide a safe transition from the highly monitored operating environment to the routine management on the patient ward.
- The goals of such transition include observation and monitoring of the resolution of anesthesia, resuscitation of blood loss and its consequences, and adequate pain management.
- Common complications after orthopedic surgery affect the cardiopulmonary and other organ systems requiring that perioperative physicians are familiar with diagnosis and treatment of these entities.
- At the Hospital for Special Surgery the recovery room also functions as a step-down unit (SDU) providing care and observation for specific patient populations such as those with obstructive sleep apnea, those at high risk for postoperative myocardial infarction, and those undergoing more invasive procedures such as simultaneous bilateral knee arthroplasties.
- In the role as an intensive care unit the recovery room at the Hospital for Special Surgery cares for unstable patients, including those with respiratory failure.

## Introduction

The orthopedic patient can be particularly challenging with regard to postoperative care. This patient group is diverse and may present for surgery with a broad variety of problems. The spectrum includes the geriatric patient with multiple comorbidities scheduled for total joint arthroplasty to the young deceptively healthy trauma patient who may have multiple associated injuries. Thus, it becomes clear that a host of different factors may significantly impact on an individual's postoperative course.

Despite general concerns associated with any postoperative patient, our greatest challenges continue to be related to the care of the elderly with significant medical comorbidities who seek surgical resolution for their chronic musculoskeletal problems, most commonly osteoarthritis. Currently 12.6 % of the US population is over 65 years old and at least 16 million of these individuals suffer from "advanced arthritis." According to the Department of Health and Human Services, the number of the US citizens over 65 is expected to increase to 71.5 million by the year 2030. Hence, it is virtually certain that an increasing number of older patients with multiple comorbidities will be presenting for orthopedic procedures.

Traditionally, the role of the PACU is to provide monitored care for the patient recovering from an anesthetic after surgery. It further represents the bridge between single

M.K. Urban (✉)
Department of Anesthesiology, Hospital for Special Surgery, 535 E70th Street, New York, NY 10021, USA
e-mail: mkpa@aol.com

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_8, © Springer New York 2014

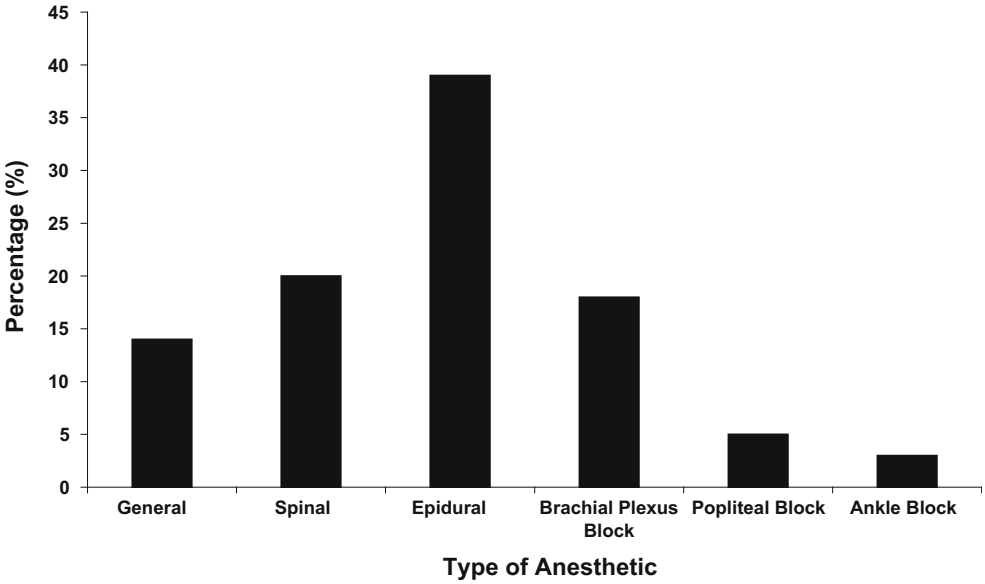


**Fig. 8.1** Distribution of types of anesthetics performed at the Hospital for Special Surgery

practitioner monitoring in the operative theater environment and periodic observational monitoring in a hospital room.

The PACU at the Hospital for Special Surgery, however, serves multiple purposes with an expanded scope compared to more traditional recovery rooms. Although its primary functions focus on the recovery of patients after surgery and anesthesia, patients are admitted postoperatively for overnight observation for potential surgical or comorbidity-related complications. Further functions include those traditionally provided by a SDU for patients who require additional monitoring of vital signs and an intensive care unit (ICU) for high-acuity and unstable patients with complications. The latter functions apply to complicated patients both directly admitted from the operating room and those transferred from patient wards within the hospital.

The goal of this chapter is not to provide in-depth discussion of components of routine postoperative care, such as monitoring the recovery from anesthesia, maintaining cardiopulmonary and hemodynamic stability, and controlling pain, but instead to focus on a brief overview of the most common problems and complications encountered in the care of specific orthopedic patient populations. Further, a specific objective of this chapter is to discuss the previous points in the context of current practice at the Hospital for Special Surgery.

## Recovery from Anesthesia and Fluid/Blood Management

The role of the PACU is to provide patients with a safe transition of care from the operating room to the patient ward. During this transition, many acute effects of surgery and anesthesia, including traumatic and drug-related factors affecting the patient physiology, need to be addressed. Since many PACUs care for patients after a variety of surgical procedures which often require general anesthesia, airway problems constitute a large number of complications and hence respiratory management is often the focus of attention. In an Australian database of 419 recovery room incidents, 43 % were related to airway and respiratory complications [1]. At the Hospital for Special Surgery, where the majority of the patients receive a regional anesthetic (Fig. 8.1), the incidence of PACU incidents related to the airway is much lower. Despite the avoidance of airway instrumentation during surgery, oxygenation and ventilation remain among the most important concerns of the PACU staff when dealing with postoperative patients, as drug effects and patient-related factors such as sleep apnea and obesity are prevalent factors affecting the respiratory system.

Since patients for lower extremity surgery will usually have been anesthetized with neuraxial anesthesia, these patients require PACU observation until both the hemodynamic and neural blockade effects have resolved. Total hip arthroplasty is often performed under controlled hypotensive anesthesia via a neuraxial block which is dosed through the epidural catheter with the goal to achieve sympathectomy. In these patients the mean arterial blood pressure may decrease significantly with either no change or a slight decrease in heart rate [2]. With this technique, blood pressure and heart rate are controlled and stabilized using epinephrine infusions in the operating room, while in the PACU these patients are at risk for continued episodes of hypotension until the neuraxial block resolves. In the PACU, blood pressure is supported with ephedrine, intravenous fluids, and when applicable blood transfusions. Crystalloid infusions are limited because of the notion that once systemic vascular resistance is normalized and volume returns to the central circulation, elderly patients, especially those with

preexisting cardiac problems, may be at risk for postoperative congestive heart failure.

The majority of the arthroplasty patients at the Hospital for Special Surgery donate blood prior to surgery. Most patients pre-donate blood in order to avoid the risk of transfusion-associated infections associated with homologous blood products. However, in the United States the risk of infection with HCV or HIV is about 1–1.5 million per transfused unit [3] while the risk of non-infectious complications from blood transfusions (i.e., clerical errors, TRALI) is much higher [4]. As the majority of these transfusions take place in the PACU, staff is aware of this fact and transfusions both autologous and homologous are used as conservatively as possible. Our customary practice is to withhold homologous blood transfusion in asymptomatic adult patients with hemoglobin levels below 8 g/dl per the results of the TRICC and FOCUS trials [5, 6].

## Pain Management

The PACU is where postoperative pain is initially addressed and treated. The goal is to establish an analgesic plan which will treat pain effectively, ameliorate the postoperative stress response, facilitate postoperative rehabilitation, and minimize side effects, with the ultimate goal to improve outcome and decrease hospital stay. At the Hospital for Special Surgery, virtually all in-patients are followed by the acute pain service and the majority of the lower extremity arthroplasty recipients are managed with patient-controlled epidural analgesia (PCEA). An important element of this postoperative pain protocol is the institution of PCEA before the level of pain experienced by the patient becomes difficult to control. Thus, it is usually initiated before complete resolution of the operative neuraxial blockade. Attention is paid, however, to frequent evaluation of the resolution of the motor blockade in order to detect rare neuraxial complications. In addition, the theoretical preemptive analgesic benefits of regional analgesia may be eliminated if postoperative pain modalities are instituted late, i.e., after the patient experiences considerable pain. Recently, the Hospital for Special Surgery implemented an electronic ordering system, which permits the treating anesthesiologist to order the patient's pain medications electronically while in the operating room and thus have it available when the patient arrives in the PACU. Following this change a study revealed that PCEA was initiated significantly earlier in the electronic ordering group (25 ± 28 min) compared with those in the paper order-based order/conventional group (51 ± 26 min). The mean pain score measured by the visual analogue scale (VAS) throughout the time spent in the PACU was significantly higher for the conventional when compared to the electronic group. One-third of the patients in the conventional group had a VAS pain score in the PACU of 6 or greater, whereas only one-fifth of the patients in the electronic group had pain score of equivalent magnitude.

Postoperative pain management is challenging in patients with preoperative narcotic dependency after spinal fusion surgery. The persistent nociceptive and neuropathic pain which these patients experience as well as perioperative opioid-induced hyperalgesia may in part be mediated through *N*-methyl-D-aspartate (NMDA) receptors. Ketamine is a noncompetitive NMDA receptor antagonist, which has been used in the treatment of chronic pain syndromes and at subanesthetic doses in the management of acute pain [7, 8]. At the Hospital for Special Surgery we have shown that a perioperative infusion of subanesthetic ketamine is effective at reducing pain in narcotic tolerant patients after posterior spinal fusions [9]. In our experience, ketamine may reverse unacceptable levels of pain in patients resistant to conventional narcotic treatment. In order to provide adequate monitoring for over-sedation on a ketamine infusion who also receives a PCA with hydromorphone, patients typically spend the night following surgery in the PACU. Chronic pain patients who were treated with ketamine perioperatively continue to have improved analgesia during physical therapy compared to the non-ketamine-treated patients on subsequent days following surgery [9].

## Common Complications and Patient Populations

### Cardiac Complications

As previously discussed, our PACU serves not only as a recovery room but also as an ICU or an SDU. When studying the distribution of indications for admission of patients to the PACU overnight, we found that the majority of patients was monitored for postoperative cardiac complications and were entered into a rule-out-myocardial infarction (ROMI) protocol. This relatively high level of monitoring for this event is based on the fact that the mortality associated with myocardial infarction after hip and knee arthroplasty surgery ranges from 0.4 to 4.6 %, with revision procedures carrying the highest risk [10, 11]. Furthermore, cardiac complications were most often associated with perioperative mortality. For example in the POISE trial of prophylactic perioperative *β*-blocker therapy in patients undergoing non-cardiac surgery ($n = 8{,}351$), the incidence of a nonfatal myocardial infarction was 4.4 % and cardiovascular death 1.6 % [12]. In orthopedic surgery, the incidence of a perioperative myocardial infarction, defined by elevated troponin I levels, was 0.6 % of all non-ambulatory procedures ($n \sim 8{,}000$) and

6.5 % of those patients at risk for myocardial ischemia in one report [13]. In their review of 1,636 consecutive hip and knee arthroplasties, Parvizi et al. reported a 6.4 % incidence of serious postoperative complications, the majority of which were cardiac [11]. Hence, given the increasing rates and feasibility of surgery in the elderly, and the current prevalence of perioperative cardiovascular morbidity and mortality, it should be anticipated that postoperative cardiac complications will remain a common problem going forward. Given these data, we continue to monitor a significant percentage of the at-risk population for postoperative cardiac complications in the PACU for more than 12 h. Using more stringent monitoring practices as compared to those proposed by the 2009 AHA/ACCF guidelines, we monitor serum troponins (cTnI) on arrival and 12 h postoperatively [14]. In addition, ECGs are performed on arrival and the morning of postoperative day one. The rational for this approach is based on the assumption that the initial cTnI should reflect events during surgery and the following cTnI presumably reflects the stressful events during the initial recovery. The diagnosis of postoperative myocardial ischemia is important in the orthopedic population since these events are often associated with further cardiac morbidity if not treated appropriately. Furthermore, the decision to initiate postoperative physical therapy, which is important for a favorable outcome not only in orthopedic patients, may depend on the correct diagnosis of postoperative myocardial ischemia.

As mentioned previously, our approach to monitoring for perioperative cardiac ischemic events is more extensive than that supported by ACCF/AHA guidelines and a recent analysis of institutional data was launched to evaluate the feasibility of our practice. Using our electronic ordering system, we were able to capture all patients with cardiac risk factors [15] who underwent major non-ambulatory orthopedic procedures and were evaluated for a postoperative myocardial infarction using cTnI analysis over a 1-year period. Preoperative cardiac risk factors and postoperative complications were tracked using a Web-based medical information management system. During this period 10,627 non-ambulatory orthopedic procedures were performed and 807 patients with cardiac risk factors were assessed for postoperative myocardial infarction; 104 of the 807 patients (12.9 %) had postoperatively detectable cTnI levels [16]. The incidence of myocardial ischemia, defined as positive cTnI levels, was similar for both hip (10 %) and knee arthroplasty (11.3 %) patients but was significantly higher for posterior spinal fusions (17 %).

Since 8 % of our surgical population remain in the PACU for >12 h for a rule-out postoperative myocardial infarction protocol (ROMI) while only 1 % demonstrate detectable cTnI leaks, the question remains if this practice represents a suboptimal use of health care resources. While we are currently reevaluating this broad approach, two key findings should be considered: (1) patients with coronary stents in addition to another cardiac risk factor had significantly higher cTnI levels (Fig. 8.2), and (2) those patients with higher cTnI levels were more likely to suffer cardiac complications. These findings would support a more stringent approach that would only require patients with perioperative cardiac events, inducible ischemia, and/or coronary artery stents to be kept in the PACU for a ROMI.

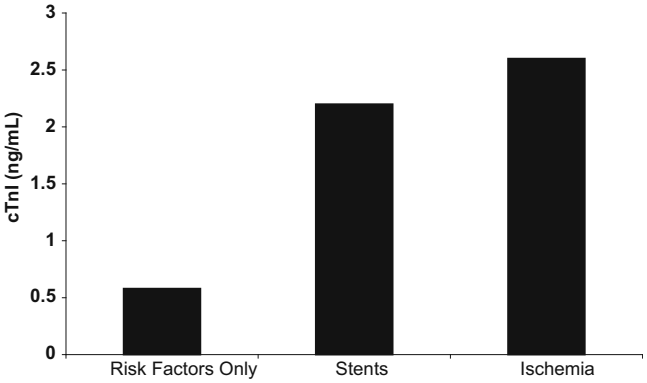


**Fig. 8.2** Troponin levels in orthopedic patients at risk for myocardial ischemia

Another question which should be considered when evaluating our approach is that our ROMI surveillance period for the day of surgery does not correlate with published reports that suggest that most postoperative myocardial infarctions are identified after postoperative day 1 [17]. In addition, it has been suggested that the increased myocardial oxygen demand associated with surgery, pain, and sympathetic stimulation precedes troponin elevations by 18 h [17], thus further questioning the window of surveillance. Finally, the question needs to be raised whether a 12.9 % postoperative myocardial infarction incidence among all orthopedic surgical patients with cardiac risks is higher than expected. Part of the answers will have to come from the interpretation of the significance of various cTnI levels. The majority of patients studied at our institution had low cTnI level releases (approximately 90 % of patients had cTnI levels below 1 ng/ml), and these were not related to major cardiac complications. Only two of the patients had documented postoperative myocardial infarctions on the basis of an ECG and new echocardiographic changes. Seventeen of the 807 ROMI patients with an elevated cTnI level were transferred to a cardiac critical care unit for congestive heart failure or hemodynamic instability. Using previously discussed criteria to define a postoperative myocardial infarction, this would put the incidence to 0.2 % (2/807) or 2.1 % of all (17/807) orthopedic surgical patients with cardiac risk factors. These low event rates may possibly be related to our aggressive treatment of pain,

judicious use of fluids, and interventions, particularly beta-blockade, invasive monitoring, and maintenance of hemodynamic stability [18].

## Respiratory Complications

Since most patients in a PACU will have received a variety of intraoperative medications and interventions which potentially compromise the respiratory system, related problems constitute some of the most commonly encountered postoperative complications. At an orthopedic institution where the majority of the patients receive a regional anesthetic with minimal to moderate sedation, the incidence of PACU complications related to the airway and respiratory system is much lower. However, given the high prevalence of obesity and obstructive sleep apnea among patients undergoing arthroplasty and spine surgeries, respiratory concerns and complications remain a primary concern. Furthermore, in patients with rheumatological diseases (i.e., rheumatoid arthritis, ankylosing spondylitis) both airway management and issues regarding oxygenation/ventilation secondary to restrictive lung disease can be particularly challenging. Elderly patients undergoing hip procedures are affected more commonly by hypoxic events compared to patients undergoing non-orthopedic procedures [19]. This hypoxia may reflect embolization of bone marrow debris into the pulmonary system. In some of these patients preexisting pulmonary arterial hypertension will be exacerbated by the embolization of cement and bone marrow debris during hip and knee arthroplasty. Thus, our practice dictates that this patient population requires at least 12–24 h of monitoring in the PACU.

Fat embolization is a well-known complication of skeletal trauma and surgery involving instrumentation of the femoral canal [20]. Patients undergoing bilateral hip and knee arthroplasty as well as revision hip arthroplasty are at increased risk for fat embolism syndrome (FES) [21]. The clinical manifestations of FES include respiratory derangements, ranging from mild hypoxemia to adult respiratory distress syndrome; cardiac abnormalities, including tachycardia and arrhythmias to heart failure; neurologic changes, including somnolence and confusion to coma; and hematologic abnormalities with thrombocytopenia and disseminated intravascular coagulopathy [22]. The signs and symptoms of FES and their incidence are described by Schonfeld and are discussed elsewhere in this book [23]. Since the management of FES is supportive and based on early intervention to minimize the deleterious effects of the systemic inflammatory response to the initial insult, patients at increased risk are monitored in our PACU.

## Renal Complications

In an analysis of 1,636 patients undergoing lower extremity joint arthroplasty, acute renal failure (ARF) constituted one of the major postoperative life-threatening complications [24]. Using the RIFLE system to classify patients into ARF severity categories, many orthopedic patients fall into the group at risk for ARF [25]. Risk factors include advanced age, elevated body mass index, preoperatively elevated creatinine, and significant perioperative blood loss. The operative procedures which are most likely to result in ARF include bilateral knee arthroplasty, revision knee and hip arthroplasty, and posterior spine fusions. These procedures not only involve significant blood loss but may also induce FES and/or an inflammatory response which produces capillary leakage and decreased intravascular circulating volume. Hence, in the majority of cases oliguria/anuria is the result of hypoperfusion of the kidney secondary to a relative hypovolemia. Perioperatively, it is important to restore appropriate intravascular volume through the infusion of crystalloid, colloid, and when required blood products to prevent the development of acute renal dysfunction.

## Obstructive Sleep Apnea

After the patient group with cardiac disease, the next largest category of patients who are monitored in the PACU for an extended period at the Hospital for Special Surgery are those with obstructive sleep apnea (OSA). OSA is a chronic condition resulting in partial or complete obstruction of the airway during sleep with potential adverse cardiovascular complications. The prevalence of OSA in the adult middle aged to elderly population may approach 10 %. These patients may be at risk for adverse postoperative cardiorespiratory complications, including death. However, there is insufficient evidence-based data in the literature to provide guidelines with regard to the postoperative management of patients with diagnosed OSA. In a retrospective analysis of patients undergoing total hip or total knee arthroplasties, OSA was associated with increased incidence of postoperative transfer to an ICU [26]. The use of the STOP-BANG questionnaire for OSA has been advocated by some as a means of identifying those patients at risk for postoperative complications [27]. Hence, at this institution, the majority of patients with diagnosed or suspected OSA undergoing all inpatient procedures and some outpatient procedures are monitored overnight in the PACU. Patients who use continuous positive airway pressure at home are asked to bring their masks to the hospital, thus facilitating continuation of care during their stay.

## Patients After Bilateral Joint Arthroplasty and Revision Arthroplasty

Patients undergoing bilateral lower extremity or revision arthroplasty are observed for 24 h in our PACU, based on the fact that these operations are associated with increased blood loss, longer surgical duration, and an increase in the perioperative inflammatory response. Single-stage bilateral lower extremity arthroplasty, particularly that involving the knee joints (SBTKA), has been reported to be associated with increased morbidity and mortality [28]. The major postoperative complications after SBTKA include myocardial infarction, fat embolization, respiratory insufficiency, and thromboembolic events. As these complications may be the result of multiple comorbidities, increased blood loss and fluid shifts, pain, and cardiopulmonary stress compared to unilateral joint arthroplasty, careful patient selection and increased postoperative vigilance seem prudent in an attempt to improve outcomes. At our institution all SBTKA recipients are screened by an anesthesiologist preoperatively with the goal to restrict these higher risk procedures to patients without significant comorbidities [29]. With this approach, when consecutive SBTKA and unilateral patients were matched for age and cardiac disease, and were assessed for postoperative complications, only fat embolism-like symptoms were significantly more prevalent in SBTKA patients (Table 8.1).

**Table 8.1** Comparison of postoperative complications in matched unilateral total knee arthroplasty (UTKA) and single-stage bilateral total knee arthroplasty (SBTKA) patients

| | UTKA (*n*) | SBTKA (*n*) |
|---|---|---|
| Postoperative myocardial infarction | 2 | 2 |
| Congestive heart failure | 0 | 1 |
| Renal failure | 1 | 1 |
| Transfer to intensive care unit | 2 | 2 |
| Pulmonary embolism | 0 | 0 |
| Hypoxemia | 0 | 7[a] |
| Confusion | 2 | 6[a] |
| New-onset atrial fibrillation | 3 | 12[a] |

[a]Fat embolism syndrome

## Postoperative Delirium

Another significant patient population requiring extended monitoring and interventions is that suffering from postoperative delirium. Delirium is a common complication in the geriatric population following orthopedic surgery, with a reported incidence of up to 50 %, with the highest occurring after the repair of femoral neck fractures [30]. Postoperative delirium commonly presents 24 h after surgery and resolves within 48 h. However, in 6 % of patients evidence of confusion may persist for up to 6 months. Postoperative delirium is associated with longer hospital stay, more complications, poor recovery, increased mortality, and increased health care costs [31]. The diagnosis can be challenging as postoperative delirium can present in various forms. A fluctuating hyperactive state is often associated with agitation, sweating, and tachycardia, but a hypoactive type may present with passive confusion. Since in most cases patients present with a change in mental status without a clear etiology, they are often subjected to an extensive neurological evaluation including brain scans. A more measured approach includes a neurological examination to rule out focal deficits. Further, blood laboratory analysis may be performed to eliminate electrolyte abnormalities, hypercarbia, and hypoxemia. A review of all medications to eliminate unnecessary centrally acting medications is mandatory. And finally, care should be taken to assure adequate pain management. Once the diagnosis of postoperative delirium has been established, the managing physician is faced with the problem of treatment options. If removal of the delirium-inciting agents (i.e., narcotics, benzodiazepines) does not improve the confusion and/or the patient's hyperactive state, pharmacological treatment has traditionally constituted in the use of neuroleptic medications such as haloperidol. At our institution, however, we have had significant success with low-dose (<0.5 μg/kg/h) infusions of dexmedetomidine for 6–8 h. This approach is used primarily in hyperactive patients and produces mild-to-moderate sedation, control of agitation, and associated hypertension and tachycardia while allowing the patient to rest without significant depression of the respiratory system.

## Readmission to the PACU

Since our PACU functions as the hospital ICU, we provide care for patients whose medical condition deteriorates during the remainder of their hospitalization. When studying all patients undergoing major orthopedic surgery over a 1-year period ($n = 12{,}229$) at our institution, 1.7 % ($n = 206$) were readmitted to the PACU within 6 days of discharge. This represented 1.6 % of all total hip arthroplasties, 1.8 % of all total knee arthroplasties, and 3.4 % of all spinal fusion surgeries (3.4 %) [32]. Patients readmitted to the PACU after surgery had multiple comorbidities, including cardiac (40.3 %), diabetes mellitus (18.4 %), chronic renal insufficiency (14.1 %), and pulmonary disease (12.6 %). About 9 % of the returning patients had ≥3 comorbidities. Of the patients with a final diagnosis of myocardial ischemia, 80 % had at least one cardiac risk factor [15]. Patients requiring PACU readmission were also significantly older and had a longer length of hospital stay.

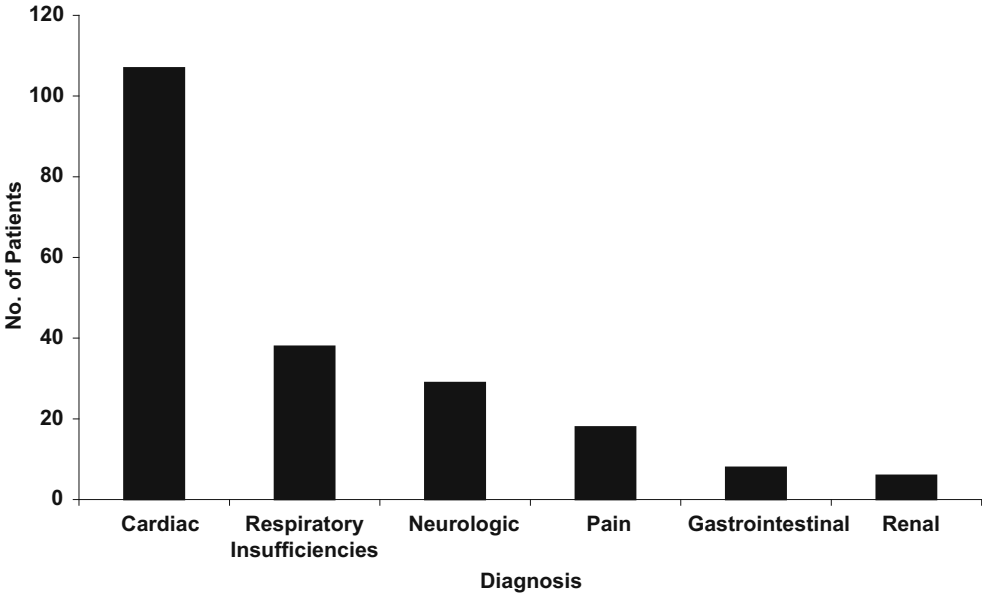


**Fig. 8.3** Return to monitored setting ($n = 206$)

Cardiac complications were the major reason for readmission to the PACU (51 %), followed by respiratory insufficiency (18 %) and neurological complications (14 %). Cardiac problems included chest pain, arrhythmias (mostly supraventricular tachycardia), and congestive heart failure (Fig. 8.3). Patients with respiratory insufficiency were hypoxic as measured by pulse oximetry. In most cases, the admitting diagnosis was similar to the final diagnosis. However, some of the patients who were admitted with a respiratory diagnosis were ultimately determined to have cardiogenic causes for their findings, such as cardiac ischemia with congestive heart failure. Delirium was the most common diagnosis among the neurologic symptomatology category and was often a "catch-basket" for other postoperative problems: hypoxemia, intractable pain, and ischemia. About 25 % (50/206) of the returning patients had elevated cTnI levels, giving them a final diagnosis of myocardial ischemia.

The diagnosis of congestive heart failure was more common in returning patients after total knee arthroplasties and spine fusions compared to hip arthroplasty recipients. The cause for this finding may be that the former patient group loses considerably more blood than hip arthroplasty patients, hence requiring more fluid and blood transfusions, thus increasing their risk for congestive heart failure. Since there is increased pressure to reduce the length of the hospital stay after major orthopedic procedure, it is important to identify which patients are at risk for acute postoperative complications and develop interventions which may reduce poor outcome.

## Summary

The PACU at the Hospital for Special Surgery functions as a recovery room, SDU, and ICU. Much of our emphasis is devoted to the recovery of patients from regional anesthesia and the institution of adequate postoperative analgesia. Common problems encountered in the orthopedic patient population often stem from blood loss and fluid resuscitation. Complications are infrequent but are often related to respiratory or cardiac events. In contrast to a traditional PACU our recovery room functions as an SDU, which devotes resources to the observation and management of patients after more invasive procedures such as bilateral lower extremity arthroplasty, or patients with specific medical problems such as OSA and postoperative delirium and those at high risk for postoperative myocardial infarction. Our critical care is focused on complications prevalent among patients undergoing orthopedic surgery. Patients frequently found in this category are those patients requiring mechanical ventilation due to pulmonary insufficiency and those suffering large blood loss. Further, patient categories are those with severe complications related to FES and those presenting with cardiopulmonary resuscitative emergencies. However, since many of our arthroplasty patients are geriatric, we also provide monitored care for the common medical complications associated with this age group. This careful attention to the postoperative issues of our specific patient population is paramount in keeping perioperative complications to a minimum.

**Summary Bullet Points**

- In order to optimize patient outcomes the postoperative care of orthopedic patients should focus on observation of organ function, monitoring of the resolution of anesthesia, resuscitation of blood loss and its consequences, and adequate pain management.
- Physicians caring for orthopedic patients need to be familiar with common perioperative complications in order to address them expediently.
- The model of postoperative care at HSS which allows for the adjustment of recovery room resources to care for problems encountered at various stages of the hospitalization has proven to be efficient and successful.

## Case Study

A case study for this chapter is included in Appendix E at the end of this book.

## References


1. Kluger MT, Bullock MF. Recovery room incidents: a review of 419 reports from the anaesthetic incident monitoring study (AIMS). Anaesthesia. 2002;57:1060–6.
2. Sharrock NE, Mineo R, Urquhart B. Haemodynamic effects and outcome analysis of hypotensive extradural anaesthesia in controlled hypertensive patients undergoing total hip arthroplasty. Br J Anaesth. 1991;67:17–25.
3. Kitchen AD, Barbara JAJ. Current information on the infectious risks of allogeneic blood transfusion. TATM. 2008;10:102–11.
4. Kumar A. Perioperative management of anemia: limits of blood transfusion and alternatives to it. Cleve Clin J Med. 2009;76 Suppl 4:S112–8.
5. Carson JL, Terrin ML, Noveck H, Sanders DW, Chaitman BR, Rhoads GG, Nemo G, Dragert K, Beaupre L, Hildebrand K, Macaulay W, Lewis C, Cook DR, Dobbin G, Zakriya KJ, Apple FS, Horney RA, Magaziner J. Liberal or restrictive transfusion in high-risk patients after hip surgery. N Engl J Med. 2011;365:2453–62.
6. Hebert PC, Wells G, Blajchman MA, Marshall J, Martin C, Pagliarello G, Tweeddale M, Schweitzer I, Yetisir E. A multicenter, randomized, controlled clinical trial of transfusion requirements in critical care. transfusion requirements in critical care investigators, Canadian Critical Care Trials Group. N Engl J Med. 1999;340:409–17.
7. Bell RF, Dahl JB, Moore RA, Kalso E. Peri-operative ketamine for acute post-operative pain: a quantitative and qualitative systematic review (cochrane review). Acta Anaesthesiol Scand. 2005;49:1405–28.
8. Hocking G, Cousins MJ. Ketamine in chronic pain management: an evidence-based review. Anesth Analg. 2003;97:1730–9.
9. Urban MK, Ya Deau JT, Wukovits B, Lipnitsky JY. Ketamine as an adjunct to postoperative pain management in opioid tolerant patients after spinal fusions: a prospective randomized trial. HSS J. 2008;4:62–5.
10. Zhan C, Kaczmarek R, Loyo-Berrios N, Sangl J, Bright RA. Incidence and short-term outcomes of primary and revision hip replacement in the United States. J Bone Joint Surg Am. 2007;89:526–33.
11. Parvizi J, Pour AE, Keshavarzi NR, D'Apuzzo M, Sharkey PF, Hozack WJ. Revision total hip arthroplasty in octogenarians. A case–control study. J Bone Joint Surg Am. 2007;89:2612–8.
12. Devereaux PJ, Yang H, Yusuf S, Guyatt G, Leslie K, Villar JC, Xavier D, Chrolavicius S, Greenspan L, Pogue J, Pais P, Liu L, Xu S, Malaga G, Avezum A, Chan M, Montori VM, Jacka M, Choi P. Effects of extended-release metoprolol succinate in patients undergoing non-cardiac surgery (POISE trial): a randomised controlled trial. Lancet. 2008;371:1839–47.
13. Urban MK, Jules-Elysee K, Loughlin C, Kelsey W, Flynn E. The one year incidence of postoperative myocardial infarction in an orthopedic population. HSS J. 2008;4:76–80.
14. Fleischmann KE, Beckman JA, Buller CE, Calkins H, Fleisher LA, Freeman WK, Froehlich JB, Kasper EK, Kersten JR, Robb JF, Valentine RJ. 2009 ACCF/AHA focused update on perioperative beta blockade. J Am Coll Cardiol. 2009;54:2102–28.
15. Lee TH, Marcantonio ER, Mangione CM, Thomas EJ, Polanczyk CA, Cook EF, Sugarbaker DJ, Donaldson MC, Poss R, Ho KK, Ludwig LE, Pedan A, Goldman L. Derivation and prospective validation of a simple index for prediction of cardiac risk of major noncardiac surgery. Circulation. 1999;100:1043–9.
16. Urban MK, Wolfe S, Sangavi N, Magid S. One year incidence of postoperative myocardial infarction (PMI) in patients undergoing major orthopedic surgery (abstract). International Anesthesia Research Society: San Diego, CA; 2009.
17. Biccard BM, Rodseth RN. The pathophysiology of peri-operative myocardial infarction. Anaesthesia. 2010;65:733–41.
18. Urban MK, Markowitz SM, Gordon MA, Urquhart BL, Kligfield P. Postoperative prophylactic administration of beta-adrenergic blockers in patients at risk for myocardial ischemia. Anesth Analg. 2000;90:1257–61.
19. Sari A, Miyauchi Y, Yamashita S, Yokota K, Ogasahara H, Yonei A. The magnitude of hypoxemia in elderly patients with fractures of the femoral neck. Anesth Analg. 1986;65:892–4.
20. Gitin TA, Seidel T, Cera PJ, Glidewell OJ, Smith JL. Pulmonary microvascular fat: the significance? Crit Care Med. 1993;21:673–7.
21. Urban MK, Sheppard R, Gordon MA, Urquhart BL. Right ventricular function during revision total hip arthroplasty. Anesth Analg. 1996;82:1225–9.
22. Ereth MH, Weber JG, Abel MD, Lennon RL, Lewallen DG, Ilstrup DM, Rehder K. Cemented versus noncemented total hip arthroplasty–embolism, hemodynamics, and intrapulmonary shunting. Mayo Clin Proc. 1992;67:1066–74.
23. Schonfeld SA, Ploysongsang Y, DiLisio R, Crissman JD, Miller E, Hammerschmidt DE, Jacob HS. Fat embolism prophylaxis with corticosteroids. A prospective study in high-risk patients. Ann Intern Med. 1983;99:438–43.
24. Parvizi J, Mui A, Purtill JJ, Sharkey PF, Hozack WJ, Rothman RH. Total joint arthroplasty: when do fatal or near-fatal complications occur? J Bone Joint Surg Am. 2007;89:27–32.
25. Bellomo R, Ronco C, Kellum JA, Mehta RL, Palevsky P. Acute renal failure – definition, outcome measures, animal models, fluid therapy and information technology needs: the second international consensus conference of the acute dialysis quality initiative (ADQI) group. Crit Care. 2004;8:R204–12.
26. Gupta RM, Parvizi J, Hanssen AD, Gay PC. Postoperative complications in patients with obstructive sleep apnea syndrome undergoing hip or knee replacement: a case–control study. Mayo Clin Proc. 2001;76:897–905.

27. Vasu TS, Doghramji K, Cavallazzi R, Grewal R, Hirani A, Leiby B, Markov D, Reiter D, Kraft WK, Witkowski T. Obstructive sleep apnea syndrome and postoperative complications: clinical use of the STOP-BANG questionnaire. Arch Otolaryngol Head Neck Surg. 2010;136:1020–4.
28. Memtsoudis SG, Ma Y, Gonzalez Della Valle A, Mazumdar M, Gaber-Baylis LK, MacKenzie CR, Sculco TP. Perioperative outcomes after unilateral and bilateral total knee arthroplasty. Anesthesiology. 2009;111:1206–16.
29. Urban MK, Chisholm M, Wukovits B. Are postoperative complications more common with single-stage bilateral (SBTKR) than with unilateral knee arthroplasty: guidelines for patients scheduled for SBTKR. HSS J. 2006;2:78–82.
30. Bruce AJ, Ritchie CW, Blizard R, Lai R, Raven P. The incidence of delirium associated with orthopedic surgery: a meta-analytic review. Int Psychogeriatr. 2007;19:197–214.
31. Allen SR, Frankel HL. Postoperative complications: delirium. Surg Clin North Am. 2012;92:409–31.
32. Urban MK, Magid S, Mangini M. One year incidence for admission to a critical care unit after major orthopedic surgery (abstract), 7th annual perioperative medicine summit. Miami, FL; 2011.

# Postoperative Pain Management in the Orthopedic Setting

9

Cassie Kuo and Spencer S. Liu

**Objectives**

- To describe the general principles and methods of postoperative pain management in the orthopedic setting.
- To review the benefits and risks of systemic and regional analgesic approaches.
- To provide information on pain management regimens provided at the Hospital for Special Surgery for total joint arthroplasties, upper extremity, foot/ankle, and spine surgeries.
- To discuss the purpose of a recuperative pain service.
- To discuss how to manage an orthopedic patient with chronic pain.

**Key Points**

- Acute postoperative pain management is important for facilitating a patient's recovery and can be achieved utilizing a variety of techniques.
- Each analgesic technique has unique benefits, risks, and side effects that should be considered when deciding on appropriateness for each patient.
- Commonly used pain regimens at the Hospital for Special Surgery are presented for a number of procedures, including joint arthroplasties, foot/ankle, upper extremity, and spine procedures.
- There is a subset of patients who will require specialized care from a recuperative pain or chronic pain service.

C. Kuo
Department of Anesthesiology, Mid-Atlantic Permanente Medical Group, Rockvillie, MD, USA

Mid-Atlantic Permanente Medical group, 205 Crofton Place, Falls Church, VA 22043, USA

S.S. Liu (✉)
Department of Anesthesiology, Hospital for Special Surgery, 535 E70th Street, New York, NY 10021, USA
e-mail: liusp@hss.edu

## Introduction

The goal of postoperative pain control is to prevent the detrimental acute and chronic effects of acute pain and to facilitate patient recovery. For orthopedic patients, recovery is partially dependent on physical therapy (PT), which is not infrequently started on the day of surgery. Pain control plays a critical role in a patient's physical and mental readiness to participate in PT as well as the effectiveness of PT.

A multimodal approach to acute pain control is advocated at the Hospital for Special Surgery because it decreases perioperative morbidity, reduces length of hospitalization, and improves patient satisfaction [1, 2]. Systemic agents such as opioids and nonsteroidal anti-inflammatory drugs are commonly used. Opioids are powerful analgesics but their use is often limited by associated side effects, ranging from nausea to respiratory depression. In an effort to decrease patients' opioid consumption and therefore decrease side effects, frequently a regional analgesic technique is employed and non-opioid, systemic analgesics are added. Regional analgesia has been shown to provide superior postoperative analgesia to systemic agents alone [3]. However, the appropriateness of a regional analgesic regimen is dependent on the type of surgery and expected postoperative pain experience, surgeon's preference, patient's comorbidities, and ultimately, the patient's willingness to participate with a proposed approach.

Postoperative pain management does not end with ordering the analgesics or performing a peripheral or central nerve block. Recognizing the patients' frequent need for continued follow-up for postoperative pain control, the Hospital for Special Surgery has developed a

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_9, 

Recuperative Pain Medicine service to address this void. Orthopedic patients with chronic pain will need the expertise of the chronic pain service to manage their postoperative pain regimen.

To provide an overview of the issues surrounding postoperative pain management in the orthopedic patient, the topics discussed in this chapter include: (1) General principles of postoperative pain management, (2) Systemic analgesic techniques, (3) Regional analgesic techniques, (4) Hospital for Special Surgery pain management regimens for various procedures, (5) Recuperative pain model, and (6) Orthopedic patients with chronic pain.

## General Principles of Postoperative Pain Management

### Pathophysiology of Pain

Surgery causes tissue injury and subsequent release of inflammatory mediators, which include peptides, lipids, and neurotransmitters [4]. These mediators activate central and peripheral mechanisms of pain. In the central pathway, the mediators stimulate peripheral nociceptors and the information is transmitted via the spinothalamic and spinoreticular tract to the central nervous system. Peripherally, mediators induce local neurogenic inflammation, which involves vasodilatation and plasma extravasation [4]. Mediators also sensitize functional nociceptors and activate dormant nociceptors [5]. Central sensitization in the CNS may occur and result in pain hypersensitivity and augment pain perception [6]. The activity and interaction between mediators and receptors at multiple levels of the pain pathway are integral to the development of acute and chronic pain after an acute injury [7].

### Acute and Chronic Effects of Postoperative Pain

There are both acute and chronic effects of uncontrolled postoperative pain, affecting patient morbidity and mortality. Firstly, a neuroendocrine stress response occurs acutely leading to increased sympathetic tone, increased catecholamine and catabolic hormone secretion and decreased secretion of anabolic hormones. This stress response likely also plays a role in the phenomenon of postoperative hypercoagulability, postoperative immunosupression, and poor wound healing [8–10]. Clinical factors such as type of anesthesia and intensity of surgical injury can modulate the neuroendocrine stress response [9]. Secondly, pain may lead to direct activation of the sympathetic nervous system leading to increased myocardial oxygen consumption and decreased myocardial oxygen supply, which are risk factors for developing myocardial ischemia. Sympathetic-mediated decreased gastrointestinal (GI) activity and delayed return of GI motility both potentially contribute to a paralytic ileus. Thirdly, the activation of inhibitory spinal reflex arcs may lead to a decrease in postoperative respiratory and GI function [11–13].

Poorly controlled acute postoperative pain plays an important role in the potential development of chronic pain [14]. The transition from acute to chronic pain is not well understood, although it is likely related to prolonged central sensitization and hyperexcitability.

### Preemptive Analgesia

The concept of preemptive analgesia describes interventions initiated prior to surgical incision to prevent central sensitization from mechanical and inflammatory injuries [15]. This approach, theoretically results in short- and long-term benefits in pain control and recovery. Clinical trials investigating a variety of agents and techniques have concluded with mixed results [16]. However, evidence exists that complete nerve blockade of noxious stimuli intraoperatively and postoperatively seems to provide maximal benefit [17].

### Multimodal Perioperative Management

A variety of techniques can be utilized for controlling pain, including multimodal analgesia, patient education, and early mobilization. Multimodal analgesia involves a combination of regional anesthetic techniques and systemic parenteral and oral analgesics. Research has shown that a multimodal strategy decreases perioperative morbidity, reduces length of hospitalization, and improves patient satisfaction [1, 2, 12].

## Systemic Analgesic Techniques

### Opioids

Opioids are the mainstay for treatment of postoperative pain. They act on the μ (mu) receptors in the central nervous system and potentially on peripheral opioid receptors. One advantage of opioids is the theoretical absence of an analgesic ceiling to dosing. However, patients do develop tolerance or side effects such as nausea, sedation, and respiratory depression with escalating doses. Another advantage lies in the ability to administer opioids via many different routes (oral, intravenous, intramuscular, subcutaneous, transcutaneous, transmucosal, neuraxial). Each route will have an effect on onset, bioavailability, and

duration of action of the drug. Opioids are preferentially given parenterally (intravenously or intramuscularly) for moderate to severe postoperative pain because these modes of administration provide more rapid and reliable onset of analgesic action than the oral route. Patients are typically transitioned to enteral opioids when they are able to tolerate oral intake and an appropriate level of pain control has been established.

## Intravenous Patient-Controlled Analgesia (PCA)

Opioids vary widely in achieved serum concentration and analgesic response from patient to patient. This variability along with other factors, such as delays in administration, led to adaptation of IV patient-controlled analgesia (PCA) to optimize delivery of analgesics for the individual patient. Intravenous PCA has been shown to provide superior postoperative analgesia and improve patient satisfaction when compared to traditional postoperative regimens [18, 19]. However, a PCA does not eliminate the side effects of complications related to administering opioids. Common PCA settings are presented in Table 9.1.

**Table 9.1** Common IV PCA settings

| Opioid concentration | Demand | Lockout (min) | Basal infusion |
|---|---|---|---|
| *Morphine (1 mg/mL)* | | | |
| Adult | 0.5–2.5 mg | 5–10 | |
| Pediatrics | 0.01–0.03 mg/kg (max = 0.15 mg/kg/h) | 5–10 | 0.01–0.03 mg/kg/h |
| *Hydromorphone (0.2 mg/mL)* | | | |
| Adult | 0.05–0.25 mg | 5–10 | |
| Pediatrics | 0.003–0.005 mg/kg (max = 0.02 mg/kg/h) | 5–10 | 0.003–0.005 mg/kg/h |
| *Fentanyl (0.01 mg/mL)* | | | |
| Adult | 10–20 μg | 4–10 | |
| Pediatrics | 0.5–1 μg/kg (max = 4 μg/kg/h) | 5–10 | 0.5–1 μg/kg/h |

## Nonopioid Analgesics

A variety of non-opioid analgesics are utilized at the Hospital for Special Surgery for the purpose of controlling postoperative pain (Table 9.2), either in addition or instead of opioid-based regimens. Their advantages and disadvantages are reviewed next.

**Table 9.2** Nonopioid analgesics

| Analgesic | Dosing | Maximum daily dose |
|---|---|---|
| Ibuprofen | 600–800 mg PO q6 h | 3,200 mg/day |
| Ketorolac | 15–30 mg IM/IV q6 h | 120 mg/day |
| Meloxicam | 7.5–15 mg PO q24 h | 15 mg/day |
| Diclofenac | 50 mg PO q8–12 h | 150 mg/day |
| Acetaminophen | 650–1,000 mg PO/PR q4–6 h | 4 g/day |
| Tramadol | 50–100 mg PO q4–6 h | 400 mg/day |
| Aspirin | 325–650 mg PO q4 h | 4 g/day |
| Gabapentin | 300–1,200 mg PO q8 h | 3,600 mg/day |
| Pregabalin | 75–300 mg PO q8–12 h | 600 mg/day |

## Nonsteroidal Anti-inflammatory Agents (NSAIDs)

Nonsteroidal anti-inflammatory agents (NSAIDs) inhibit cyclooxygenase (COX) and prostaglandin synthesis, which are mediators for peripheral sensitization and hyperalgesia. There are at least two isoforms of COX. COX-1 is involved in platelet aggregation, hemostasis, and gastric mucosal protection. COX-2 is involved in pain, inflammation, and fever pathways. Traditional NSAIDs are nonselective COX inhibitors, while NSAIDs such as celecoxib are COX-2-inhibitors. COX-3, which is targeted by acetaminophen, may be involved in pain and fever pathways [20].

NSAIDs can be administered parenterally or orally. They can provide adequate analgesia when used alone for treating mild to moderate pain. This drug category is a useful adjunct to opioids for treating moderate to severe pain. NSAIDs can potentially reduce opioid requirements up to 50 %, which is essential to reducing opioid-related side effects [21].

There are a number of side effects to consider when utilizing NSAIDs. Among them, decreased hemostasis secondary to platelet dysfunction and inhibition of thromboxane $A_2$ is a concern [22]. In the clinical setting, however, the effect on perioperative bleeding has been shown to be equivocal [22]. Renal dysfunction has been described, particularly in patients with hypovolemia, preexisting renal dysfunction, or electrolyte abnormalities [23]. There is a higher incidence of GI bleeding with NSAIDs because of COX-1 inhibition, which is needed for synthesis of cytoprotective gastric mucosal prostaglandins [24]. Additionally, detrimental effects on bone healing and osteogenesis are of concern [25]. When utilizing COX-2 inhibitors, there is a lower incidence of GI complications and minimal platelet inhibition, but similar incidence of renal dysfunction compared to nonselective NSAIDs [26, 27].

## Tramadol

Tramadol is a synthetic opioid with weak μ (mu)-agonist activity and inhibits reuptake of serotonin and norepinephrine. Patients with moderate postoperative pain are good candidates for tramadol. The advantages of tramadol over other opioids include relative lack of respiratory depression,

effect on GI motility, and low potential for abuse [28]. Side effects include dizziness, drowsiness, nausea/vomiting, dry mouth, and headache [29]. Care should be taken when administering tramadol in patients with seizures, increased intracranial pressure, or those taking monoamine oxidase inhibitors [29].

### Gabapentin and Pregabalin

Gabapentin and pregabalin are anticonvulsants that bind to calcium channels and subsequently inhibit the release of excitatory neurotransmitters in the pain pathways. These drugs are traditionally used to treat neuropathic pain and/or chronic pain. When taken preoperatively, they have been found to reduce opioid requirements in the postoperative period [30]. Among others, side effects include dizziness and sedation.

## Regional Analgesic Techniques

Regional analgesic techniques, neuraxial or peripheral nerve blocks, are frequently utilized for postoperative pain control for orthopedic procedures. They can provide superior postoperative analgesia compared to systemic agents [3].

### Single-Dose Neuraxial Opioids (Table 9.3)

Opioids can be used as a sole or adjuvant single-dose neuraxial (intrathecal, epidural) analgesic. The properties of a neuraxial opioid are primarily determined by its degree of lipophilicity versus hydrophilicity.

Lipophilic opioids, such as fentanyl and sufentanil, have a rapid onset of analgesia and clearance from the cerebral spinal fluid (CSF). They act on the spinal cord and potentially have a systemic effect after absorption. Advantages of lipophilic opioids include a lower incidence of side effects. Also, because of limited cephalad spread in the CSF, there is a decreased possibility of delayed respiratory depression with neuraxial lipophilic opioids. These properties are useful for ambulatory surgery patients, who require rapid analgesic onset, moderate duration of action and minimal risk of respiratory depression.

Hydrophilic opioids, such as morphine and hydromorphone, stay longer in the CSF and therefore are associated with a comparably delayed onset with longer duration of action. Their site of action is primarily at the spinal cord. There is more significant cephalad spread in the CSF and therefore a higher incidence of side effects, including respiratory depression. Patients should be monitored in the inpatient setting after receiving neuraxial hydrophilic opioids given the potential for delayed respiratory compromise.

**Table 9.3** Dosing of neuraxial opioids

| Opioid | Intrathecal single dose | Epidural single dose |
|---|---|---|
| Fentanyl | 5–25 μg | 50–100 μg |
| Sufentanil | 2–10 μg | 10–50 μg |
| Morphine[a] | 0.1–0.3 mg | 1–5 mg |
| Hydromorphone | n/a | 0.5–1 mg |

[a]Given increased risk of delayed respiratory depression, patient should be in monitored setting until 12 h after administration

### Continuous Epidural Analgesia

Epidural catheters (EDC) often serve a dual purpose, for intraoperative anesthesia and postoperative analgesia. Intraoperative use of an EDC is associated with less postoperative pain when compared to general anesthesia and systemic opioids [31]. Patient-controlled epidural analgesia (PCEA) can be employed for postoperative analgesia. EDC are recommended for patients undergoing lower extremity procedures where moderate to severe postoperative pain is anticipated, i.e., total hip or knee arthroplasties, who will be on aspirin and/or warfarin for postoperative thromboprophylaxis. They should be avoided in patients on low-molecular weight heparin (LMWH) because of the increased risk of epidural hematomas when placing or removing indwelling catheters.

### Epidural Drugs

Local anesthetics and opioids can be used as solo epidural agents or in combination. The combined approach provides superior analgesia but does not decrease the incidence of side effects of opioids. Local anesthetic alone is preferable when avoidance of opioid-related side effects is a priority, although this step can lead to sympathectomy-mediated hypotension and denser motor blockade as usually higher concentrations are required to achieve adequate analgesic effects.

Several drugs have been investigated as adjuvants in epidural infusions to improve analgesia. One of the most commonly used, clonidine, has been shown to enhance analgesia but its use is limited by its side effects, including hypotension and bradycardia [32].

### Side Effects of Neuraxial Analgesic Drugs

Side effects do occur with epidural analgesics; however, the clinician should consider other potential causes to explain

potential symptoms that may be encountered. For example, postoperative hypotension may be secondary to the sympathectomy caused by an epidural agent, low intravascular volume or cardiac output, and/or bleeding. Further, use of epidural opioids, a cerebrovascular accident, pulmonary edema, and sepsis could all be potential explanations for postoperative respiratory depression. If a patient's hypotension is determined to be secondary to the local anesthetic-related sympathectomy, consider lowering the rate or concentration of the epidural infusion. The epidural agent could also be changed to an opioid-only infusion.

A dense motor block can pose problems for the surgical team when assessing neurologic function, and can affect patients' ability to participate in rehabilitation exercises. In this setting, the epidural infusion could be decreased or stopped altogether to lessen the extent of the motor blockade. A motor block typically resolves within hours after discontinuing the infusion, but is dependent on the type of agent used. If the motor block persists or worsens, further evaluation is required to rule out a spinal hematoma, spinal abscess, or catheter migration. The symptoms of a neuraxial hematoma develop within minutes to hours and include severe localized back pain, delayed radicular symptoms, and bowel and/or bladder incontinence. An abscess develops over hours to days and symptoms include fever, bowel or bladder incontinence, urinary retention, and back pain.

Nausea and vomiting are common side effects of epidural opioids, particularly when given in an infusion. Treatments include the administration of opioid antagonists or drugs with antiemetic properties such as metoclopramide, dexamethasone, and transdermal scopolamine. Symptoms should also resolve if the opioid is eliminated from the epidural infusion.

Another common side effect of epidural opioids is pruritis, which occurs in up to 60 % of patients [33]. Although the exact mechanism remains unknown, it is thought to involve primarily central nervous system processes and may not be, as commonly assumed, related to peripheral histamine release. Partial and full opioid antagonists such as naloxone, naltrexone, and nalbuphine can be used to treat pruritis [34]. Diphenhydramine or hydroxyzine may also be prescribed, but these drugs are often sedating and less effective than opioid antagonists.

Similarly to systemic opioids, epidural opioids can lead to respiratory depression in a dose-dependent manner. Hydrophilic opioids, i.e., morphine, may lead to delayed respiratory depression typically within 12 h after administration [35]. Additional risk factors for respiratory compromise include advanced age, concurrent systemic opioid or sedative use, prolonged or extensive surgery as well as the presence of multiple comorbidities [36]. Naloxone, a pure opioid antagonist, should be administered to facilitate reversal of respiratory depression.

**Table 9.4** Common patient-controlled epidural analgesia regimens

| Analgesic solution | Continuous rate (mL/h) | Demand dose (mL) | Lockout interval (min) |
|---|---|---|---|
| 0.0625–0.125 % bupivacaine + 5 μg/mL fentanyl | 4–6 | 3–5 | 10–15 |
| 0.0625–0.125 % bupivacaine + 0.01 mg/mL hydromorphone | 4–6 | 3–5 | 10–15 |
| 0.05–0.2 % ropivacaine + 4 μg/mL fentanyl | 4–6 | 3–5 | 10–15 |

Urinary retention has been linked to the use of epidural opioids or local anesthetics. Treatment consists of low-dose naloxone and/or the lowering of the infusion rate of either agent. To avoid this problem, a urinary catheter should remain in place until the epidural infusion is discontinued.

## Patient-Controlled Epidural Analgesia

Patient-controlled epidural analgesia (PCEA) can provide effective postoperative pain control. Common regimens used at the Hospital for Special Surgery are presented in Table 9.4.

## Benefits of Epidural Analgesia

A variety of benefits associated with epidural analgesia when compared to systemic opioids have been reported, including a reduction in mortality and morbidity, superior analgesia, and higher patient satisfaction [12, 37, 38]. Additionally, epidural analgesia may be linked to a decrease in the incidence of postoperative gastrointestinal, pulmonary, and possibly cardiac complications [12]. Although intraoperative regional anesthesia decreases the incidence of hypercoagulable-related events (DVTs), no evidence is available to suggest that postoperative epidural analgesia also contributes to a reduction in the incidence of clot formation in orthopedic surgical patients [35].

## Risks of Epidural Analgesia

Complications of epidural analgesia are rare, but can be related to catheter placement. If the catheter is accidentally placed or migrates intravascularly, an injection of local anesthetic could potentially lead to systemic toxicity, including seizures and cardiac dysrhythmias or even arrest. Intrathecal location of the catheter tip may lead to a high spinal level requiring ventilatory support should inadvertent administration of an epidural local anesthetic dose occur.

The incidence of neurologic injury is not increased with epidural catheter placements; however, an increased incidence of spinal hematomas in anticoagulated patients upon epidural catheter removal has been suggested [39]. Therefore, neurologic monitoring for 24 h after epidural catheter removal should be enforced in certain anticoagulated patients. Patients with longer duration of epidural analgesia or certain comorbidities such as malignancy and trauma may have a higher incidence of epidural abscesses [40]. Concerns that epidural analgesia could potentially mask symptoms of lower extremity compartment syndrome more so than systemic opioids have not been substantiated.

## Peripheral Regional Analgesia

There are a variety of peripheral nerve blocks (PNB), either as single-injection or catheter, which can be performed to provide acute postoperative pain control. For upper extremity procedures, the brachial plexus can be targeted via an interscalene, supraclavicular, infraclavicular, or axillary approach. Lumbar plexus, femoral, sciatic, popliteal, and ankle blocks can be utilized to provide analgesia for lower extremity surgery. When compared to systemic opioids for controlling postoperative pain, PNB provide superior analgesia, are associated with a decrease in opioid-related side effects, and improvement in patient satisfaction [41, 42].

As a single injection, the duration of a PNB depends on the local anesthetic and adjuvant administered. The duration can range from a few hours to days. The patient, surgeon, and anesthesiologist should consider a priori what duration is optimal and expected before performing the PNB, while taking into account the need for neurologic assessment in the postoperative period. A major advantage of an analgesic using PNB catheters is that it can potentially provide an opioid-free postoperative analgesic regimen, when adequate concentrations of local anesthetics are being used.

Potential side effects and complications of PNB need to be considered. Although permanent neuropathies following PNB are rare, the rate of transient events affecting nerve structures is approximately 3 % [43]. Additionally, each PNB carries its own unique set of side effects and complications. For example, an interscalene PNB is associated with ipsilateral phrenic nerve paresis in 100 % of patients, thus potentially leading to a decrease in pulmonary function. Such an event may not be tolerated in patients with severe respiratory disease [44]. In the case of a psoas compartment block, which involves deep needle placement, an increased risk of neuraxial or intravascular injection has to be considered.

## Hospital for Special Surgery Pain Management for Specific Procedures

Pain management at the Hospital for Special Surgery seeks to employ the advantages of regional anesthetic techniques whenever possible. The choice of a specific postoperative pain control regimen is based on many factors, including patient preference, expected levels of pain, rehabilitation goals, presence of contraindications for certain techniques (i.e., extensive previous spine pathology, neuropathies) and the planned approach for thromboprophylaxis. Although protocols have been developed that seek to address the optimal balance between factors to be considered, it must be stressed that the actual approach will depend on each patient's needs and adjustments will have to be made accordingly. In addition to the described regional analgesia-based techniques, oral and parenteral use of anti-inflammatory agents is considered after discussion with the surgical team.

## Total Hip Replacement

If the choice of anticoagulation postoperatively involves warfarin, a patient-controlled epidural analgesic regimen is routinely used. The infusion mixture consists of 0.0625 % bupivacaine plus 0.01 mg hydromorphone, started at 4 mL/h with a demand dose of 4 mL every 10 min to an hourly maximum of 20 mL [45]. On the morning of postoperative day 1 (POD 1), the basal rate is discontinued and demand dosing remains available until noon of the same day. Patients are encouraged to request PRN oral analgesics while the epidural demand dose is used as a back-up during this transition period. If successful, the patient will be transitioned to oral analgesics only and the epidural catheter removed.

If a patient will be placed on LMWH postoperatively, an IV PCA and/or a single injection psoas compartment block are considered. The psoas compartment block, targeting L2–L4, can be performed intra- or postoperatively with a long-acting local anesthetic such as ropivacaine or bupivacaine. Early transition to oral analgesics is encouraged.

## Total Knee Replacement

A variety of options are available, and among other factors they are dictated by the postoperative anticoagulation regimen. If a patient is anticoagulated with warfarin or aspirin, a continuous epidural infusion (0.0625 % bupivacaine plus 0.01 mg hydromorphone at 4 mL/h) with demand dosing (4 mL q10 min) and/or single injection femoral or saphenous PNB comprises the standard treatment. On POD 1 the epidural basal infusion is cut in half and discontinued on POD

2. Demand dosing is maintained until the afternoon of POD 2. The addition of a femoral PNB has been shown to also facilitate early ambulation and reduce length of stay for knee arthroplasties [46], and is thus routinely performed. If an epidural is not employed for postoperative pain control, the placement of a femoral catheter is considered using a basal infusion (0.2 % ropivacaine 6–8 mL/h) for POD 0–1. Patients with a femoral catheter may or may not need IV opioids.

If the patient is anticoagulated with LMWH, consider a femoral PNB (anterior knee) as a single injection or catheter and/or a single-injection sciatic PNB (posterior knee). However, the risk of perineural hematoma should be considered and carefully evaluated against the benefits of a catheter placement. The addition of an IV PCA for POD 0–1 should also be contemplated, as patients may develop posterior knee pain as the sciatic PNB wears off. A complete transition to oral analgesics usually occurs on POD 2. Should any regional analgesic technique be contraindicated an IV PCA for POD 0–2 is prescribed.

### Foot/Ankle Procedures

An ankle block can be performed for any procedure involving the fore foot. A popliteal PNB, either as a single-injection with local anesthetic with or without clonidine or dexamethasone or via use of a catheter has been found to be useful for any procedure involving the ankle and below [47]. Usually, the popliteal PNB is supplemented with a saphenous PNB to provide analgesia to the medial ankle area, should the surgical intervention require it. As the PNBs wear off, the patient will require either an IV PCA or PO analgesics.

### Upper Extremity Procedures

For shoulder procedures, an interscalene or supraclavicular PNB will provide appropriate analgesic coverage. For elbow and distal procedures, a supraclavicular, infraclavicular, or axillary PNB can be performed. Depending on the extent of the surgery and the pain to be expected, the patient should be placed on an IV PCA or oral agents for supplemental analgesia.

### Spine Procedures

Many patients undergoing spine procedures will be opioid tolerant secondary to long-term use of agents in this drug class. Thus, postoperative adequate pain control may be difficult to achieve, especially since regional analgesic techniques are usually not available, except the use of an epidural catheter above the level of fusion in selected patients. The mainstay of the pain control regimen consists of an opioid IV PCA. A patient on preoperative opioids will likely require an increase in the settings of the PCA from the typical settings outlined in Table 9.1. It is not infrequent that long-acting opioids, such as methadone or continuous release oxycodone, are added. Adjuvants such as gabapentin and pregabalin are often included and may be especially beneficial in those patients with a component of neuropathic pain. Low-dose ketamine perioperatively has been shown to help manage postoperative pain [48].

## Recuperative Pain Model

A significant number of patients have difficulty with pain control during the in-hospital transition from patient-controlled analgesia modalities to oral analgesics. This difficult transition hinders the hand-off of patient care from the Acute Pain Service to the surgical service. A Recuperative Pain Medicine (RPM) service, as created at the Hospital for Special Surgery, can help bridge the hand-off gap in pain management [49]. The RPM service is not only involved in managing the in-hospital oral analgesic regimen, but also in preparing the patient for pain management at home. Further, the RPM service can provide short-term outpatient evaluation and follow-up for patients continuing to have post-surgical pain issues. These patients are typically seen until 8 weeks postoperatively, and may be referred to a chronic pain specialist for further management thereafter.

## Orthopedic Patients with Chronic Pain

Postoperative pain control in patients who suffer from chronic pain and/or are opioid-tolerant can be extremely challenging. Therefore, patients will most commonly see a chronic pain specialist in preoperative consultation, in order to allow for adequate perioperative planning of treatment. Chronic pain patients may have a longer hospital stay because of pain control issues. It is to be expected that this patient population may require higher doses of analgesics due to opioid tolerance. In assessing such patients, the clinician needs to identify both the basal and acute surgical pain opioid requirements. The basal opioid requirement should be replaced in the form of controlled-release oral opioids or IV infusion via PCA to facilitate pain relief and prevent opioid withdrawal.

Strategies for optimizing pain control should include managing patient expectations, anticipating the increased analgesics requirements, using adjuvant agents, regional PNBs and preparing the patient for a transition to an oral analgesic regimen. Upon discharge, these patients will typically be on a combination of regularly administered

controlled-release opioids, PRN short-acting, immediate-release opioids and around the clock adjuvants.

## Summary

Acute pain control is a critical component of an orthopedic patient's recovery. Pain control minimizes the acute and chronic effects of postoperative pain, and furthermore can significantly facilitate physical therapy. As the pain pathway involves both peripheral and central mechanisms, multiple potential areas which are amenable to be targeted with analgesics need to be addressed by a sophisticated pain management plan. We advocate using a multimodal approach because it provides benefits beyond effective pain control, including the reduction of side effects of single methodology approaches. Which analgesics or techniques to use will depend on many factors, including the type of surgery, patient's comorbidities, and preferences. Systemic opioids continue to be the mainstay of regimens but their use is often limited by side effects. Supplementing or replacing opioids with other systemic and/or regional analgesics will help minimize opioid-related side effects. Each of these non-opioid options has its own risks and benefits, and should be carefully considered.

As described previously, our institution has developed effective postoperative regimens for a variety of procedures. The ideal regimen for these procedures is not known and our regimens should be adjusted to the individual patient's needs. Most importantly, a preoperative discussion should be held between the patient, surgeon, and pain service to agree on a plan that can be implemented in a timely manner. Expecting that some patients will have difficulty transitioning to an outpatient analgesic regimen, an RPM service is helpful in managing such patients. The chronic pain service should ideally be involved when dealing with a chronic pain patient because of the higher level of care needed when treating opioid-tolerant individuals.

**Summary Points**

- Controlling acute postoperative pain will minimize acute and chronic effects of postoperative pain and facilitate physical therapy.
- A multimodal approach to the pain management regimen may include systemic opioids and non-opioids and/or regional analgesics.
- The analgesic agents and techniques chosen will depend on a variety of factors including the type of surgery, patient's comorbidities, and preferences.
- There will be a subset of patients who will require a recuperative pain medicine or chronic pain medicine consult to manage the postoperative pain regimen and to transition to an appropriate outpatient regimen.

## Case Study

A case study for this chapter is included in Appendix F at the end of this book.

## References

1. Brodner G, Van Aken H, Hertle L, Fobker M, Von Eckardstein A, Goeters C, Buerkle H, Harks A, Kehlet H. Multimodal perioperative management-combining thoracic epidural analgesia, forced mobilization, and oral nutrition – reduces hormonal and metabolic stress and improves convalescence after major urologic surgery. Anesth Analg. 2001;92:1594–600.
2. Basse L, Raskov HH, Hjort Jakobsen D, Sonne E, Billesbolle P, Hendel HW, Rosenberg J, Kehlet H. Accelerated postoperative recovery programme after colonic resection improves physical performance, pulmonary function and body composition. Br J Surg. 2002;89:446–53.
3. Dolin SJ, Cashman JN, Bland JM. Effectiveness of acute postoperative pain management: I. Evidence from published data. Br J Anaesth. 2002;89:409–23.
4. Julius D, Basbaum AI. Molecular mechanisms of nociception. Nature. 2001;413:203–10.
5. Carr DB, Goudas LC. Acute pain. Lancet. 1999;353:2051–8.
6. Kissin I. Preemptive analgesia. Anesthesiology. 2000;93:1138–43.
7. Basbaum AI. Spinal mechanisms of acute and persistent pain. Reg Anesth Pain Med. 1999;24:59–67.
8. Rosenfeld BA. Benefits of regional anesthesia on thromboembolic complications following surgery. Reg Anesth. 1996;21:9–12.
9. Desborough JP. The stress response to trauma and surgery. Br J Anaesth. 2000;85:109–17.
10. Pomposelli JJ, Baxter 3rd JK, Babineau TJ, Pomfret EA, Driscoll DF, Forse RA, Bistrian BR. Early postoperative glucose control predicts nosocomial infection rate in diabetic patients. JPEN J Parenter Enteral Nutr. 1998;22:77–81.
11. Fratacci MD, Kimball WR, Wain JC, Kacmarek RM, Polaner DM, Zapol WM. Diaphragmatic shortening after thoracic surgery in humans. Effects of mechanical ventilation and thoracic epidural anesthesia. Anesthesiology. 1993;79:654–65.
12. Liu S, Carpenter RL, Neal JM. Epidural anesthesia and analgesia. Their role in postoperative outcome. Anesthesiology. 1995;82:1474–506.
13. Wu CL, Fleisher LA. Outcomes research in regional anesthesia and analgesia. Anesth Analg. 2000;91:1232–42.
14. Perkins FM, Kehlet H. Chronic pain as an outcome of surgery. A review of predictive factors. Anesthesiology. 2000;93:1123–33.
15. Woolf CJ, Chong MS. Preemptive analgesia–treating postoperative pain by preventing the establishment of central sensitization. Anesth Analg. 1993;77:362–79.
16. Moiniche S, Kehlet H, Dahl JB. A qualitative and quantitative systematic review of preemptive analgesia for postoperative pain relief: the role of timing of analgesia. Anesthesiology. 2002;96:725–41.
17. Kissin I, Lee SS, Bradley Jr EL. Effect of prolonged nerve block on inflammatory hyperalgesia in rats: prevention of late hyperalgesia. Anesthesiology. 1998;88:224–32.
18. Ballantyne JC, Carr DB, Chalmers TC, Dear KB, Angelillo IF, Mosteller F. Postoperative patient-controlled analgesia: meta-analyses of initial randomized control trials. J Clin Anesth. 1993;5:182–93.
19. Walder B, Schafer M, Henzi I, Tramer MR. Efficacy and safety of patient-controlled opioid analgesia for acute postoperative pain. A quantitative systematic review. Acta Anaesthesiol Scand. 2001;45:795–804.

20. Chandrasekharan NV, Dai H, Roos KL, Evanson NK, Tomsik J, Elton TS, Simmons DL. COX-3, a cyclooxygenase-1 variant inhibited by acetaminophen and other analgesic/antipyretic drugs: cloning, structure, and expression. Proc Natl Acad Sci U S A. 2002;99:13926–31.
21. Grass JA, Sakima NT, Valley M, Fischer K, Jackson C, Walsh P, Bourke DL. Assessment of ketorolac as an adjuvant to fentanyl patient-controlled epidural analgesia after radical retropubic prostatectomy. Anesthesiology. 1993;78:642–8. discussion 21A.
22. Schafer AI. Effects of nonsteroidal anti-inflammatory therapy on platelets. Am J Med. 1999;106:25S–36.
23. Whelton A. Nephrotoxicity of nonsteroidal anti-inflammatory drugs: physiologic foundations and clinical implications. Am J Med. 1999;106:13S–24.
24. FitzGerald GA. Cardiovascular pharmacology of nonselective nonsteroidal anti-inflammatory drugs and coxibs: clinical considerations. Am J Cardiol. 2002;89:26D–32.
25. Maxy RJ, Glassman SD. The effect of nonsteroidal anti-inflammatory drugs on osteogenesis and spinal fusion. Reg Anesth Pain Med. 2001;26:156–8.
26. Laine L. Gastrointestinal safety of coxibs and outcomes studies: what's the verdict? J Pain Symptom Manage. 2002;23:S5–10. discussion S11–4.
27. Harris CJ, Brater DC. Renal effects of cyclooxygenase-2 selective inhibitors. Curr Opin Nephrol Hypertens. 2001;10:603–10.
28. Scott LJ, Perry CM. Tramadol: a review of its use in perioperative pain. Drugs. 2000;60:139–76.
29. Edwards JE, McQuay HJ, Moore RA. Combination analgesic efficacy: individual patient data meta-analysis of single-dose oral tramadol plus acetaminophen in acute postoperative pain. J Pain Symptom Manage. 2002;23:121–30.
30. Ho KY, Gan TJ, Habib AS. Gabapentin and postoperative pain – a systematic review of randomized controlled trials. Pain. 2006;126:91–101.
31. Handley GH, Silbert BS, Mooney PH, Schweitzer SA, Allen NB. Combined general and epidural anesthesia versus general anesthesia for major abdominal surgery: postanesthesia recovery characteristics. Reg Anesth. 1997;22:435–41.
32. Paech MJ, Pavy TJ, Orlikowski CE, Lim W, Evans SF. Postoperative epidural infusion: a randomized, double-blind, dose-finding trial of clonidine in combination with bupivacaine and fentanyl. Anesth Analg. 1997;84:1323–8.
33. Bucklin BA, Chestnut DH, Hawkins JL. Intrathecal opioids versus epidural local anesthetics for labor analgesia: a meta-analysis. Reg Anesth Pain Med. 2002;27:23–30.
34. Kjellberg F, Tramer MR. Pharmacological control of opioid-induced pruritus: a quantitative systematic review of randomized trials. Eur J Anaesthesiol. 2001;18:346–57.
35. Dalldorf PG, Perkins FM, Totterman S, Pellegrini Jr VD. Deep venous thrombosis following total hip arthroplasty. Effects of prolonged postoperative epidural anesthesia. J Arthroplasty. 1994;9:611–6.
36. Mulroy MF. Monitoring opioids. Reg Anesth. 1996;21:89–93.
37. Rodgers A, Walker N, Schug S, McKee A, Kehlet H, van Zundert A, Sage D, Futter M, Saville G, Clark T, MacMahon S. Reduction of postoperative mortality and morbidity with epidural or spinal anaesthesia: results from overview of randomised trials. BMJ. 2000;321:1493.
38. Wu CL, Naqibuddin M, Fleisher LA. Measurement of patient satisfaction as an outcome of regional anesthesia and analgesia: a systematic review. Reg Anesth Pain Med. 2001;26:196–208.
39. Vandermeulen EP, Van Aken H, Vermylen J. Anticoagulants and spinal-epidural anesthesia. Anesth Analg. 1994;79:1165–77.
40. Wang LP, Hauerberg J, Schmidt JF. Incidence of spinal epidural abscess after epidural analgesia: a national 1-year survey. Anesthesiology. 1999;91:1928–36.
41. Allen HW, Liu SS, Ware PD, Nairn CS, Owens BD. Peripheral nerve blocks improve analgesia after total knee replacement surgery. Anesth Analg. 1998;87:93–7.
42. Al-Kaisy A, McGuire G, Chan VW, Bruin G, Peng P, Miniaci A, Perlas A. Analgesic effect of interscalene block using low-dose bupivacaine for outpatient arthroscopic shoulder surgery. Reg Anesth Pain Med. 1998;23:469–73.
43. Brull R, McCartney CJ, Chan VW, El-Beheiry H. Neurological complications after regional anesthesia: contemporary estimates of risk. Anesth Analg. 2007;104:965–74.
44. Urmey WF, Talts KH, Sharrock NE. One hundred percent incidence of hemidiaphragmatic paresis associated with interscalene brachial plexus anesthesia as diagnosed by ultrasonography. Anesth Analg. 1991;72:498–503.
45. Liu SS, Bieltz M, Wukovits B, John RS. Prospective survey of patient-controlled epidural analgesia with bupivacaine and hydromorphone in 3736 postoperative orthopedic patients. Reg Anesth Pain Med. 2010;35:351–4.
46. YaDeau JT, Cahill JB, Zawadsky MW, Sharrock NE, Bottner F, Morelli CM, Kahn RL, Sculco TP. The effects of femoral nerve blockade in conjunction with epidural analgesia after total knee arthroplasty. Anesth Analg. 2005;101:891–5. Table of contents.
47. YaDeau JT, LaSala VR, Paroli L, Kahn RL, Jules-Elysee KM, Levine DS, Wukovits BL, Lipnitsky JY. Clonidine and analgesic duration after popliteal fossa nerve blockade: randomized, double-blind, placebo-controlled study. Anesth Analg. 2008;106:1916–20.
48. Loftus RW, Yeager MP, Clark JA, Brown JR, Abdu WA, Sengupta DK, Beach ML. Intraoperative ketamine reduces perioperative opiate consumption in opiate-dependent patients with chronic back pain undergoing back surgery. Anesthesiology. 2010;113:639–46.
49. Philips BD, Liu SS, Wukovits B, Boettner F, Waldman S, Liguori G, Goldberg S, Goldstein L, Melia J, Hare M, Jasphey L, Tondel S. Creation of a novel recuperative pain medicine service to optimize postoperative analgesia and enhance patient satisfaction. HSS J. 2010;6(1):61–5.

# Part III

# Medical Management in Specific Clinical Settings

# Perioperative Care of the Orthopedic Patient with Connective Tissue Disease

10

Susan M. Goodman

**Objectives**

- To discuss the characteristics of the patients with systemic lupus erythematosis (SLE), and inflammatory arthritis (IA) such as rheumatoid arthritis (RA), spondyloarthropathy (SpA), and psoriatic arthritis (PsA) to predict the need for orthopedic surgery.
- To characterize the multisystem involvement common to these patients, enumerate the appropriate preoperative evaluations, and discuss the relevance of disease control to perioperative optimization.

**Key Points**

- Patients with connective tissue disease frequently require orthopedic surgery due to the presence of poorly controlled inflammatory arthritis.
- Occult multisystem involvement, including cardiac and pulmonary disease [1], increases the risk of surgery.
- Anti-rheumatic therapy suppresses immune function and impairs wound healing.
- Patients are likely to be on medications that may affect wound healing or raise the infection risk, an important consideration in the perioperative setting.
- Due to variable half-lives, medication-specific decisions concerning such therapy are required in the perioperative setting.
- The results of orthopedic surgery in such patients is gratifying with respect to pain relief but functional improvements may not be as complete as seen in patients with osteoarthritis.
- Patients with inflammatory muscle diseases, scleroderma, and vasculitis are not disproportionately likely to undergo orthopedic surgery and will not be discussed in this chapter.

## Introduction

Patients with SLE and inflammatory arthritis (IA) comprise 3 % of the general population, but 15 % of the patients undergo orthopedic surgery. Although advances in medical therapy have decreased the severity of IA [2], up to 30 % of patients fail to respond fully to therapy, and are at ongoing risk for joint damage. Historically, up to 50 % of RA patients could expect to undergo orthopedic surgery, most commonly arthroplasty, over the course of their illness, but current surveys reveal a decrease in reconstructive surgery for RA patients [3–6], concurrent with more widespread use of potent medical therapies. The risk for multisystem disease is greatest in those patients with persistent inflammation who have failed to respond to medical therapy, placing the patient who requires orthopedic reconstruction at highest risk for occult multisystem disease.

Arthroplasty is a major surgical procedure with attendant-recognized risk. Serious and potentially life-threatening cardiopulmonary complications include myocardial infarction, arrhythmia, and pulmonary embolization. Arthroplasty is recognized by the American College of Cardiology/American Heart Association as an intermediate risk procedure, which indicates a 1–5 % incidence of cardiac death or nonfatal myocardial infarction [7](MI). The risk of an ischemic cardiac event has been reported as 0.6 % in patients undergoing arthroplasty [1]. The prevalence of occult

S.M. Goodman (✉)
Department of Medicine, Weill Cornell Medical College, Hospital for Special Surgery, 535 E70th Street, New York, NY 10021, USA
e-mail: goodmans@hss.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_10, 

atherosclerotic disease in the population of patients with inflammatory arthritis and SLE is high, estimated to be equivalent to the risk seen in patients with diabetes. The national inpatient sample reveals that the in-hospital mortality for SLE patients undergoing total hip arthroplasty (THA) is significantly increased, a risk associated with renal dysfunction [8]. Atherosclerotic disease is increased in patients with persistent inflammation such as SLE, RA, AS, and PsA patients; their excess mortality is largely due to the increase in cardiovascular disease. In patients with SLE and RA, cardiac risk is independent of traditional risk factor but is magnified by them [9, 10]. AS and PsA are not as strong an independent cardiac risk factor as RA and SLE, but these patients are more likely to have multiple traditional risk factors such as metabolic syndrome and dyslipidemia. Additional risk factors such as obesity, smoking, hypertension, and diabetes are also increased in PsA patients [11–14]. PsA patients with severe skin involvement are at an increased risk for ASCVD, but mildly affected PsA patients are not. Prolonged therapy with disease modifying drugs (DMARDS), however, decreases the cardiac risk in patients with RA [15, 16], and can improve the lipid profile in patients with AS [17]. Cardiac risk assessment and risk modification in the perioperative period will be addressed.

Multiple factors contribute to risk of perioperative respiratory complications. Respiratory disease is estimated to be present in up to 80 % of SLE patients, and can affect the airways, parenchyma, as well as the bellows function with diaphragm compromise [18]. Patients with RA have an estimated 30–46 % incidence of interstitial lung disease [19–21], and may have upper airway compromise due to involvement of the cricoarytenoid joints [22, 23]. SpA patients may have significant chest wall restriction when the costovertebral joints fuse or the thoracic spine becomes ankylosed. Pulmonary function impairment increases the risk of postoperative atelectasis and pneumonia, which is more frequent when patients mobilize slowly. The majority of patients studied undergoing hip arthroplasty reveal transient hypoxemia during THA, related to fat embolization occurring during pressurization of the femoral canal, which is magnified in the presence of underlying pulmonary impairment [24]. However, regional anesthesia is the technique of choice for extremity surgery, and is less likely to be associated with pulmonary complications. Extremity surgery is generally well tolerated in the presence of pulmonary disease, as perioperative pulmonary risk is greatest in procedures performed near the diaphragm, but spine surgery may increase the risk of post operative pulmonary complications. Upper airway management can pose complex challenges when general endotracheal anesthesia (GETA) is necessary in patients with cervical spine fusion, as seen in SpA patients, or instability, present in 40 % of RA patients undergoing arthroplasty [25]. Pulmonary and airway evaluation and risk assessment, and considerations to mitigate risk by preoperative optimization and planning will be discussed.

Thromboembolic risk is increased in patients with the anti-cardiolipin antibody syndrome (ACLA) and mandates aggressive anticoagulation. Preoperative planning with anesthesia and surgery to minimize the risk of post operative hemarthrosis by restricting physical therapy may be necessary. Pulmonary Artery Hypertension (PAH) may complicate SLE, and is characterized by marked elevations in right heart pressure and decreased venous return to the heart, which can result in catastrophic hypotension and shock when magnified by the effects of anesthesia [26]. These complex manifestations of systemic connective tissue disease are addressed in detail elsewhere.

Renal impairment may increase perioperative risk in the connective tissue disease patient undergoing orthopedic surgery [8]. Underlying renal dysfunction is a significant risk factor for perioperative renal damage [27]. Renal compromise may be intrinsic to the disease state, such as glomerulonephritis in a patient with SLE. SLE patients rarely undergo TJA due to erosive joint disease, but are more likely to sustain joint damage due to organ preserving therapy including high dose corticosteroid therapy, which is the major risk factor for osteonecrosis (ON). SLE patients undergoing orthopedic surgery are therefore largely drawn from this pool of severely affected patients with intrinsic renal disease who have received high dose corticosteroid therapy [28, 29]. Renal functional impairment may also be attributed to medications such as nonsteroidal anti-inflammatory drugs (NSAIDS) or renin-angiotensin blocking agents (ACEI/ARA), which can increase the likelihood of perioperative renal damage [30]. Finally, medications used to treat IA and SLE can impair wound healing and increase the risk of infection [31]. Strategies to minimize perioperative risk while avoiding disease flare will be discussed.

## Rheumatoid Arthritis

Cartilage erosion by untreated or unresponsive rheumatoid synovial pannus typically leads to joint destruction, resulting in pain and loss of function. Reports drawn from large cohorts reveal that 34–58 % of RA patients will undergo an orthopedic intervention, usually arthroplasty. Those patients most likely to undergo surgery were those who had persistent elevations in ESR and CRP, positive rheumatoid factor, nodules, worse function scores on the Health Assessment Questionnaire (HAQ) scores, and erosions on serial radiographs [3, 4, 32]. Gratifyingly, as aggressive

therapy has become the standard of care, the natural course of RA has changed. Comparing a cohort of patients treated in 1985, only 10 % of whom were taking MTX, to a cohort studied in 2000, 76 % of whom were taking MTX, revealed that the 2000 cohort had better function on HAQ scores, lower ESR, fewer swollen joints, and fewer radiographic erosions [2]. The introduction of widespread ant-tnf therapy has further improved RA status, with improved function on HAQ scores and more frequent remissions [33]. Although the rate of orthopedic interventions has decreased overall, up to 30 % of patients fail to respond to therapy, comprising the group with persistent inflammation who are most at risk for joint damage [5].

The reported mortality after TJA is .21–68 %, based on large computerized databases. RA, underlying cardiovascular disease, as well as bilateral surgery, have been identified as factors associated with an increased surgical mortality [34, 35]. RA patients have a significant increase in atherosclerotic cardiovascular disease (ASCVD) and coronary artery disease (CAD) compared to normal controls. Carotid atherosclerosis has been demonstrated in 44%o f RA patients compared to 15 % of matched controls. ASCVD may be subclinical, and contributes to the increased mortality in RA [9, 36]. The patients at greatest risk of ASCVD are those patients with persistent active inflammation and active RA, while patients in remission are less likely to bear ASCVD risk markers such as elevated CRP or elevations of brachial blood pressure. Prolonged exposure to MTX has been shown to decrease ASCVD risk [16], an observation that has recently been extended to therapy with tnf antagonists [15]. RA therapy and low disease activity decreases cardiac risk, reinforcing cardiac concerns in the RA patients who require orthopedic surgery, who are characterized by persistent inflammation and treatment failure.

Patients with RA may not be able to exercise sufficiently to predict cardiac risk under the ACC/AHA guidelines. Demonstration of the ability to perform 4 mets of energy, achieved by walking up stairs, is sufficient for an intermediate risk surgery such as arthroplasty [7]. RA patients are frequently unable to demonstrate this, and may require formal cardiac imaging. Echocardiography can provide information on valve anatomy and cardiac function measured as ejection fraction, but stress testing is required to provide information regarding ischemic risk. Beta blockade, which is protective in regard to cardiac events, can be considered in cases where ischemic cardiac risk outweighs the recent demonstration of significant hypotension, bradycardia, and stroke associated with beta blocker use [37].

Pulmonary involvement is common in RA patients, with a reported prevalence of 50 %. When patients are screened by high resolution computed tomography (HRCT), 67 % of scans are abnormal, most commonly revealing a reticulonodular pattern and ground glass opacities typical of interstitial lung disease (ILD) and bronchiectasis [19, 38] When respiratory symptoms are used to screen for the presence of pulmonary disease, 42 % of a population of RA patients reported cough, phlegm, dyspnea, or wheezing on a validated questionnaire, in a population where 28 % of patients had abnormalities of pulmonary function testing (PFT) [21]. Patients with high titer RF positivity, high Larson or Sharp score demonstrating indicating cartilage erosion, ESR, or CRP elevations are more likely to have pulmonary abnormalities, indicating a high risk for pulmonary involvement in the population of RA patients undergoing orthopedic surgery, who share these characteristics. Risk of perioperative pulmonary complications is increased in patients with underlying pulmonary disease, as well as smoking, poor functional state, and advanced age. Surgical site is the greatest predictor of pulmonary complications, and extremity surgery is therefore low risk for pulmonary complications, which increase with proximity to the diaphragm. Spine surgery places the patient at greater risk for pulmonary complications [39]. Patient with RA undergoing extremity surgery can be screened by history, but those in whom spine surgery is planned may benefit from more comprehensive evaluation. Pulmonary function testing may be useful in estimating pulmonary reserve.

Airway obstruction is a rare but potentially fatal complication of upper airway involvement in RA. Patients may have a history of hoarseness as the only indication of cricoarytenoid arthritis. The cricoarytenoid joints, small diarthrodial joints, may be affected in patients who have longstanding polyarticular disease. Edema produced at the time of intubation may result in airway closure after extubation. Preoperative evaluation with pulmonary function testing or fiberoptic laryngoscopy may provide information needed for airway management [22, 23]. Regional anesthesia is preferred for extremity surgery, but when general anesthesia is necessary nasotracheal intubation may be employed with direct fiberoptic visualization of the airway to lessen airway trauma. Preoperative consultation with anesthesia is helpful in preparation for safe airway management.

Cervical spine involvement in RA patients accompanies severe erosive disease, and can be prevented by aggressive use of DMARDS [40]. Asymptomatic cervical spine involvement has been reported in 44 % of RA patients screened at the time of referral for arthroplasty [41, 42]. Screening should be performed on all RA patients using lateral flexion and extension x-rays. Lateral films in neutral missed 48 % of 65 known cases of atlanto-axial subluxation, and failed to fully characterize the severity of the

subluxation in 66 % [25]. MRI is a better modality to fully characterize cervical spine instability as well as basilar invagination when screening radiographs suggest spine pathology. Cervical spine instability may be a rare cause of sudden death or paraplegia. Although there are no randomized controlled trails comparing conservative therapy to surgical therapy or addressing optimal timing for intervention, neurologic deterioration occurs consistently in symptomatic patients [43]. Loss of mobility, attributed to involvement of weight-bearing joints, may be the result of neurologic compromise caused by cervical spine involvement with myelopathy. This requires evaluation by neurology and treatment, usually by surgical stabilization, prior to extremity surgery. Extremity surgery should be performed when possible under regional anesthesia, but if general anesthesia is required, fiberoptic guided nasotracheal intubation avoids hyperextension of the neck which is otherwise necessary to visualize the airway.

The rheumatoid shoulder may remain clinically silent, in spite of progressive soft tissue destruction which will eventually impact function and cause pain. Shoulder involvement may be better tolerated in light of the dominance of symptoms produced by damage to the hands or weight bearing joints. Additionally, patients may compensate with scapulothoracic motion until significant damage to the soft tissue shoulder envelop has occurred. Plain radiographs are insensitive to shoulder damage, as damage to the structures of the rotator cuff cannot be visualized without ultrasound or MRI, which reveal three times the incidence of supraspinatus tendon rupture and five times the incidence of infraspinatus tendon rupture when compared to OA patients [44]. The relatively silent nature of shoulder involvement in RA has implications at the time of total shoulder arthroplasty (TSA) surgery, however. In a series of 55 shoulders in 49 patients with RA, improvement in pain, decrease in sleep disturbance as well as improvements in activities of daily living (ADL) such as personal hygiene were reported over a 20 year period of observation [45]. Improvement after TSA depends on the preoperative status of the rotator cuff, or its repair at the time of surgery. Hemiarthroplasty remains a good option when the glenoid is severely eroded and the rotator cuff is irreparable [46]. Complications are rare, and no significant difference has been seen when OA patients are compared to RA patients undergoing TSA [47].

RA patients undergoing arthroplasty have an excellent response in terms of pain relief as measured by VAS pain scales, but lag in functional measures. When measurements of global well-being such as the SF-36 and are studied by RA patients after arthroplasty, the scores predictably improve. Functional measurements such as the HAQ lag behind the scores of osteoarthritis patients [48]. Long term outcome for THA and TKA in RA patients, measured as implant durability, is equivalent or better than implant survival for OA patients [4, 49]. RA patients report high levels of satisfaction after arthroplasty, even when objective measures lag behind the less satisfied OA arthroplasty patients [50].

## Systemic Lupus Erythematosus

Although 90 % of SLE patients have joint inflammation, it is typically benign and does not erode cartilage. Some SLE patients, however, may have RA features, leading to joint destruction. Joint destruction severe enough to warrant arthroplasty, however, occurred in only 3.8 % of 500 SLE patients in a well studied cohort, significantly fewer than the 58 % of RA patients who undergo orthopedic surgery. Of the 19/500 SLE patients undergoing arthroplasty, osteonecrosis (ON) was more likely to lead to surgery, in 10/19 patients, than SLE-RA overlap [29, 51]. ON occurs early in SLE patients beginning therapy with corticosteroids. MRI, a very sensitive technique for diagnosing ON, reveals asymptomatic ON in 40 % of studied patients, as early as 1–3 months after starting corticosteroid therapy [51]. (Symptomatic ON is less common, present in 12.8 % of patients [52].) The risk of ON is primarily conferred by corticosteroid dose alone. Although other factors such as renal involvement, cushingoid appearance, and Raynaud's phenomenon have been linked to an increase in ON, careful analysis of 570 SLE patients, 11.5 % of whom had ON, failed to demonstrate any other factor associated with ON when matched for corticosteroid dose [53]. Unlike the RA population, need for arthroplasty may reflect successful aggressive organ preserving therapy in SLE, rather than demonstrating a failure to respond to treatment. There are few successful interventions to lessen ON, although small series suggest bisphosphonates may play a mitigating role [54].

Patients with large ON lesions occupying more than 2/3 of the weight bearing surface of the femoral head are likely to develop subchondral collapse, and will usually require TJA to preserve function. Non-arthroplasty surgical interventions for ON such as core decompression remain a possible option when pain is intractable, but should be reserved for cases where subchondral fracture and collapse have not occurred. Free vascularized fibular grafts have been described to treat ON, but the results have not been widely reproducible [52, 55, 56]. In our experience, all joint sparing procedures are less likely to succeed in SLE patients who require ongoing steroid therapy.

SLE patients undergoing TJA have higher in-hospital mortality as revealed in a recent analysis of a national inpatient database [8]. SLE patients are known to have an excess mortality due to atherosclerotic cardiovascular disease, a finding independent of the presence of traditional risk factors such as diabetes or hypertension [57]. Arthroplasty is

an intermediate risk procedure in the risk stratification strategy proposed by the American College of Cardiology/American Heart Association, which correlates with a 1–5 % risk of cardiac death or nonfatal MI. SLE patients should be screened, as should all patients, by history. When exercise tolerance permits 4–10 mets of exertion, achieved by walking up stairs or performing vigorous sports, no further cardiac evaluation may be necessary. As many of these patients are not capable of exercise due to their arthritis, inclusion of pharmacologic stress testing to identify subclinical ischemic disease should be considered in these patients whose risk is estimated to be analogous to that of diabetic patients [7].

The higher in hospital mortality in SLE patients undergoing arthroplasty revealed in the national inpatient database was closely associated with chronic kidney disease, a co-morbidity know to increase post-operative renal damage and perioperative mortality in settings such as non-SLE hip fracture. SLE patients frequently have impaired renal function, as well as hypertension, increasing the risk of postoperative renal dysfunction [27, 58]. Careful preoperative identification of impaired renal function in SLE patients permits discontinuing other modifiable nephrotoxic agents such as NSAIDS and ACEI/ARA [59].

Secondary Antiphospholipid Antibody Syndrome (APS) may be seen in SLE, and increases the risk of vascular thrombosis. APS is a prothrombotic state defined by both the presence of antibodies directed against phospholipid and plasma proteins, in a patient with either vascular thrombosis or pregnancy loss. These antibodies include the antiphospholipid antibodies and b-2 glycoprotein [60]. The lupus anticoagulant interferes with phospholipid dependent clotting factors, resulting in a prolongation of the APTT, and less frequently, the PT. Not all patients who have evidence of a lupus anticoagulant are at increased risk of thrombosis, but the presence of these antibodies in a patient considering arthroplasty or any surgery raises concerns [61, 62]. When patients with known APS are indicated for surgery, careful coordination with anesthesia and orthopedics is mandatory. Exacerbations of APS can occur in the setting of perioperative hypercoagulability, and may include recurrent thrombosis due to withdrawal of anticoagulation, as well as breakthrough thrombosis in spite of anticoagulation due to the prothrombotic state induced by surgery. Catastrophic APS consisting of widespread thrombosis has also been described after surgery in susceptible patients. Risk of thromboembolic events can be diminished by bridging the patient from coumadin to heparin or low molecular weight heparin prior to surgery, thus minimizing the time off anticoagulants. Post-operative and intra-operative use of ancillary measures such as venous compression devices and limiting tourniquet time when possible may be helpful in decreasing the thromboembolic risk [61]. Statins and hydroxychloroquine may confer an additional antithrombotic effect, although this has not been proven. Aggressive anticoagulation is necessary in these patients, with the attendant risk of post-op hemarthrosis. Experience gained at our institution suggests that this can be minimized by slowing the post-operative physical therapy regimen, and should be discussed prior to surgery. Additional compromises in terms of anesthesia and post op analgesia may be necessary, as spinal or epidural regional anesthesia and epidural analgesia should not be employed when the patient is receiving heparin for prophylaxis or therapy in light of the risk of spinal or epidural hematomas. Bridging heparin or low molecular weight heparin may be discontinued 24 h prior to anesthesia and surgery so that regional anesthesia can be utilized, and restarted 3 h after the epidural catheter is removed. In some cases, placement of an inferior vena cava filter may be indicated.

Surgical outcome has been generally good in SLE patients undergoing arthroplasty, as reported in multiple small retrospective studies. When revision is used as the endpoint, SLE patients have the same arthroplasty survival as other patients, and have a 94 % 5 year arthroplasty survival [63–65]. Outcome for bipolar prosthesis is poor, however, with a 27 % failure rate, and bipolar prosthesis are no longer recommended for ON patients [56]. Early complications have been reported to be increased in some series, however. In 47 THA performed in 36 patients there were two intra-operative fractures which did not require further surgery, delayed wound healing was reported in 3 patients, 1 of whom required debridement 3 weeks after surgery, 2 patients had early, nonrecurrent dislocations, and 1 late deep infection [66]. Another series of 19 THA reported a complication rate of 21 %, with 2 surgical site infections, 1 hematoma, and 1 DVT [29]. These high complication rates have not been consistently reported, however.

## Spondyloarthropathy

The SpA group includes patients with AS, PsA, reactive arthritis, and the arthritis associated with Crohn's disease (CD) and ulcerative colitis (UC). The clinical unifying features include prominent enthesitis, peripheral arthritis that is frequently asymmetric, sacroiliitis with or without AS, as well as extra-articular features. This include psoriasiform skin lesions and nail pitting, mucosal ulceration extending throughout the GI tract as well as the genitalia, inflammation of the genitor-urinary (GU) tract, absence of RF and nodules, and ocular inflammation such as uveitis and conjunctivitis. The recognition of the high frequency of HLA-B27 positivity and familial clustering has strengthened the association. Specific clinical features, such as the presence of psoriasis, permit division into clinically relevant subgroups.

## Ankylosing Spondylitis

AS is characterized by vertical spinal syndesmophytes, which may lead to spinal ankylosis as well as inflammatory and erosive axial and peripheral arthritis. The goal of medical therapy is to prevent spinal ankylosis and prevent destruction of peripheral joints, for which a combination of modalities have been employed including NSAIDS, traditional and biologic DMARDS, and physical therapy modalities. There has been little success in treating the progression of spinal ankylosis, however [67]. Younger age of onset of AS and severity of spine involvement predict hip involvement [68].

Hip arthritis is present in 30–50 % of AS patients, and may progress in spite of therapy [67]. The characteristic exaggerated lordosis seen in advanced AS may result in the development of a flexed knee, flexed hip gait which magnifies symptomatic arthritis in the hips or knees. Hip involvement may include significant flexion contractures and ankylosis of the hips. Bilateral hip involvement is common and in our experience, correction of both hips under the same anesthesia should be considered when there are significant contractures, to decrease the likelihood of recurrent contracture in the operated leg. THA is usually performed for pain, poor posture, and poor function, with multiple series reporting benefit in these areas. Pain relief is reported in 83–90 % of patients. Durability of the implant is also very good, with 90 % survival of the implant at 10 years, 79 % survival of the implant at 15 years, and 61 % survival of the implant at 20 years. Function is not necessarily improved as significantly as pain, however. Although ambulatory status improved in all patients, one study observed that only 42 % of AS patients who had undergone THA were employed, compared to 64 % of AS patients who had not undergone THA [69, 70].

Knee involvement may also be severe in patients with AS. TKA performed on 30 knees in 20 patients with AS were reported to provide excellent pain relief, demonstrated by an improvement in Knee Society Scores (KSS). This scale assesses pain and function and ranges from 0 to 100, with 100 indicating excellent function and no pain. Patients improved from an average score of 14 prior to surgery to 87.5 points on post-operative study. Function improved from a score of 16 pre-op to 80 points at 2 years. There was minimal change in range of motion, however. The average arc of motion was 84° prior to surgery, and although the average range of motion was 94° at 2 years, this deteriorated to an average of 86° when last seen by the authors in follow-up [71]. When patients have advanced arthritis in both the hips and the knees, hip replacement should generally be performed first to restore hip motion and correct contractures, which will facilitate rehabilitation after knee replacement surgery.

Surgery may be undertaken for spine deformities in AS, and may be indicated to restore balance or restore horizontal gaze. Opening wedge osteotomy, closed wedge osteotomy, or polysegmental wedge osteotomy may be performed to correct exaggerated spinal kyphosis. This is high risk surgery, however, with 4 % mortality, and 33 % incidence of instrumentation failure [72]. Spine surgery may be indicated for osteoporotic spine fractures, which typically occur after low impact trauma. Spine fractures are significantly increased in AS patients, but fractures of the wrist and hip are not [73]. Fracture diagnosis is frequently delayed, due in part to difficulty visualizing fracture on standard x-rays in an ankylosed spine. There is a 50 % complication rate for patients who require surgery due to neurologic deficits, and a 17.7 % 3 month mortality [74, 75].

Heterotopic ossification (HO) is reported in AS patients, and may contribute to a compromised range of motion. Revision surgeries and surgery performed in young men increase the risk of developing HO. Prophylaxis with low dose radiation or indomethacin can be used to decrease the rate of HO formation [76].

Although patients with AS frequently have pulmonary involvement, the greatest contribution to perioperative pulmonary risk is the site of surgery, with the greatest risk conferred by surgical procedures near the diaphragm [39, 77]. Extremity surgery is therefore generally well tolerated. Pulmonary manifestations of AS include chest wall restriction, and patients may develop severe restrictive ventilatory impairment due to fusion of the costovertebral joints, ankylosis of the thoracic spine, or involvement of the anterior chest wall, and become obligate diaphragmatic breathers when the costovertebral joints fuse [78]. AS patients should be mobilized quickly with attention to bowel function in light of concern for post-operative abdominal distention or ileus which might compromise the respiratory status of these patients by upward pressure on the diaphragm. There are no available studies determining the perioperative risk conferred by restrictive pulmonary or chest wall pathology, however. In addition, a common cause of restrictive pulmonary physiology, obesity, has not been shown to increase perioperative pulmonary risk [39, 79].

Upper extremity surgery, frequently performed with scalene nerve block anesthesia, typically paralyzes the ipsilateral diaphragm and may not be well tolerated in patients with the chest wall restriction frequently seen in AS. AS patients should be evaluated by anesthesia prior to surgery and regional anesthesia should be used whenever possible for lower extremity surgery. Fiberoptic visualization may be necessary for intubation when general anesthesia is necessary when the cervical spine is fused to prevent injury and fracture.

Patients with AS have an increase in cardiac disease compared to those without chronic inflammatory diseases, which may be responsible for the doubled mortality reported in AS patients. Aortic valve disease with regurgitation and aortic root dilatation has been described historically. More recent studies have not confirmed these finding, although there is a high prevalence of diastolic dysfunction [80, 81]. Conduction abnormalities such as 1′ A-V block and prolongation of the QRS interval are described and are associated with prolonged disease duration [82]. The prevalence of coronary artery disease in AS may be related to an increase in traditional risk factors such as hypertension and the presence of chronic inflammation with persistent elevations of CRP, as well as dyslipidemia with lower levels of protective high density lipoproteins(hdl) [83]. Preoperative cardiac evaluation should include careful assessment of AS patients for traditional cardiac risk factors, and imaging studies such as echocardiography or stress testing should be performed when history or physical exam suggests cardiac symptoms or limitation, or when the patient is unable to achieve 4 mets of exertion necessary to undertake orthopedic surgery.

Osteoporosis and osteopenia is highly prevalent in AS, described in the spine in 57 % and the femoral neck in 47 % of patients [84]. Osteoporosis is associated with male gender, high levels of inflammatory markers such as CRP, high disease activity score, and low functional capacity [85]. Diagnosis may be difficult due to concurrent spinal syndesmophytes, which can lead to overestimation of bone mineral density(BMD), but bone turnover markers such as collagen crosslinks and low vitamin D levels may be helpful [86–88]. The role of osteoporosis in arthroplasty outcome or the rate of periprosthetic osteolysis is not clear, but evaluation of BMD and vitamin D levels with treatment where indicated may have benefits in arthroplasty outcome.

## Psoriatic Arthritis

PsA has variable presentations. Skin lesions may be the dominant clinical feature, or may be absent at the time of diagnosis. Arthritis typically develops 10 years after the skin lesions have been present. Observational cohort studies are ongoing to define the course and prognostic features of this disease. Careful longitudinal study has demonstrated the development of severe erosive disease in 20 % of patients. Additionally, over half of the patients followed for greater than 10 years will progress to joint damage. Those patients with more than five involved joints at the time of onset, persistent joint inflammation, and persistent elevations of CRP are the patients likely to progress [87, 88]. Although only 17 % of patients in this large observational cohort were able to sustain a remission, another 34 % had minimal disease activity, indicating a substantial benefit from therapy [89]. In a cohort of 504 PsA patients, only 32 patients, or 6.3 % developed hip arthritis, of whom only 9/32 patients, or 1.8 % of the total cohort underwent THA. Patients likely to progress to THA were those with an earlier age at onset of PsA and spondylosis [90].

Patients with psoriatic arthritis appear to have an increase in subclinical cardiovascular disease, similar to patients with other systemic inflammatory diseases. Cardiovascular disease in PsA correlates with the severity and extent of the skin disease. Cohorts including patients with mild disease are less likely to show an increase in cardiovascular disease or an excess mortality [14, 91]. Although cardiovascular disease in severely affected PsA patients is independent of traditional risk factors, PsA patients also have an increase in known cardiac risk factors such as diabetes, hypertension, smoking, and hyperlipidemia [92]. Patients undergoing arthroplasty should therefore be evaluated for cardiac disease following the American College of Cardiology/America Heart association guidelines when a history demonstrating adequate exercise tolerance is not available.

The orthopedic literature is of little help in guiding an approach to optimizing arthroplasty outcome in infection rate in patients undergoing TKA. Early reports revealed a high rate of both superficial (9.1 %) and deep (5.5 %) infection in PsA patients undergoing THA. PsA patients undergoing TKA were reported to have an infection rate of 17 % [93–95]. When perioperative antibiotics were employed, this extreme rate of infection was not duplicated [94]. Current routine precautions include treatment of the psoriatic skin prior to surgery, with particular attention to the operative site, as well as routine use of perioperative antibiotics, which have resulted in a decrease in infection. Antibiotic laden cement may be appropriate for selected cases.

## Medications

Medications that suppress the immune system and may affect wound healing are frequently prescribed for the treatment of systemic rheumatic diseases, and may contribute to the increase in perioperative complications seen in these patients. The three major drug categories used in these patients are corticosteroids, DMARDs including synthetic molecules such as methotrexate, hydroxychloroquine, azathiaprine, and leflunomide, and the biologic agents including the TNF blocking agents.

## Corticosteroid

Corticosteroids are used in rheumatic diseases for their striking anti-inflammatory effect, but are known to increase

infection risk and to have a negative effect on wound healing. Patients who have received daily corticosteroid therapy have suppression of their endogenous adrenal function as demonstrated by ACTH stimulation tests. Because of the risk of hypotension, "stress-dose," or supraphysiologic steroid is typically administered at the time of surgery. Although suppression of the adrenal axis is easily demonstrated after relatively short courses of corticosteroid, it is less clear when supraphysiologic doses of cortisone are actually needed. When patients on chronic daily steroid, all of whom had been demonstrated to have adrenal insufficiency by ACTH stimulation testing, underwent surgery such as arthroplasty and were randomized to either receive parenteral corticosteroid or saline alone, in addition to their usual daily steroid dose, there was no hemodynamic difference between the groups. Similar results were obtained when patients treated with long term corticosteroid were hospitalized with significant stress such as sepsis [96, 97]. Endogenous cortisol production has been measured in healthy patients undergoing surgery to determine the normal response to stress. Patients undergoing arthroscopy have no increase in their cortisol production, whereas patients undergoing arthroplasty have a 17-fold increase from baseline cortisol production [98]. Recommendations can be extrapolated from these studies. We recommend that patients undergoing minor procedures such as arthroscopy or carpal tunnel surgery can take only their usual daily steroid dose. Patients undergoing moderate surgery such as unilateral arthroplasty should receive 50 mg of hydrocortisone acetate (HCA) in the operating room, and 20 mg HCA every 8 h throughout the day of surgery and on post-op day one. Patients undergoing major surgery such as bilateral arthroplasty or revision surgery should receive 50 mg of HCA in the operating room and 50 mg HCA every 8 h throughout the day of surgery and on post-op day 1. Resumption of the usual daily dose of cortisone can begin on post-operative day 2.

## Synthetic DMARDS

Methotrexate has been extremely well studied in the perioperative period [99, 100]. Continuing methotrexate in the perioperative period does not increase surgical site infections and has no negative impact on wound healing. Moreover, patients who discontinue methotrexate predictably flare, compromising rehabilitation. Methotrexate therefore should be continued through the operative period. Hydroxychloroquine has not been studied in the perioperative period but does not suppress the immune system and has a favorable toxicity profile. It should be continued through surgery. Several small studies have demonstrated an increase in surgical site infection in patients taking leflunomide at the time of arthroplasty. Leflunomide should be discontinued until bowel and renal function have returned to baseline status, cognizant of the persistence of leflunomide levels without chelation [31, 100–102].

## Biologic Agents

Use of anti-TNF agents in inflammatory arthritis has significantly decreased the disease burden for patients with IA, but there is a clear risk of severe infection which is highest within the first 6 months of therapy [2, 103–105]. Although there are no randomized clinical trials to test the impact on surgical site infections, there are multiple retrospective studies as well as studies drawn from large population databases that show an association of TNF inhibitor therapy with surgical site infection. Biologic agents are traditionally discontinued prior to surgery, based on the pharmacologic half-life of the drug. The last dose of etanercept should be 2 weeks prior to surgery, adalimumab; 2–3 weeks prior to surgery, and infliximab should be discontinued 4–6 weeks prior to surgery [104–108]. These agents can be restarted 2 weeks after surgery once the wound has healed and there is no sign of wound drainage or erythema.

## Summary

Patients with systemic connective tissue diseases and inflammatory arthritis frequently require orthopedic joint reconstruction to restore function and diminish pain, either in the setting of poorly responsive IA or as a consequence of therapy in patients with ON. Multisystem involvement in these patients frequently includes occult cardiopulmonary disease, which can be evaluated preoperatively so that the patients' status can be optimized. Results of surgery are gratifying in terms of pain relief, although functional improvements may lag behind patients undergoing the same procedures for osteoarthritis. Careful collaboration between surgeons, anesthesiologists, and rheumatologists is fundamental to optimize outcome.

**Summary Bullet Points**

- Patients with Rheumatoid Arthritis undergoing orthopedic reconstruction are those who have failed to respond to medical management, and typically have multiple affected joints, occult multisystem

disease, and significant functional disability, all contributing to the perioperative challenge.

- Patients with Systemic Lupus Erythematosus undergoing orthopedic reconstruction are typically those who have required high dose corticosteroid therapy for severe manifestations, and may have functional impairment in renal or cardiac systems at the time of surgery.
- Patients with Ankylosing Spondylitis undergoing orthopedic reconstruction of their hips or knees may have concurrent deformities of the spine, which can complicate mechanical alignment and additionally compromise respiratory function.
- Spondyloarthropathy patients with Psoriatic Arthritis undergoing orthopedic reconstruction may have active skin disease, a potential source of infection, and have a significant increase in associated obesity, diabetes, and smoking, all of which can increase perioperative risk.

## Case Study

A case study for this chapter is included in Appendix G at the end of this book.

## References


1. Urban MK, Jules-Elysee K, Loughlin C, Kelsey W, Flynn E. The one year incidence of postoperative myocardial infarction in an orthopedic population. HSS J. 2008;4(1):76–80.
2. Pincus T, Sokka T, Kautiainen H. Patients seen for standard rheumatoid arthritis care have significantly better articular, radiographic, laboratory, and functional status in 2000 than in 1985. Arthritis Rheum. 2005;52(4):1009–19.
3. Massardo L, Gabriel SE, Crowson CS, O'Fallon WM, Matteson EL. A population based assessment of the use of orthopedic surgery in patients with rheumatoid arthritis. J Rheumatol. 2002;29(1):52–6.
4. Wolfe F, Zwillich SH. The long-term outcomes of rheumatoid arthritis: a 23-year prospective, longitudinal study of total joint replacement and its predictors in 1,600 patients with rheumatoid arthritis. Arthritis Rheum. 1998;41(6):1072–82.
5. Weiss RJ, Ehlin A, Montgomery SM, Wick MC, Stark A, Wretenberg P. Decrease of RA-related orthopaedic surgery of the upper limbs between 1998 and 2004: data from 54,579 Swedish RA inpatients. Rheumatology (Oxford). 2008;47(4):491–4.
6. Weiss RJ, Stark A, Wick MC, Ehlin A, Palmblad K, Wretenberg P. Orthopaedic surgery of the lower limbs in 49,802 rheumatoid arthritis patients: results from the Swedish National Inpatient Registry during 1987 to 2001. Ann Rheum Dis. 2006;65(3):335–41.
7. FleisherLA B, Brown KA, et al. ACC/AHA 2007 guidelines on perioperative cardiovascular evaluation and care for noncardiac surgery: a report of the American College of Cardiology/American Heart Association Task Force on practice guidelines. J Am Coll Cardiol. 2007;50:159–242.
8. Domsic RT, Lingala B, Krishnan E. Systemic lupus erythematosus, rheumatoid arthritis, and postarthroplasty mortality: a cross-sectional analysis from the nationwide inpatient sample. J Rheumatol. 2010;37(7):1467–72.
9. Salmon JE, Roman MJ. Subclinical atherosclerosis in rheumatoid arthritis and systemic lupus erythematosus. Am J Med. 2008;121(10 Suppl 1):S3–8.
10. Roman MJ, Shanker BA, Davis A, et al. Prevalence and correlates of accelerated atherosclerosis in systemic lupus erythematosus. N Engl J Med. 2003;349(25):2399–406.
11. Mathieu S, Gossec L, Dougados M, Soubrier M. Cardiovascular profile in ankylosing spondylitis. A systematic review and metaanalysis. Arthritis Care Res (Hoboken). 2011;63(4):557–63.
12. McCarey D, Sturrock RD. Comparison of cardiovascular risk in ankylosing spondylitis and rheumatoid arthritis. Clin Exp Rheumatol. 2009;27(4 Suppl 55):S124–6.
13. Gladman DD. Mortality in psoriatic arthritis. Clin Exp Rheumatol. 2008;26(5 Suppl 51):S62–5.
14. Gladman DD, Ang M, Su L, Tom BD, Schentag CT, Farewell VT. Cardiovascular morbidity in psoriatic arthritis. Ann Rheum Dis. 2009;68(7):1131–5.
15. Greenberg JD, Kremer JM, Curtis JR, et al. Tumour necrosis factor antagonist use and associated risk reduction of cardiovascular events among patients with rheumatoid arthritis. Ann Rheum Dis. 2011;70(4):576–82.
16. Naranjo A, Sokka T, Descalzo MA, et al. Cardiovascular disease in patients with rheumatoid arthritis: results from the QUEST-RA study. Arthritis Res Ther. 2008;10(2):R30.
17. van Eijk IC, de Vries MK, Levels JH, et al. Improvement of lipid profile is accompanied by atheroprotective alterations in high-density lipoprotein composition upon tumor necrosis factor blockade: a prospective cohort study in ankylosing spondylitis. Arthritis Rheum. 2009;60(5):1324–30.
18. Calderaro DC, Ferreira GA. Presentation and prognosis of shrinking lung syndrome in systemic lupus erythematosus: report of four cases. Rheumatol Int. 2012;32(5):1391–6.
19. Bilgici A, Ulusoy H, Kuru O, Celenk C, Unsal M, Danaci M. Pulmonary involvement in rheumatoid arthritis. Rheumatol Int. 2005;25(6):429–35.
20. Wolfe F, Caplan L, Michaud K. Rheumatoid arthritis treatment and the risk of severe interstitial lung disease. Scand J Rheumatol. 2007;36(3):172–8.
21. Pappas DA, Giles JT, Connors G, Lechtzin N, Bathon JM, Danoff SK. Respiratory symptoms and disease characteristics as predictors of pulmonary function abnormalities in patients with rheumatoid arthritis: an observational cohort study. Arthritis Res Ther. 2010;12(3):R104.
22. Kolman J, Morris I. Cricoarytenoid arthritis: a cause of acute upper airway obstruction in rheumatoid arthritis. Can J Anaesth. 2002;49(7):729–32.
23. Segebarth PB, Limbird TJ. Perioperative acute upper airway obstruction secondary to severe rheumatoid arthritis. J Arthroplasty. 2007;22(6):916–9.
24. Fabian TC, Hoots AV, Stanford DS, Patterson CR, Mangiante EC. Fat embolism syndrome: prospective evaluation in 92 fracture patients. Crit Care Med. 1990;18(1):42–6.
25. Kauppi M, Neva MH. Sensitivity of lateral view cervical spine radiographs taken in the neutral position in atlantoaxial subluxation in rheumatic diseases. Clin Rheumatol. 1998;17(6):511–4.
26. Ramakrishna G, Sprung J, Ravi BS, Chandrasekaran K, McGoon MD. Impact of pulmonary hypertension on the outcomes of noncardiac surgery: predictors of perioperative morbidity and mortality. J Am Coll Cardiol. 2005;45(10):1691–9.

27. Aveline C, Leroux A, Vautier P, Cognet F, Le Hetet H, Bonnet F. Risk factors for renal dysfunction after total hip arthroplasty. Ann Fr Anesth Reanim. 2009;28(9):728–34.
28. Gladman DD, Urowitz MB, Chaudhry-Ahluwalia V, Hallet DC, Cook RJ. Predictive factors for symptomatic osteonecrosis in patients with systemic lupus erythematosus. J Rheumatol. 2001;28(4):761–5.
29. Mourao AF, Amaral M, Caetano-Lopes J, Isenberg D. An analysis of joint replacement in patients with systemic lupus erythematosus. Lupus. 2009;18(14):1298–302.
30. White SM, Rashid N, Chakladar A. An analysis of renal dysfunction in 1511 patients with fractured neck of femur: the implications for peri-operative analgesia. Anaesthesia. 2009;64 (10):1061–5.
31. Scanzello CR, Figgie MP, Nestor BJ, Goodman SM. Perioperative management of medications used in the treatment of rheumatoid arthritis. HSS J. 2006;2(2):141–7.
32. Kapetanovic MC, Lindqvist E, Saxne T, Eberhardt K. Orthopaedic surgery in patients with rheumatoid arthritis over 20 years: prevalence and predictive factors of large joint replacement. Ann Rheum Dis. 2008;67(10):1412–6.
33. Hyrich KL, Lunt M, Dixon WG, Watson KD, Symmons DP, BSR Biologics Register. Effects of switching between anti-TNF therapies on HAQ response in patients who do not respond to their first anti-TNF drug. Rheumatology (Oxford). 2008;47 (7):1000–5.
34. SooHoo NF, Lieberman JR, Ko CY, Zingmond DS. Factors predicting complication rates following total knee replacement. J Bone Joint Surg Am. 2006;88(3):480–5.
35. Parvizi J, Mui A, Purtill JJ, Sharkey PF, Hozack WJ, Rothman RH. Total joint arthroplasty: when do fatal or near-fatal complications occur? J Bone Joint Surg Am. 2007;89(1):27–32.
36. Roman MJ, Devereux RB, Schwartz JE, et al. Arterial stiffness in chronic inflammatory diseases. Hypertension. 2005;46 (1):194–9.
37. Devereaux PJ, Xavier D, Pogue J, et al. Characteristics and short-term prognosis of perioperative myocardial infarction in patients undergoing noncardiac surgery: a cohort study. Ann Intern Med. 2011;154(8):523–8.
38. Bongartz T, Nannini C, Medina-Velasquez YF, et al. Incidence and mortality of interstitial lung disease in rheumatoid arthritis: a population-based study. Arthritis Rheum. 2010;62(6):1583–91.
39. Smetana GW, Lawrence VA, Cornell JE, American College of Physicians. Preoperative pulmonary risk stratification for noncardiothoracic surgery: systematic review for the American College of Physicians. Ann Intern Med. 2006;144(8):581–95.
40. Kauppi M, Laiho K, Neva M. Diagnosing atlantoaxial impaction and basilar invagination. J Bone Joint Surg Am. 2002;84-A (3):491–2.
41. Neva MH, Isomaki P, Hannonen P, Kauppi M, Krishnan E, Sokka T. Early and extensive erosiveness in peripheral joints predicts atlantoaxial subluxations in patients with rheumatoid arthritis. Arthritis Rheum. 2003;48(7):1808–13.
42. Neva MH, Hakkinen A, Makinen H, Hannonen P, Kauppi M, Sokka T. High prevalence of asymptomatic cervical spine subluxation in patients with rheumatoid arthritis waiting for orthopaedic surgery. Ann Rheum Dis. 2006;65(7):884–8.
43. Wolfs JF, Kloppenburg M, Fehlings MG, van Tulder MW, Boers M, Peul WC. Neurologic outcome of surgical and conservative treatment of rheumatoid cervical spine subluxation: a systematic review. Arthritis Rheum. 2009;61(12):1743–52.
44. Sanja MR, Mirjana ZS. Ultrasonographic study of the painful shoulder in patients with rheumatoid arthritis and patients with degenerative shoulder disease. Acta Reumatol Port. 2010;35 (1):50–8.
45. Betts HM, Abu-Rajab R, Nunn T, Brooksbank AJ. Total shoulder replacement in rheumatoid disease: a 16- to 23-year follow-up. J Bone Joint Surg Br. 2009;91(9):1197–200.
46. Rozing PM, Nagels J, Rozing MP. Prognostic factors in arthroplasty in the rheumatoid shoulder. HSS J. 2011;7(1):29–36.
47. Hambright D, Henderson RA, Cook C, Worrell T, Moorman CT, Bolognesi MP. A comparison of perioperative outcomes in patients with and without rheumatoid arthritis after receiving a total shoulder replacement arthroplasty. J Shoulder Elbow Surg. 2011;20(1):77–85.
48. Osnes-Ringen H, Kvien TK, Henriksen JE, Mowinckel P, Dagfinrud H. Orthopaedic surgery in 255 patients with inflammatory arthropathies: longitudinal effects on pain, physical function and health-related quality of life. Ann Rheum Dis. 2009;68 (10):1596–601.
49. Rud-Sorensen C, Pedersen AB, Johnsen SP, Riis AH, Overgaard S. Survival of primary total hip arthroplasty in rheumatoid arthritis patients. Acta Orthop. 2010;81(1):60–5.
50. Bullens PH, van Loon CJ, de Waal Malefijt MC, Laan RF, Veth RP. Patient satisfaction after total knee arthroplasty: a comparison between subjective and objective outcome assessments. J Arthroplasty. 2001;16(6):740–7.
51. Oinuma K, Harada Y, Nawata Y, et al. Osteonecrosis in patients with systemic lupus erythematosus develops very early after starting high dose corticosteroid treatment. Ann Rheum Dis. 2001;60(12):1145–8.
52. Gladman DD, Chaudhry-Ahluwalia V, Ibanez D, Bogoch E, Urowitz MB. Outcomes of symptomatic osteonecrosis in 95 patients with systemic lupus erythematosus. J Rheumatol. 2001;28(10):2226–9.
53. Prasad R, Ibanez D, Gladman D, Urowitz M. The role of non-corticosteroid related factors in osteonecrosis (ON) in systemic lupus erythematosus: a nested case–control study of inception patients. Lupus. 2007;16(3):157–62.
54. Agarwala S, Jain D, Joshi VR, Sule A. Efficacy of alendronate, a bisphosphonate, in the treatment of AVN of the hip. A prospective open-label study. Rheumatology (Oxford). 2005;44(3):352–9.
55. Sun Y, Zhang CQ, Chen SB, Sheng JG, Jin DX, Zeng BF. Treatment of femoral head osteonecrosis in patients with systemic lupus erythematosus by free vascularised fibular grafting. Lupus. 2009;18(12):1061–5.
56. Chen YW, Chang JK, Huang KY, Lin GT, Lin SY, Huang CY. Hip arthroplasty for osteonecrosis in patients with systemic lupus erythematosus. Kaohsiung J Med Sci. 1999;15(12):697–703.
57. Salmon JE, Roman MJ. Accelerated atherosclerosis in systemic lupus erythematosus: implications for patient management. Curr Opin Rheumatol. 2001;13(5):341–4.
58. Bennet SJ, Berry OM, Goddard J, et al. Acute renal dysfunction following hip fracture. Injury. 2010;41(4):335–8.
59. Arora P, Rajagopalam S, Ranjan R, et al. Preoperative use of angiotensin-converting enzyme inhibitors/angiotensin receptor blockers is associated with increased risk for acute kidney injury after cardiovascular surgery. Clin J Am Soc Nephrol. 2008;3 (5):1266–73.
60. Erkan D, Lockshin MD. Antiphospholipid syndrome. Curr Opin Rheumatol. 2006;18(3):242–8.
61. Erkan D, Leibowitz E, Berman J, Lockshin MD. Perioperative medical management of antiphospholipid syndrome: hospital for special surgery experience, review of literature, and recommendations. J Rheumatol. 2002;29(4):843–9.
62. Kreikemeier J, Tobias JD. Antiphospholipid antibody syndrome manifested as a postoperative cerebrovascular event in a child. South Med J. 2000;93(11):1115–9.
63. Johannson HR, Zywiel MG, Marker DR, Jones LC, McGrath MS, Mont MA. Osteonecrosis is not a predictor of poor outcomes in

primary total hip arthroplasty: a systematic literature review. Int Orthop. 2011;35(4):465–73.
64. Mont MA, Glueck CJ, Pacheco IH, Wang P, Hungerford DS, Petri M. Risk factors for osteonecrosis in systemic lupus erythematosus. J Rheumatol. 1997;24(4):654–62.
65. Huo MH, Salvati EA, Browne MG, Pellicci PM, Sculco TP, Johanson NA. Primary total hip arthroplasty in systemic lupus erythematosus. J Arthroplasty. 1992;7(1):51–6.
66. Ito H, Matsuno T, Hirayama T, Tanino H, Minami A. Health-related quality of life in patients with systemic lupus erythematosus after medium to long-term follow-up of hip arthroplasty. Lupus. 2007;16(5):318–23.
67. Zochling J, van der Heijde D, Burgos-Vargas R, et al. ASAS/EULAR recommendations for the management of ankylosing spondylitis. Ann Rheum Dis. 2006;65(4):442–52.
68. Chen HA, Chen CH, Liao HT, et al. Factors associated with radiographic spinal involvement and hip involvement in ankylosing spondylitis. Semin Arthritis Rheum. 2011;40(6):552–8.
69. Sochart DH, Porter ML. Long-term results of total hip replacement in young patients who had ankylosing spondylitis. Eighteen to thirty-year results with survivorship analysis. J Bone Joint Surg Am. 1997;79(8):1181–9.
70. Sweeney S, Gupta R, Taylor G, Calin A. Total hip arthroplasty in ankylosing spondylitis: outcome in 340 patients. J Rheumatol. 2001;28(8):1862–6.
71. Parvizi J, Duffy GP, Trousdale RT. Total knee arthroplasty in patients with ankylosing spondylitis. J Bone Joint Surg Am. 2001;83-A(9):1312–6.
72. van Royen BJ, de Kleuver M, Slot GH. Polysegmental lumbar posterior wedge osteotomies for correction of kyphosis in ankylosing spondylitis. Eur Spine J. 1998;7(2):104–10.
73. Vosse D, Landewe R, van der Heijde D, van der Linden S, van Staa TP, Geusens P. Ankylosing spondylitis and the risk of fracture: results from a large primary care-based nested case–control study. Ann Rheum Dis. 2009;68(12):1839–42.
74. Westerveld LA, Verlaan JJ, Oner FC. Spinal fractures in patients with ankylosing spinal disorders: a systematic review of the literature on treatment, neurological status and complications. Eur Spine J. 2009;18(2):145–56.
75. Caron T, Bransford R, Nguyen Q, Agel J, Chapman J, Bellabarba C. Spine fractures in patients with ankylosing spinal disorders. Spine (Phila Pa 1976). 2010;35(11):E458–64.
76. Iorio R, Healy WL. Heterotopic ossification after hip and knee arthroplasty: risk factors, prevention, and treatment. J Am Acad Orthop Surg. 2002;10(6):409–16.
77. Qaseem A, Snow V, Fitterman N, et al. Risk assessment for and strategies to reduce perioperative pulmonary complications for patients undergoing noncardiothoracic surgery: a guideline from the American College of Physicians. Ann Intern Med. 2006;144(8):575–80.
78. Kanathur N, Lee-Chiong T. Pulmonary manifestations of ankylosing spondylitis. Clin Chest Med. 2010;31(3):547–54.
79. Blouw EL, Rudolph AD, Narr BJ, Sarr MG. The frequency of respiratory failure in patients with morbid obesity undergoing gastric bypass. AANA J. 2003;71(1):45–50.
80. Brunner F, Kunz A, Weber U, Kissling R. Ankylosing spondylitis and heart abnormalities: do cardiac conduction disorders, valve regurgitation and diastolic dysfunction occur more often in male patients with diagnosed ankylosing spondylitis for over 15 years than in the normal population? Clin Rheumatol. 2006;25(1):24–9.
81. Yildirir A, Aksoyek S, Calguneri M, Oto A, Kes S. Echocardiographic evidence of cardiac involvement in ankylosing spondylitis. Clin Rheumatol. 2002;21(2):129–34.
82. Dik VK, Peters MJ, Dijkmans PA, et al. The relationship between disease-related characteristics and conduction disturbances in ankylosing spondylitis. Scand J Rheumatol. 2010;39(1):38–41.
83. Bremander A, Petersson IF, Bergman S, Englund M. Population-based estimates of common comorbidities and cardiovascular disease in ankylosing spondylitis. Arthritis Care Res (Hoboken). 2011;63(4):550–6.
84. Muntean L, Rojas-Vargas M, Font P, et al. Relative value of the lumbar spine and hip bone mineral density and bone turnover markers in men with ankylosing spondylitis. Clin Rheumatol. 2011;30(5):691–5.
85. van der Weijden MA, van Denderen JC, Lems WF, Heymans MW, Dijkmans BA, van der Horst-Bruinsma IE. Low bone mineral density is related to male gender and decreased functional capacity in early spondylarthropathies. Clin Rheumatol. 2011;30(4):497–503.
86. Arends S, Spoorenberg A, Bruyn GA, et al. The relation between bone mineral density, bone turnover markers, and vitamin D status in ankylosing spondylitis patients with active disease: a cross-sectional analysis. Osteoporos Int. 2011;22(5):1431–9.
87. Gladman DD, Chandran V. Observational cohort studies: lessons learnt from the University of Toronto psoriatic arthritis program. Rheumatology (Oxford). 2011;50(1):25–31.
88. Gladman DD, Shuckett R, Russell ML, Thorne JC, Schachter RK. Psoriatic arthritis (PSA) – an analysis of 220 patients. Q J Med. 1987;62(238):127–41.
89. Gladman DD, Mease PJ, Choy EH, Ritchlin CT, Perdok RJ, Sasso EH. Risk factors for radiographic progression in psoriatic arthritis: subanalysis of the randomized controlled trial ADEPT. Arthritis Res Ther. 2010;12(3):R113.
90. Michet CJ, Mason TG, Mazlumzadeh M. Hip joint disease in psoriatic arthritis: risk factors and natural history. Ann Rheum Dis. 2005;64(7):1068–70.
91. Buckley C, Cavill C, Taylor G, et al. Mortality in psoriatic arthritis – a single-center study from the UK. J Rheumatol. 2010;37(10):2141–4.
92. Tobin AM, Veale DJ, Fitzgerald O, et al. Cardiovascular disease and risk factors in patients with psoriasis and psoriatic arthritis. J Rheumatol. 2010;37(7):1386–94.
93. Stern SH, Insall JN, Windsor RE, Inglis AE, Dines DM. Total knee arthroplasty in patients with psoriasis. Clin Orthop Relat Res. 1989;248(248):108–10. discussion 111.
94. Beyer CA, Hanssen AD, Lewallen DG, Pittelkow MR. Primary total knee arthroplasty in patients with psoriasis. J Bone Joint Surg Br. 1991;73(2):258–9.
95. Zangger P, Esufali ZH, Gladman DD, Bogoch ER. Type and outcome of reconstructive surgery for different patterns of psoriatic arthritis. J Rheumatol. 2000;27(4):967–74.
96. Bromberg JS, Alfrey EJ, Barker CF, et al. Adrenal suppression and steroid supplementation in renal transplant recipients. Transplantation. 1991;51(2):385–90.
97. Glowniak JV, Loriaux DL. A double-blind study of perioperative steroid requirements in secondary adrenal insufficiency. Surgery. 1997;121(2):123–9.
98. Leopold SS, Casnellie MT, Warme WJ, Dougherty PJ, Wingo ST, Shott S. Endogenous cortisol production in response to knee arthroscopy and total knee arthroplasty. J Bone Joint Surg Am. 2003;85-A(11):2163–7.
99. Grennan DM, Gray J, Loudon J, Fear S. Methotrexate and early postoperative complications in patients with rheumatoid arthritis undergoing elective orthopaedic surgery. Ann Rheum Dis. 2001;60(3):214–7.
100. Bongartz T. Elective orthopedic surgery and perioperative DMARD management: many questions, fewer answers, and some opinions. J Rheumatol. 2007;34(4):653–5.

101. Jenks KA, Stamp LK, O'Donnell JL, Savage RL, Chapman PT. Leflunomide-associated infections in rheumatoid arthritis. J Rheumatol. 2007;34(11):2201–3.
102. Mushtaq S, Goodman SM, Scanzello CR. Perioperative management of biologic agents used in treatment of rheumatoid arthritis. Am J Ther. 2011;18(5):426–34.
103. Bongartz T, Halligan CS, Osmon DR, et al. Incidence and risk factors of prosthetic joint infection after total hip or knee replacement in patients with rheumatoid arthritis. Arthritis Rheum. 2008;59(12):1713–20.
104. Galloway JB, Hyrich KL, Mercer LK, et al. Anti-TNF therapy is associated with an increased risk of serious infections in patients with rheumatoid arthritis especially in the first 6 months of treatment: updated results from the British Society for rheumatology biologics register with special emphasis on risks in the elderly. Rheumatology (Oxford). 2011;50(1):124–31.
105. Giles JT, Bartlett SJ, Gelber AC, et al. Tumor necrosis factor inhibitor therapy and risk of serious postoperative orthopedic infection in rheumatoid arthritis. Arthritis Rheum. 2006;55(2):333–7.
106. Bongartz T, Sutton AJ, Sweeting MJ, Buchan I, Matteson EL, Montori V. Anti-TNF antibody therapy in rheumatoid arthritis and the risk of serious infections and malignancies: systematic review and meta-analysis of rare harmful effects in randomized controlled trials. JAMA. 2006;295(19):2275–85.
107. den Broeder AA, Creemers MC, Fransen J, et al. Risk factors for surgical site infections and other complications in elective surgery in patients with rheumatoid arthritis with special attention for anti-tumor necrosis factor: a large retrospective study. J Rheumatol. 2007;34(4):689–95.
108. Dixon WG, Watson K, Lunt M, et al. Rates of serious infection, including site-specific and bacterial intracellular infection, in rheumatoid arthritis patients receiving anti-tumor necrosis factor therapy: results from the British Society for rheumatology biologics register. Arthritis Rheum. 2006;54(8):2368–76.

# Perioperative Care of the Orthopedic Patient with Cardiac Disease

11

Lawrence F. Levin

**Objectives**

- To identify cardiac conditions affecting postoperative outcome.
- To optimize the cardiac conditions affecting postoperative outcome via pharmacologic therapy and interventional therapy.
- To review postoperative considerations and conditions in light of cardiac revascularization, devices, valvular heart disease, atrial fibrillation, and myocardial ischemia.

**Key Points**

- Significant cardiac morbidity and mortality are experienced by patients in the setting of orthopedic surgery.
- Risk to an individual patient can be stratified, incorporating clinical information including the patient's functional capacity as well as their medical history, specifically preexisting ischemic heart disease, heart failure, cerebrovascular disease, renal insufficiency, and diabetes.
- Supplemental testing beyond a thorough history and physical examination is necessary only in the patient deemed to be at high risk based on the aforementioned clinical criteria.
- Maintenance of ongoing cardiac pharmacotherapy is generally appropriate; initiation of B-blocker should be considered in the higher risk population, ideally at least a week in advance of the procedure.
- Preoperative coronary revascularization does not reduce the risk of orthopedic surgery and therefore should be performed only to reduce the patient's lifetime risk of adverse cardiac events.

L.F. Levin (✉)
Department of Cardiovascular Disease, Hospital for Special Surgery, 407 East 70th Street, New York, NY 10021, USA
e-mail: lawrencelevin@optonline.net

## Introduction

Cardiac complications of surgery are a major public health concern. Two hundred million people undergo noncardiac surgery yearly with a cardiac complication rate reported from 0.5 % to 3.5 % [1]. In 4,315 undergoing major surgery from 1989 to 1994, Lee et al. report a 2.1 % rate of such complications [2]. Between 1996 and 2008, the Dutch Echocardiographic Cardiac Risk Evaluating Applying Stress Echo (DECREASE) trials reported a 3.5 % incidence of major cardiac complications among intermediate- and high-risk patients [3].

Orthopedic surgery increases the risk for cardiac events by multiple mechanisms. Catecholamines are significantly heightened due to tissue injury inherent to orthopedic surgery as well as perioperative pain. The increased catecholamines induce tachycardia and thus increase myocardial contractility and oxygen demand. Demand ischemia—the mismatch of myocardial oxygen demand and myocardial perfusion—accounts for half of cardiac complications of orthopedic surgery [1]. Additionally surgical stress induces a systemic inflammatory response, which can lead to rupture of previously stable atherosclerotic plaque. A significant portion of the orthopedic population suffers from underlying rheumatologic illness further heightening inflammatory responses and potentially destabilizing plaque. Inherent to all surgeries including orthopedic procedures are fluid shifts with fluctuating intravascular volume due to capillary leakage also related to postoperative inflammatory responses. Such surgery evokes a hypercoagulable response as fibrinogen levels and

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_11, © Springer New York 2014

coagulation factors are upregulated. Platelets are activated with heightened aggregation. These influences, coupled with a decrease in fibrinolytic factors, all contribute to a hypercoagulable state.

With this in mind, the orthopedic patient is at risk for cardiac complications. The goal of this chapter is to help minimize this risk and to assist in the treatment of cardiac complications. The first step is to stratify the patient for risk of cardiac complications after which the preoperative measures used to optimize cardiac risk will be elucidated. A discussion of the management of those cardiac conditions commonly seen in orthopedic populations concludes the chapter.

## The Identification of Cardiac Conditions Affecting Postoperative Outcome

The goal of perioperative cardiac care is to minimize the cardiac complications after surgery. Risk stratification for perioperative cardiac events is not only used in the implementation of perioperative therapies but is also useful in discussions with the patient and family as they consider different therapies for their orthopedic condition. If a patient's risk for perioperative cardiac events is significantly elevated and not modifiable, and if surgery is deemed elective, the patient, the clinician, and the orthopedist may decide not to pursue that procedure treating the patient conservatively. Likewise, if the patient's risk for perioperative cardiac events is high but the risk modifiable a decision to postpone surgery to pursue therapies, either pharmacologic or invasive, to minimize perioperative risk would seem in order. Lastly, a surgical patient deemed low risk for cardiac complications might have a lower threshold for pursuing surgery if on balance the benefit of surgery outweighs the risk.

The functional capacity of the patient has been shown in multiple analyses to predict perioperative cardiac events: the greater the preoperative exercise capacity of the patient, the lower the postoperative cardiac event rate [4–6]. The Duke Activity Status Index is often used to determine this parameter [7, 8]. The basal metabolic rate of an average sized male is one metabolic equivalent. This is the average energy expenditure while lying down performing no physical activity. Inability to perform four metabolic equivalents of activity is considered a poor functional capacity, while climbing two flights of stairs without stopping (4–7 metabolic equivalents of exercise) has been associated with reduced cardiovascular complications (Fig. 11.1). Seven to ten metabolic equivalents are considered good while >10 metabolic equivalents are excellent and place the patient at low risk for perioperative cardiac events.

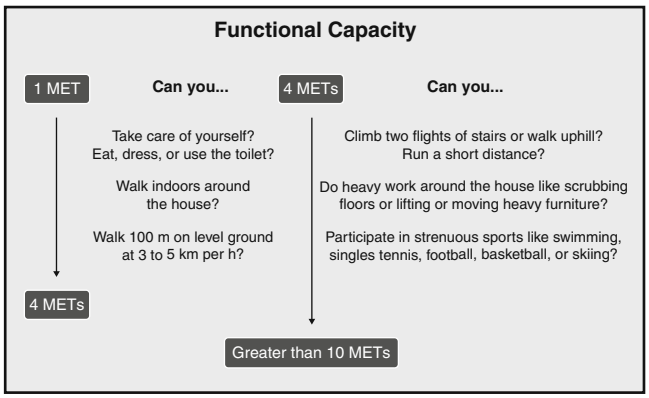


**Fig. 11.1** Estimated energy requirements for various activities. *km per h* kilometers per hour, *MET* metabolic equivalent. Based on Hlatky et al. [7] and Fletcher et al. [8]. (Used with permission from Poldermans D, Bax JJ, Boersma E, De Hert S, Eeckhout E, Fowkes G, Gorenek B, Hennereci MG, Iung B, Kelm M, Kjeldsen KP, Kristensen SD, Lopez-Sendon J, Pelosi P, Philippe F, Pierard L, Ponikowski P, Schmid J, Sellevold OFM, Sicari R, den Berghe GV, Vermassen F. Guidelines for preoperative cardiac risk assessment and perioperative cardiac management in noncardiac surgery. Eur Heart J 2009;30:2769–2812)

In the orthopedic population, functional capacity is often limited not by cardiovascular reserve but instead by joint deformities and associated pain. In a patient with an unknown or a limited functional capacity, risk indices should be used to assess the risk of cardiac complications. In 1977, Goldman et al. developed the earliest validated models [9]. Subsequently Lee et al. modified the index presenting a model (Revised Cardiac Risk Index) using primarily the patient history to assess the cardiac risk [2]. Variables include history of ischemic heart disease, congestive heart failure, cerebrovascular disease, diabetes on insulin, renal insufficiency, and the inherent risk of the surgical procedure (Table 11.1).

History of ischemic heart disease is defined as a history of myocardial infarction, ongoing chest pain or nitroglycerin use, abnormal preoperative stress test, or an ECG with evidence for an old myocardial infarction. History of congestive heart failure is defined as a history of prior pulmonary edema or ongoing nocturnal dyspnea, or a physical examination with edema, rales, or an S3 on cardiac auscultation. A chest X-ray with pulmonary vascular congestion can also be used as a marker for heart failure. A known history of cerebrovascular disease as demonstrated by a history of transient ischemic event or stroke has been strongly associated with peripheral vascular and cardiovascular atherogenesis, which increases the risk for perioperative events. Diabetics—particularly those on insulin—have an altered metabolism and hyperinsulinemia, factors that destabilize atherosclerotic plaque and increase the risk of cardiac events. Likewise, renal insufficiency—specifically with a creatinine >2.0 mg/dL—is associated with atherosclerotic events.

**Table 11.1** Variables in patient history used to assess cardiac risk in orthopedic surgery

| |
|---|
| 1. History of ischemic heart disease (history of MI or a positive exercise test, current complaint of chest pain considered to be secondary to myocardial ischemia, use of nitrate therapy, ECG with pathological Q waves; do not count prior coronary revascularization procedure unless one of the other criteria for ischemic heart disease is present) |
| 2. History of HF |
| 3. History of cerebrovascular disease |
| 4. Diabetes mellitus requiring treatment with insulin |
| 5. Preoperative serum creatinine >2.0 mg/dL (177 μmol/L) |
| 6. High-risk type of surgery (examples include vascular surgery and any open intraperitoneal or intrathoracic procedures) |

In addition the inherent risk of the specific surgery must also be considered. High risk surgery clearly increases the risk of postoperative cardiac events. Orthopedic surgery is considered intermediate risk given the 1–5 % cardiac event rate [10]. Interestingly, some of the more recent data suggest a less than 1 % incidence of cardiac events in elective knee surgery. However, the greater the number of cardiac risk factors as defined by the risk index, the greater the incidence of major cardiovascular complications [11]. The patient with less than two risk factors has less than 1 % incidence of major cardiovascular events. Greater than or equal to three risk factors carries an 11 % incidence of cardiac complications.

There are multiple minor risk factors whose role in cardiac risk assessment is unclear. These risk factors are clinically relevant but statistically do not contribute to risk assessment. Specifically, age greater than 70, suboptimally controlled hypertension, and the presence of atrial fibrillation with normal ventricular response do not increase the risk of cardiac complications. A chronically abnormal electrocardiogram—including a baseline bundle-branch block or ST changes in the setting of left ventricular hypertrophy—does not increase the risk of cardiac complications.

The routine physical examination of the patient also contributes to risk assessment by confirming the previously identified risk factors. Cardiac auscultation revealing an S3 suggests decompensated heart failure. Pulmonary auscultation with crackles suggests pulmonary edema particularly in the presence of an elevated jugular venous pressure. Given the association between peripheral arterial disease and adverse cardiac events, findings consistent with peripheral vascular disease increase the patient's risk for ischemic events. Therefore, auscultation and palpation of the carotid arteries as well as the distal extremities can be revealing.

Preoperative cardiac testing may be necessary in patients whose clinical evaluation places them at an unclear or increased risk for cardiac complications. The most basic cardiac test is a routine electrocardiogram. According to the American College of Cardiology (ACC)/American Heart Association (AHA) 2007 Guidelines on Perioperative Cardiovascular Evaluation and Care for Noncardiac Surgery [12], routine electrocardiographic testing is absolutely indicated only in the setting of high-risk surgery or an intermediate-risk surgery—including orthopedic surgery—in a patient with known vascular disease. In intermediate-risk surgery, electrocardiography should also be considered if the patient has at least one risk factor. A retrospective review of 23,036 surgical patients identified a 1.8 % incidence of cardiac complications among patients with an abnormal ECG and a 0.3 % incidence of cardiac complications among the patients with a normal ECG [13]. In the patients undergoing low or intermediate-risk surgery, there was only a 0.5 % incidence of cardiac complications among the entire population. With this in mind, while electrocardiography is relatively inexpensive and available to most clinicians, its routine use in low-risk surgery for a low-risk population is not recommended. Pre-operative ECG should be used in high risk surgery or in a high risk patient. It should be considered in intermediate risk surgery in a patient with at least one risk factor.

The assessment of left ventricular function is also not required because in patients without evidence of active congestive heart failure, echocardiography will not affect clinical outcome. However, in patients with evidence of ongoing or recent heart failure, the preoperative optimization of cardiac status will improve not only the patient's long term event rate but also the patient's risk for perioperative exacerbation of heart failure. For example in a study of patients undergoing high-risk vascular surgery, the echocardiographic determination of an ejection fraction less than 35 % had only a 50 % sensitivity and 91 % specificity in predicting postoperative myocardial infarction or death [14]. Similarly a patient with a known cardiomyopathy and stable symptomatology, routine echocardiography is not necessary preoperatively though could be considered if deemed appropriate to optimize long term care. Only in patients with a history of congestive heart failure with a recent or ongoing exacerbation should preoperative echocardiography be considered [12]. In summary, preoperative assessment of left ventricular function is recommended only in patients with a recent change in their left ventricular function or a recent change in their clinical status suggesting congestive heart failure. Chronic, stable left ventricular dysfunction does not warrant routine assessment.

The role of preoperative stress testing has created much controversy particularly in the current health care

environment with its emphasis on optimizing resource utilization. Current guidelines recommend stress testing only in patients with active or potentially sub-optimally controlled cardiac conditions, in other words in patients whose care would benefit from the results of the test even were they not going for surgery. Thus the American College of Cardiology/American Heart Association guidelines recommend stress testing in patients with a history of New York Heart Association Class II or greater angina, consistent with severe obstructive epicardial coronary artery disease [12]. Further in a sedentary patient, chronic stable angina suggests an undefined and potentially significant ischemic burden and warrants testing. A myocardial infarction in the past 7–30 days suggests the presence of unstable plaque, the nature of which should be determined preoperatively. Also new or progressive congestive heart failure may be caused by myocardial stunning and warrants stress testing. Last, ventricular arrhythmias increase the risk of cardiac events and typically warrant exclusion of ischemic substrate as an etiology.

Any of the previously described cardiac conditions may not only affect perioperative outcomes but may also have long term adverse consequences. As such stress testing would be considered justified in less well defined circumstances, for instance in a patient with >1–2 clinical risk factors (as defined by the Revised Cardiac Risk Index) with a decreased functional capacity undergoing intermediate-risk surgery. Such testing could be considered particularly if the result might change clinical management. However, stress testing would not be indicated in a patient with a good functional capacity (>4 METS) and without clinical risk factors in the setting of intermediate-risk surgery.

As there are multiple available modalities for preoperative stress testing, deciding which to perform requires both clinical judgment and a familiarity across a range of techniques. The gold standard is a routine treadmill test, the benefits of which include the determination of functional capacity, the measurement of blood pressure and the heart rate response to exercise, and assessment of ischemic burden. In a population awaiting vascular surgery, and thus patients enriched with coronary artery disease, routine treadmill testing has a 74 % sensitivity and a 69 % specificity for predicting cardiac complications [14]. While the negative predictive value is high (98 %), the positive predictive value is only 10 %. Therefore, routine treadmill testing is a reasonable way to reassure the patient and the surgeon that the operative risk is low. However, many patients proceeding with orthopedic surgery have a markedly reduced exertional tolerance based upon their underlying orthopedic condition. With this in mind, pharmacologic testing is often necessary. In such testing, vasodilators—including Dipyridamole, Adenosine, or Regadenoson—are often combined with radiotracers (Technetium or Thallium in SPECT, and fluorodeoxyglucose in PET) to localize regions of poor perfusion. Distal to an obstructive lesion in a coronary artery, the Adenosine receptor is upregulated to maximize endogenous vasodilatation to optimize coronary flow. The amount of vasodilatation induced by exogenous Adenosine or Dipyridamole (which decreases the breakdown of Adenosine) is inversely proportionate to the severity of the stenosis. Therefore, the greater the stenosis in an artery, the less exogenously induced vasodilatation, and, therefore, the less the increase in perfusion seen with Adenosine or Dipyridamole.

In a study of 1,179 patients undergoing vascular surgery, the extent of myocardial ischemia on vasodilator perfusion imaging strongly correlated with the risk of postoperative cardiac events [15]. If the extent of myocardial ischemia was less than 20 % of the left ventricle, there was no significant increase in the risk of cardiac events. The likelihood ratio increased to 1.6 if 20–29 % of the myocardium was ischemic, to 2.9 if the extent of myocardial ischemia was 30–50 %, and to 11 when greater than 50 % of the ventricle was at jeopardy. Perfusion imaging with vasodilators has been well validated to stratify risk for postoperative cardiac events in a high-risk population [16].

Dobutamine stress testing can also be used to risk stratify. Dobutamine increases myocardial oxygen demand by agonizing the beta-1 receptor. However, its beta-2 agonism has the disadvantage of potentially causing hypotension. Likewise, dobutamine stress testing is poorly tolerated by many patients with an incidence of refractory chest pain and arrhythmias approaching 2 % [17]; dobutamine is therefore relatively contraindicated in patients with ventricular or atrial arrhythmias, refractory hypertension, or ongoing hypotension. In contrast, dobutamine stress echocardiography is well validated as a risk stratifier for perioperative cardiac events with a sensitivity of 85 % and a specificity of 70 % [14]. The negative predictive value is reported as high as 100 % with a positive predictive value in the 25–48 % range. Several studies have compared perfusion studies and Dobutamine echocardiography for preoperative risk assessments [16]. Ultimately, the sensitivity and specificity are comparable, and choosing which study is appropriate should be determined by availability and local expertise.

A number of emerging modalities are also being more commonly used to assess ischemic burden and coronary anatomy. Specifically, magnetic resonance imaging and CT angiography are becoming more standardized. However, there are very limited data utilizing these modalities for preoperative risk assessment. In a meta-analysis, MRI has been reported to have a sensitivity of 83 % and a specificity of 86 % in predicting ischemia [18]. Further when weighted perfusion modalities are employed, test performance

improves to 91 % sensitivity and 81 % specificity. While MRI has been analyzed preoperatively for major high-risk surgery [19], there are currently no published data utilizing MRI in the intermediate-risk population. With respect to CT angiography, a meta-analysis has reported a 96 % sensitivity and a 74 % specificity for predicting obstructive coronary artery disease in the individual patient [20]. CT angiography also has the advantage of characterizing and quantifying nonobstructive soft plaque which tends to be more unstable and at greater risk for rupture. While promising, CT angiography has also not been validated as a preoperative risk assessment tool.

Stress testing and imaging modalities predict risk of myocardial ischemia which logically correlates with the risk of demand (postoperative) ischemia. However, stress testing does not necessarily predict the risk of plaque rupture, the pathological process accounting for up to 50 % of postoperative myocardial infarctions. As such biomarkers should therefore be considered to assess the risk of perioperative plaque rupture. High-sensitivity C-reactive protein (HS-CRP), a marker for vascular inflammation has received considerable attention. Expressed in smooth muscle cells and atherosclerotic arteries, the HS-CRP has been associated with increased plaque vulnerability, increased expression of adhesion molecules, induction of nitric oxide, altered cardiac function, and inhibition of lipolysis [21]. All these histological variables increase the patient's risk for plaque rupture. However, there are no published trials supporting the routine assessment of perioperative CRP. Thus no well informed recommendations concerning its use in the preoperative setting have been formulated.

Beta Natriuretic Peptide (BNP) has been well validated as a marker for increased myocardial wall stress, which may at times be related to impaired compliance due to myocardial ischemia [22]. Specifically, N-terminal pro-BNP has been shown to be a predictor of heart failure and cardiac events in the general population [23]. Likewise, a severely elevated preoperative BNP suggests the presence of decompensated congestive heart failure and/or increased wall stress which increases the patient's risk for cardiac events. This has been validated in multiple trials of patients undergoing high-risk surgery [24–26]. While routine BNP determination is not appropriate prior to orthopedic surgery, assessing BNP in a patient with a limited exertional tolerance and a history suggestive but not diagnostic of CHF may confirm or exclude the diagnosis and alter treatment strategies.

Troponin is a sensitive marker of myocardial ischemia in patients with clinical evidence of obstructive coronary artery disease. Preoperative ischemia or unstable cardiac plaque increases the risk of postoperative myocardial events. However, routine assessment of troponin preoperatively is not recommended. If a patient presents with evidence of acute onset or active ischemic heart disease, assessment of troponin is logical. A thorough history and physical examination as well as additional cardiac testing would routinely be implemented in such a patient. Therefore, routine assessment of troponin in a patient without additional evidence of myocardial ischemia is not appropriate.

## The Optimization of Cardiac Conditions Affecting Postoperative Outcome

### Pharmacologic Therapy

The goal of the perioperative management of the orthopedic patient is to optimize the patient's condition before proceeding to the operating room and thereby to minimize perioperative cardiac events. The potential benefits of a therapy include reducing the patient's risk of perioperative cardiac events as well as reducing the long-term consequences of the cardiac pathology. However, all interventions carry a risk. Whether pharmacologic or interventional in nature, the risk of these therapies must be weighed against the potential benefit.

One of the most hotly debated pharmacologic therapies for perioperative care is beta-blockade. There are multiple mechanisms via which such therapy could theoretically reduce the risk of cardiac events. Reduced heart rate and myocardial contractility decrease myocardial oxygen demand. The slower heart rate also allows increased diastolic flow through the epicardial coronaries, increasing myocardial perfusion. Additionally, the pharmacologically reduced adrenergic stimulation stabilizes plaque and reduces susceptibility to ventricular arrhythmias.

However, despite these advantages, there are conflicting data about the role of beta-blocker in the perioperative setting. Most recently, Devereux et al. published the POISE trial, which included 8,351 surgical patients considered high risk based on their age (>45 years) and the presence of ischemic heart disease (≥3 risk factors) all undergoing major surgery [27]. High-dose beta-blocker was initiated immediately preoperatively. Specifically, Metoprolol 100 mg was given 2–4 h prior to surgery, as well as an additional dose 6 h postoperatively (and potentially 12 h later), achieving an average dose of 400 mg of Metoprolol in the immediate perioperative setting. Not surprisingly there was a significantly increased incidence of bradycardia and hypotension in the treated group. While the 30-day cardiovascular event rate was reduced by 17 % in patients receiving beta-blocker, this benefit was offset by an increased incidence of stroke as well as a 33 % increase in all-cause mortality in the treated patients. Additional analysis suggests that the high and rapid dosing of the beta-blocker resulted in hypotension thus cerebrovascular and cardiovascular

hypoperfusion and the higher instances of stroke and mortality.

In the DECREASE trial [3], 112 patients with abnormal stress tests awaiting vascular surgery received Bisoprolol at 2.5–5.0 mg daily for at least 1 week preoperatively titrated to a stable heart rate in the perioperative period. There was an 89 % decrease in the incidence of cardiac events at 1 month which persisted at 3 year follow-up; notably there was no increased incidence of stroke seen with b-blocker use [28]. Earlier Mangano et al. determined that Atenolol given pre- and postoperatively to 200 high-risk patients—defined as having at least two cardiac risk factors or known ischemic heart disease—reduced cardiac events at both 6 months and 2 years postoperatively [29].

Beta-blocker therapy has also been evaluated in low surgical risk patients and found to be ineffective perioperatively. Examples include the POBBLE trial which enrolled 103 low-risk patients proceeding to vascular surgery who received Metoprolol in the perioperative setting [30]. No change in the 30-day event rate was noted. Similarly the Metoprolol after Vascular Surgery (MaVS) trial confirmed that metoprolol did not reduce the risk of adverse events in a comparable low-risk population [31]. In this study, up to 90 % of the patients had two or less risk indices and 60 % had less than or equal to one.

In an attempt to reconcile these discrepant studies, Bangalore et al. [32] published a meta-analysis confirming that the greater the preoperative risk of the patient, the greater the risk reduction from preoperative beta-blocker therapy. Specifically, 16 fewer nonfatal myocardial infarctions per 1,000 patients occurred in those treated with B-blocker, a benefit occurring at the expense of three additional strokes and three additional fatalities. Multiple subgroup analyses suggest that heart rate control is appropriate but not at the expense of hypotension [33]. The American College of Cardiology and American Heart Association guidelines state that perioperative beta-blockade is absolutely indicated only in patients who are taking them prior to surgery in order to avoid rebound effects associated with early discontinuation [12]. According to the ACC/AHA, B-blockers should be considered in patients with known coronary artery disease undergoing at least intermediate-risk surgery as well as patients without previously documented coronary artery disease but with more than one clinical risk factor. Beta-blockers are not necessary but can be considered in intermediate-risk patients with one or less clinical risk factors. With this in mind the early implementation of a long acting beta-blocker without sympathomimetic activity can be considered. In such circumstances Bisoprolol, Metoprolol Succinate, or Atenolol at low doses should be initiated at least 1 week (ideally 1 month) preoperatively with a plan toward upward titration to achieve a heart rate goal of 60–70 bpm as long as systolic blood pressure remains above 100 mmHg. Beta-blockers with sympathomimetic activity should be avoided to reduce perioperative tachycardia. Most importantly, beta-blockade should not be increased at the expense of stable blood pressure, as this increases the risk of hypoperfusion and cerebrovascular ischemia. While there is no data-based consensus on duration of therapy, continuation of beta-blocker (assuming a stable blood pressure) for at least 28 days postoperatively seems reasonable as this is the timeframe during which catecholamines remain elevated.

Aspirin therapy in the perioperative setting should also be considered. Mechanistically, aspirin reduces vascular events by inhibiting platelet function and aggregation, thereby decreasing the risk of plaque destabilization and coronary thrombosis. Aspirin exhibits proven benefits in secondary prevention of cerebrovascular as well as cardiovascular therapy and is indicated in a high-risk population for primary prevention. However, aspirin also has inherent risks including increased risk of perioperative hemorrhage. Oscarsson et al. [34] randomized 220 high-risk patients to low dose (75 mg) aspirin or placebo 1 week preoperatively and found a significantly reduced risk of cardiac complications (1.8 % incidence) in the aspirin group vs. the placebo group (9 % incidence). No greater incidence of bleeding was noted in the aspirin group. Burger [35] analyzed 41 studies including 45,590 patients who underwent surgery on aspirin and found a 1.5-fold increase in the incidence of bleeding complications without an increase in the severity of the hemorrhage. Most recently Devereaux et al in the POISE-2 trial evaluated approximately 10,000 patients at increased risk for vascular events undergoing noncardiac surgery, 39% of which were undergoing orthopedic procedures. The patients who received perioperative aspirin not only experienced no reduction in perioperative death or nonfatal myocardial infarction but also - not surprisingly- suffered a greater incidence of major bleed and acute kidney injury requiring dialysis. Notably, in patients who had been on aspirin preceding the test but who discontinued it during the trial period, there was no greater incidence of thrombotic events or infarctions. Importantly, the trial did not include patients who had recently undergone implantation of a cardiac stent. With this in mind, perioperative aspirin cannot be recommended in patients with coronary risk factors or known coronary artery disease, not status post recent coronary stent implantation.

Inhibition of the renin-angiotensin system is an additional pharmacologic modality to be considered in the perioperative setting. The logic for angiotensin converting enzyme inhibition or angiotensin receptor blockade in the preoperative setting includes their role in improving endothelial function, their anti-inflammatory properties, and the potential inhibition of atherogenesis. Also in the setting of

left ventricular dysfunction, ACE inhibitors also improve myocardial function when employed long-term. Apropos of these considerations, the QUO VADIS trial compared preoperative Quinapril versus placebo in patients undergoing cardiac surgery. A reduced risk of cardiovascular events at 4 weeks as well as 1 year postoperatively was demonstrated [37]. However, this occurred at the expense of symptomatic hypotension and a decreased response to vasodepressors.

There is another caution relevant to patients undergoing lower extremity total joint arthroplasty. Perioperative ACE inhibition does increase postoperative vasodilatation, particularly in the setting of epidural anesthesia. Paralleling the postoperative B-blockers experience, the resulting postoperative hypotension may contribute to cerebral and coronary hypoperfusion. Further are the consequences of such blood pressure instability on postoperative patient mobilization. Physical therapy instituted early after surgery reduces the risk of venous thrombosis and hospital acquired infections. Thus hypotension, whether provoked by volume depletion, the effects of anesthesia/analgesia, or antihypertensive agents (B-blockers, ACE inhibitors) delays mobilization due to symptomatic orthostasis. With this in mind, Hospital for Special Surgery guidelines recommend discontinuing ACE-inhibitors at least 24 h prior to surgery, reinitiating them postoperatively only in the setting of stable hemodynamics. ACE inhibition should not be empirically initiated prior to surgery given this increased postoperative risk.

Calcium channel blockers reduce myocardial oxygen demand similar to beta-blockers. However, short acting dihydropyridine calcium channel blockers increase chronotropy and may increase ischemia. There are very limited data supporting a cardiovascular benefit of calcium channel blockers in the perioperative setting. Wijeysundera published a meta-analysis of 11 trials (1,007 patients) that suggests a reduction in perioperative ischemic events and supraventricular arrhythmias without a significant decline in myocardial infarctions or death [38]. Thus the continuation of calcium channel blockers in the perioperative setting is recommended. Conversely the preoperative initiation of calcium channel blockers is not appropriate given the risk of postoperative hypotension in the absence of proven clinical benefit.

Nitroglycerines create hemodynamic changes that theoretically benefit patients in the perioperative setting. Coronary vasodilatation increases coronary perfusion; selective venodilatation reduces preload and left ventricular wall stress. Both of these effects decrease myocardial oxygen demand and reduce ischemia. An early trial assessed intravenous nitroglycerin in the perioperative setting finding a decreased incidence of perioperative ischemia in high-risk patients with known angina or documented coronary disease but with no reduction in death or myocardial infarctions [39]. There was also an increased risk of hypotension. The American College of Cardiology guidelines state that nitroglycerine is not recommended but may be considered in the perioperative period.

Central acting alpha-2 agonists potentially afford perioperative benefits by decreasing noradrenergic stimulation by inhibition of the postganglionic receptor. This decreased catecholamine surge should empirically reduce the risk of cardiac events. In the European Mivazerol Trial [40], 1,897 patients with known ischemic heart disease undergoing intermediate or high-risk noncardiac surgery were randomized to the alpha-agonist or placebo with a decreased risk of death or MI noted only in the patients undergoing vascular surgery; patients undergoing intermediate-risk surgery received no benefit from Mivazerol. A meta-analysis of 23 randomized trials found no statistical benefit to alpha-agonism in nonvascular surgery [41]. Devereaux et al in POISE-2 found that administering Clonidine immediately preoperatively not only did not reduce death or nonfatal myocardial infarction but also increased the incidence of nonfatal cardiac arrest and -not surprisingly - hypotension and bradycardia. While earlier American College of Cardiology guidelines written prior to the release of the POISE-2 data state that alpha-2 agonists may be considered in high risk patients, the abundance of data argue against their use in the perioperative setting.

Three-hydroxy-3-methylglutaryl coenzyme A reductase inhibitors (Statins) should logically reduce perioperative cardiac events due to their plaque stabilizing effects. They are currently indicated for secondary prevention as well as primary prevention in patients without previously established coronary artery disease but known peripheral arterial disease. Histologically, their pleiotropic effects stabilize plaque and reduce the likelihood of plaque rupture. Statins decrease lipid oxidization making them less avidly absorbed by macrophages to form foam cells. The statins have an anti-inflammatory effect that reduces matrix metalloproteinase, and they reduce myocardial cell death. Each of these histological effects should logically be favorable in the perioperative setting.

Several trials have evaluated the role of statins in the perioperative setting. Fluvastatin has demonstrated a beneficial effect in vascular surgery [43]. Likewise, Atorvastatin 20 mg daily reduced cardiac events immediately following vascular surgery as well as 6-month later [44]. A meta-analysis including over 223 thousand patients demonstrated a 44 % reduction in perioperative mortality among statin users (with a 59 % reduction among statin users undergoing vascular surgery) [45]. Statins do, however, have side-effects. Rhabdomyolysis is a rare but very serious side effect with a reported incidence approximating 0.1 %; however, there is no reported increased incidence of rhabdomyolysis

in the perioperative setting. Myalgias are a frequent complication of statin therapy. In the orthopedic population specifically, the myalgias may be masked by perioperative or orthopedic pains. Likewise, myalgias from statins may complicate the normally routine treatment of perioperative pain. Given the potential rebound effects from discontinuing statins, it is important to note that there are no available intravenous statins that can be used in the event of a post-op ileus.

With this in mind, the ACC/AHA recommends continuing statins perioperatively ideally with a longer acting statin, which includes Rosuvastatin and Fluvastatin. Initiating statin preoperatively is not recommended but can be considered in the intermediate-risk population including those with at least one cardiac risk factor. Consistent with the other cardiovascular guidelines, preoperative therapy should be consistent with routine cardiac therapy. If a patient should appropriately be prescribed statins for primary or secondary prevention, such therapy would be appropriate in the perioperative setting as well. Should a statin be initiated in the perioperative setting, a long acting statin such as Rosuvastatin or Fluvastatin would be most appropriate.

## Interventional Therapy

Preoperative coronary revascularization improves myocardial perfusion and decreases the likelihood of demand ischemia. While plaque rupture accounts for at least 50 % of postoperative ischemic events, revascularization does not prevent plaque rupture. In fact, disruption of stable plaque releases chemokines that precipitate plaque rupture in nonrevascularized and otherwise stable vessels. Therefore, following percutaneous revascularization, aggressive pharmacotherapy—typically including dual anti-platelet therapy—is critical and may necessitate postponing additional surgeries.

In the Coronary Artery Revascularization Prophylaxis (CARP) trial, 5,859 patients from 18 Veterans Administration hospitals awaiting vascular surgery were screened [46]; the 510 patients found to have significant coronary artery disease were randomized to revascularization versus medical therapy. There was no difference in adverse cardiac events both perioperatively as well as at 2.7 years follow-up.

In the Dobutamine EChocardiac Risk Evaluation Application Stress Echocardiogram (Decrease V trial), 1,880 patients at risk for coronary artery disease awaiting vascular surgery were screened [47]. The 430 patients with at least three risk factors (including age greater than 70, ongoing angina, old myocardial infarction, congestive heart failure, diabetes, renal insufficiency, or cerebrovascular disease) underwent risk stratification with DSE or perfusion imaging. The 101 patients with high-risk ischemia on noninvasive testing were randomized to revascularization or medical therapy; all patients continued aspirin and beta-blocker. Of this population, 75 % had three-vessel disease or left main disease; 43 % had an ejection fraction less than or equal to 35 %. Ninety percent of the percutaneous revascularization utilized drug-eluting stents. There was no statistical difference between the 30-day rate of death or myocardial infarction postoperatively in the revascularized group as compared to those patients treated medically; indeed a trend toward more cardiac events in the group that was revascularized was reported. Long-term data are still pending, however, so it is not clear whether patients who were revascularized—particularly in this high-risk group—received greater long-term benefit. From these observations preoperative revascularization preceding intermediate or low-risk surgery (such as most orthopedic procedures) is not recommended. However, revascularization could be considered if it would improve the patient's long term risk for cardiac events. This must be weighed against the likely need to postpone the orthopedic surgery with the implicit prolonged pain and immobility while awaiting surgery.

## Postoperative Considerations and Conditions

### Orthopedic Surgery After Coronary Revascularization

Orthopedic surgery after coronary revascularization increases the likelihood of coronary artery (target vessel) restenosis as surgical stress destabilizes atherosclerotic plaque and activates clotting factors. Plaque rupture from percutaneous transluminal coronary angioplasty (PTCA) requires at least 2 weeks to heal. Atherogenesis classically starts 8 weeks following angioplasty. Therefore, the optimal timing for orthopedic surgery after angioplasty is between 2 and 8 weeks after the percutaneous coronary intervention (PCI). Reports from the Cleveland Clinic [48] describe the early experience (1984–1999), when 13.4 % (194) of patients who underwent angioplasty a median 11 days prior to major vascular surgery suffered a major cardiovascular complication. In a description of their experience at Mayo (1988–2001), Brilakis et al. describe 350 patients who underwent noncardiac surgery within 2 months of angioplasty, including 188 who underwent angioplasty $<2$ weeks prior to surgery [49]. Only three patients suffered myocardial infarction or death; all three were among the patients who underwent coronary revascularization less than 2 weeks prior to the noncardiac surgery, for an event rate of 1.6 % (3/188).

Coronary stenting markedly reduces the likelihood of such target vessel restenosis. However, it takes a minimum

of 6 weeks for the stent to endothelialize, a period during which there is a high-risk of stent thrombosis and death in the absence of dual antiplatelet therapy (aspirin plus a thienopyridine). Stent stenosis due to smooth muscle cell proliferation and neo-intimal hyperplasia starts approximately 12 weeks after stent implantation. Therefore, the ideal time for elective orthopedic surgery is between 6 and 12 weeks following coronary revascularization with a bare metal stent. A review of the 207 patients who underwent noncardiac surgery within 2 months of PCI with a bare metal stent at the Mayo Clinic revealed eight patients who suffered death or myocardial infarction, all of which underwent surgery within 6 weeks of the stent implantation [50]. In a review from the Netherlands, van Kujik et al. report a >50 % incidence of major adverse cardiac events after noncardiac surgery less than 30 days after implantation of a BMS [51]; the incidence dropped to 4 % when surgery was delayed 3 months following BMS. While perioperative dual anti-platelet therapy did increase the risk of severe bleeding, it did not statistically reduce the high risk of cardiac events in the patients with noncardiac surgery early after PCI with BMS.

Stents that elute drugs (Drug Eluting Stents, DES) to prevent neo-intimal hyperplasia have a markedly reduced rate of stent restenosis. However, the rate of stent thrombosis without dual anti-platelet therapy is significant in the first 12 months after drug-eluting stent implantation. Therefore, elective orthopedic surgery should not be performed within the first 12 months following stent implantation. At Erasmus Medical Center, there was a 35 % incidence of major adverse cardiac events if surgery was performed <30 days after DES implantation [51]. The incidence dropped to 6 % among patients who underwent surgery 6–12 months after DES. The risk of stent thrombosis increases with the number and length of the stents, and inversely with the width of the stents. Diabetic patients have a greater incidence of stent thrombosis. Lastly, thrombosis of a left main stent or a proximal Left Anterior Descending artery stent is more clinically significant than distal artery or branch vessel restenosis; therefore, stents in this region of the coronary anatomy may warrant more conservative therapy.

In summary, elective orthopedic surgery should be performed at least 2 weeks and ideally less than 8 weeks after balloon angioplasty. Surgery should be performed at least 6 weeks and ideally less than 12 weeks following implantation of a bare metal stent. Surgery should be performed at least 12 months following implantation of a drug eluting stent. If the risk of hemorrhage is acceptable, aspirin should be continued perioperatively without interruption at a dose of at least 81 mg daily. If thienopyridines had been in place prior to surgery, they should be discontinued at the discretion of the surgical team. Typically, Clopidogrel (Plavix®, Sanofi Aventis, Bridgewater, NJ, USA) is held for five doses prior to surgery, but consideration should be given to holding it for seven doses prior to spinal surgery or when epidural anesthesia is employed where the results of hemorrhage may be more catastrophic. Prasugrel (Effient®, Eli Lilly and Co, Indianapolis, IN, USA) is typically held for seven doses prior to surgery for full clearance. The decision as to whether to reinitiate thienopyridine after surgery depends upon many variables including the degree of hemostasis achieved and the concomitant use of additional anti-coagulants (Vitamin K antagonists, Heparin) for DVT prophylaxis.

If coronary revascularization is necessary prior to orthopedic surgery, the modality of revascularization should be influenced by the urgency of the orthopedic procedure. If surgery cannot be delayed for a full year to allow a full course of uninterrupted dual anti-platelet therapy following DES implantation, a BMS is most appropriate but requires postponing surgery for at least 6 weeks (6 weeks of uninterrupted dual anti-platelet therapy plus an additional 5–7 days to allow clearance of the thienopyridine pre-op). If surgery cannot be delayed 6 weeks, balloon angioplasty is most appropriate but requires delaying surgery 2 weeks to allow the ruptured plaque to heal. The clinician might consider coronary angiography after the patient has recovered from surgery to screen for restenosis and to consider definitive revascularization with a stent.

Patients who have undergone open revascularization with coronary artery bypass graft surgery (CABG) do not require special or additional consideration. In the Coronary Artery Surgery Study, of the nearly 25 thousand patients in the registry, 3,368 patients underwent noncardiac surgery over more than 4 years of follow-up [52]; 15 % of the surgeries were orthopedic. The incidence of postoperative infarction or death was less than 1 % following orthopedic surgery. Among patients who had undergone CABG and subsequent high-risk noncardiac surgery, 2.5 % suffered adverse cardiac events. If agreeable with the orthopedic and anesthesia team, aspirin can be considered perioperatively in this population given their increased plaque burden. If open revascularization is necessary prior to orthopedic surgery, there is no empiric need to delay orthopedic surgery; bypass grafts and cardiovascular hemodynamics typically normalize by the time the patient is discharged from the hospital. However, sternotomy incisions and vein graft harvest sites may require weeks to stabilize, and the sternotomy in particular may interfere with the physical therapy necessary to recover optimally from orthopedic surgery [52, 53].

## Devices

Electrical cautery during surgery may interfere with pacemaker or ICD function. Far-field electrical signals from the

cautery may be spuriously interpreted by the device as cardiac myocyte electrical activity [54]. If a patient is pacemaker dependent, the sensing of far-field activity may inhibit the pacing function of the device leaving the patient asystolic. An intracardiac defibrillator may interpret the far-field activity as ventricular arrhythmias and attempt to electrically cardiovert. The American Society of Anesthesiologists therefore recommends that in a pacemaker dependent patient, within 6 months prior to surgery, the device should be evaluated; during surgery, the device should be reprogrammed to asynchronous mode or a magnet should be placed over the device [55]. ICDs should have their anti-tachycardia algorithms turned off during surgery. Preoperatively, it is therefore critical to determine if a patient with a device is pacemaker dependent. Likewise, details about defibrillator programming including model and manufacturer should be obtained preoperatively because it is often necessary to interrogate the ICD and validate its function once its programming has been altered or a magnet applied.

## Valvular Heart Disease

Valvular heart disease increases the risk of cardiac complications of orthopedic surgery. Catecholamine surges, fluid shifts, and afterload reduction due to peripheral vasodilatation can cause hemodynamic collapse, heart failure, and tachy-arrhythmias more frequently seen in patients with significant valvular heart disease. Patients with regurgitant valve disease typically tolerate orthopedic surgery well because the associated afterload reduction from anesthesia reduces systemic vascular resistance allowing a compensatory increase in cardiac output. Stenotic valve disease on the other hand increases the risk of orthopedic surgery, because cardiac output is fixed and cannot compensate in the setting of peripheral vasodilatation.

Symptomatic aortic stenosis carries a very high short-term mortality and morbidity—independent of noncardiac surgery—and therefore requires valve surgery prior to proceeding with orthopedic surgery. Patients with asymptomatic severe aortic stenosis (defined as valve area $< 1.0$ cm$^2$ with mean trans-valvular gradient $> 40$ mmHg), often safely wait years prior to elective valve surgery. However, noncardiac surgery carries a high mortality and morbidity in the setting of severe aortic stenosis. In a retrospective study, Kertai et al. [54] compared surgical outcomes of 108 patients with moderate or severe aortic stenosis with 216 controls; 31 % of the severe AS cases suffered a nonfatal MI or death; 11 % of the moderate AS cases reached these endpoints. In an analysis of 19 patients undergoing non cardiac surgery (including 12 orthopedic procedures) at Mayo Clinic, Torsher et al. confirmed an 11 % mortality [55]. Elective orthopedic surgery is therefore not recommended in a patient with severe aortic stenosis. If a patient is not a candidate for valve surgery or refuses such surgery, percutaneous valvuloplasty may be performed to improve temporarily the trans-valvular gradient to allow for a safer orthopedic surgery. Unfortunately, balloon valvuloplasty is only palliative as the valve routinely restenoses within a year, and the patient is often left with significant aortic regurgitation.

Should the orthopedic surgery proceed in the setting a stenotic aortic valve, strict attention to volume challenges and hemodynamic monitoring may mitigate some of the morbidity. Because cardiac output is preload dependent, the patient should be aggressively volume repleted with arterial blood pressure monitoring and consideration given to right-heart catheterization. Sinus rhythm should be maintained to avoid loss of atrial systole and diastolic function. Systemic vascular resistance should be maintained because the fixed cardiac output prevents a compensatory increase when SVR drops. Phenylephrine can therefore be used to increase SVR without increasing heart rate; afterload reducing agents should be avoided.

## Atrial Fibrillation

Postoperative arrhythmias increase the patient's morbidity, mortality, and length of stay in the hospital. Stress of anesthesia and surgery precipitates arrhythmias. Medical conditions including hypoxia, hypercarbia, electrolyte and acid–base disturbances, exogenous and endogenous catecholamines, and myocardial ischemia are all associated with arrhythmias. Ectopy—both atrial and ventricular—commonly extinguishes without intervention. Ventricular arrhythmias—including Torsades de pointes—warrant immediate attention and treatment per Advanced Cardiac Life Saving guidelines.

Atrial fibrillation is the most commonly encountered postoperative arrhythmia and therefore will be discussed here. Its incidence following noncardiac and nonthoracic surgery is reported between 0.2 and 8 % [56–61]. Specifically in an orthopedic population, Kahn et al. report an incidence of atrial fibrillation or supraventricular arrhythmias of 3.1 % among 1,210 consecutive total hip or knee arthroplasties; this analysis included patients with a preoperative history of arrhythmias [57]. Further Cromwell reported a 0.36 % incidence of new onset atrial fibrillation among over 12,000 recovery room admissions; notably in this study, patients with a history of atrial fibrillation were excluded.

Risk factors for postoperative atrial fibrillation (POAF) include a history of prior cardiac disease including preoperative paroxysmal atrial fibrillation and structural heart disease (left ventricular dysfunction, valvular heart disease,

pericardial disease). Kahn's analysis suggests a possible clue on preoperative electrocardiography as he found a greater incidence of atrial ectopy as well as a left anterior hemiblock on preoperative testing among patients who developed postoperative arrhythmias [57]. Underlying pulmonary conditions including COPD are associated with POAF [59]. Cromwell found a greater incidence of pulmonary emboli among her arrhythmia patients with an incidence of <5 % among this cohort [61]. Advanced age increases the likelihood of postoperative atrial fibrillation [56, 57, 61].

Postoperative atrial fibrillation warrants therapy [61] as even asymptomatic cases, this arrhythmia has potential significant consequences [58]. The tachycardia may cause myocardial ischemia by increasing myocardial oxygen demand. The loss of atrial systole may decrease cardiac output and increase left ventricular filling pressures causing congestive heart failure. Prolonged arrhythmia (particularly those persisting beyond 48 h) precipitate stunning of the atria with poor flow in the atrial appendage thereby increasing the likelihood of thromboembolic episodes including strokes.

Rate control is the first step in therapy. Prior to starting pharmacotherapy, the preoperative ECG as well as an ECG in the arrhythmia should be reviewed to exclude an accessory pathway such as Wolf Parkinson White; administration of atrial-ventricular nodal blockers can precipitate conduction down the bypass tract converting the atrial fibrillation to life-threatening ventricular fibrillation. If a bypass tract is observed, most commonly Amiodarone or Procainamide are used with a low threshold for electrical cardioversion. In the absence of a bypass tract, beta-blockers are considered first line therapy, though calcium channel blockers are a very good alternative given their availability in an inexpensive short acting intravenous drip. Digitalis increases vagal tone and is therefore less effective in this population with heightened catecholamines; however, it is often used in patients with borderline hypotension because it will not lower blood pressure. Typically, intravenous dosing of medication is necessary to achieve rapid onset but oral therapy should also be used concomitantly to allow the patient to be rapidly weaned off the IV medications.

Anticoagulation should be considered because the likelihood of intracardiac thrombus increases after 48 h of atrial fibrillation. The risks of anticoagulation postoperatively must be weighed against the benefits. While there are no universally accepted standards, it is usually not necessary to initiate rapid-onset, full-dose anticoagulation (heparin, dabigatran) in this setting because the arrhythmias are typically self limited, and the patients are often routinely already taking some form of pharmacologic DVT prophylaxis. If the arrhythmia persists beyond 48 h, with the blessing of the surgical team, warfarin can be started with dosing to achieve a slightly higher (as compared to postoperative DVT prophylaxis) target INR (2.0–2.5).

Mirroring the experience after cardiac surgery [62], postoperative atrial fibrillation after orthopedic procedures typically resolves. However, those patients who remain in atrial fibrillation should follow-up with a cardiologist for cardioversion. The general approach is to wait approximately 4 weeks before attempting cardioversion. This period is sufficient to allow the postoperative catecholamine surge to abate, maximizing the opportunity for spontaneous conversion to sinus rhythm thereby avoiding the procedure altogether; likewise the delay allows the volume status and hematocrit to normalize, increasing the likelihood that the rhythm will remain sinus following the cardioversion.

No therapies have proven to provide certain prophylaxis against atrial fibrillation. Beta-blockers logically afford some benefit by reducing the cardiac response to catecholamines. However, cardiac surgery patients who were first started on beta-blockers perioperatively were more dependent on mechanical ventilation and remained in the hospital longer postoperatively [63]. While beta-blockade is appropriate therapy for atrial fibrillation, it is ineffective for prophylaxis against atrial fibrillation. Other agents have been studied in the cardiac surgery patients including magnesium and statins, but the role of these agents in orthopedic surgery is not defined and they are not recommended solely for atrial fibrillation prevention.

## Myocardial Ischemia

Postoperative myocardial ischemia (PMI) following orthopedic surgery is frequently seen and most commonly detected 48–72 h postoperatively. The incidence of cardiac injury following orthopedic surgery is reported up to 53 % in emergent cases and up to 9 % in elective cases [64]. At Hospital for Special Surgery, Urban et al. reported a 0.6 % incidence among all surgical cases during a 12 month period with a 6.5 % incidence among those patients considered high risk [65].

The diagnosis of postoperative myocardial ischemia is controversial. The Joint European Society of Cardiology/American College of Cardiology (ESC/ACC) define a myocardial infarction as a typical rise in cardiac biomarkers in the setting of ischemic symptoms or ECG changes or myocardial injury noted on imaging [66]. In the postoperative setting, however, biomarkers may be falsely elevated. The creatine kinase—MB fraction lacks specificity following orthopedic surgery given the significant skeletal injury inherent in these procedures. Troponin is more commonly used but is also known to be falsely elevated in the setting of pulmonary embolism, left ventricular hypertrophy, and chronic kidney disease. The immunoassay is also inhibited by circulating immunological factors including heterophile

antibody and rheumatoid factor (an antibody disproportionately encountered in patients with rheumatic disease). The troponin assay is not standardized and may vary between institutions, but an elevated troponin is defined by the ESC/ACC as above the 99th percentile of the upper reference range in the normal population. Troponin is, however, a very sensitive marker for myocyte injury as it detects increased cell membrane permeability with release of cytosolic components—the earliest stages of cell damage—as well as cell death. Following cell injury, troponin begins to rise after 4 h and peaks after 18–24 h and is detectable for 4–10 days. The height of the peak correlates with the severity and extent of myocardial damage.

Symptoms are also not a dependable indicator of postoperative myocardial ischemia. Typical ischemic symptoms may be masked by sedation or analgesics; atypical symptoms such as nausea or fatigue may be falsely blamed upon anesthesia. In the POISE trial, up to 65 % of patients with documented postoperative myocardial infarction were asymptomatic at the time of the diagnosis. Further electrocardiography lacks sensitivity to detect mild cell damage, though is usually abnormal in the setting of significant troponin elevations [67].

Perhaps as a consequence of these ambiguities, there are no established standards for postoperative MI screening. All patients with symptoms suggesting ischemia should be screened with serial troponins and ECGs at 8 h increments for at least 16 h with additional measurements until the level plateaus. Asymptomatic patients undergoing high-risk surgery—particularly those designated at high risk either by the Revised Cardiac Risk Index or based on preoperative testing—should be screened for postoperative myocardial infarction. Some clinicians favor screening such patients, even those who have undergone intermediate-risk procedures such as orthopedic surgery, because patients with postoperative ischemia have an increased risk for adverse cardiac events upwards to 1 year following surgery [65, 68]. Routine screening of low-risk patients or patients undergoing low-risk surgery is not recommended, however.

Treatment of postoperative myocardial infarction is similar to treatment of nonoperative acute coronary syndrome [66]. Pharmacologic therapy should include beta-blockade and statins. Anti-platelet therapy with at least low dose aspirin should be strongly considered. Antithrombotic therapy with heparin as well as supplemental platelet inhibition with a thienopyridine should be considered if plaque rupture is suspected; these agents are likely not necessary in the setting of demand ischemia due to stable fixed coronary disease. They also carry a greater risk of hemorrhage and must be discussed with the surgical team. Revascularization should be considered in ST elevation myocardial infarction and very high-risk non-ST elevation infarction; angiography with PCI is preferred over thrombolysis to clarify the cardiac anatomy and to minimize the high risk of surgical sight hemorrhage from thrombolytics. All patients with suspected or confirmed PMI should be watched in a monitored setting.

## Summary

In closing significant cardiac morbidity and mortality is experienced by patients in the setting of orthopedic surgery though the risk to an individual patient can be stratified incorporating various readily available clinical information. These clinical characteristics include the patient's functional capacity as well as their medical history, specifically preexisting ischemic heart disease, heart failure, cerebrovascular disease, renal insufficiency, and diabetes. Supplemental testing beyond a thorough history and physical examination are only necessary in the patient deemed to be at high risk based on the aforementioned clinical criteria. The maintenance of ongoing cardiac pharmacotherapy is generally appropriate; initiation of B-blocker should be considered in the higher risk population, ideally at least a week in advance of the procedure. Finally preoperative coronary revascularization does not reduce the risk of orthopedic surgery and therefore should only be performed to reduce the patient's lifetime risk of adverse cardiac events.

**Summary Bullet Points**

- The risk of orthopedic surgery can be accurately determined based upon clinical assessment as well as diagnostic testing.
- Pharmacologic therapy may reduce the risk of cardiac complications when utilized in the appropriate setting.
- Interventional therapy does not reduce the risk of cardiac complications of orthopedic surgery and is appropriate only to reduce the patient's long-term risk of adverse cardiac events.
- Patients presenting for orthopedic surgery often have complex cardiac conditions that require preparation to manage optimally.
- The diagnosis and management of postoperative cardiac complications is similar to the management of these conditions in the nonoperative setting.
- Amongst the various valvular lesions, only severe aortic stenosis carries a significant morbidity and mortality.

## Case Study

A case study for this chapter is included in Appendix H at the end of this book.

## References


1. Poldermans D, Bax JJ, Boersma E, De Hert S, Eeckhout E, Fowkes G, Gorenek B, Hennereci MG, Iung B, Kelm M, Kjeldsen KP, Kristensen SD, Lopez-Sendon J, Pelosi P, Philippe F, Pierard L, Ponikowski P, Schmid J, Sellevold OFM, Sicari R, den Berghe GV, Vermassen F. Guidelines for pre-operative cardiac risk assessment and peri-operative cardiac management in non-cardiac surgery. Eur Heart J. 2009;30:2769–812.
2. Lee TH, Marcantonio ER, Mangione CM, Thomas EJ, Polanczyk CA, Cook EF, Sugarbaker DJ, Donaldson MC, Poss R, Ho KK, Ludwig LE, Pedan A, Goldman L. Derivation and prospective validation of a simple index for prediction of cardiac risk of major noncardiac surgery. Circulation. 1999;100:1043–9.
3. Poldermans D, Boersma E, Bax JJ, Thomson IR, van de Ven LL, Blankensteijn JD, Baars HF, Yo TI, Trocino G, Vigna C, Roelandt JR, van Urk H. The effect of bisoprolol on peri-operative mortality and myocardial infarction in high risk patients undergoing vascular surgery. Dutch Echocardiographic Cardiac Risk Evaluating Applying Stress Echo Study Group. N Engl J Med. 1999;341:1789–94.
4. Morris CK, Ueshima K, Kawaguchi T, Hideg A, Froelicher VF. The prognostic value of exercise capacity: a review of the literature. Am Heart J. 1991;122:1423–31.
5. Biccard BM. Relationship between the inability to climb two flights of stairs and outcome after major non-cardiac surgery; implications for the preoperative assessment of functional capacity. Anesthesia. 2005;60:588–93.
6. Wiklund RA, Stein HD, Rosenbaum SH. Activities of daily living and cardiovascular complications following elective, noncardiac surgery. Yale J Biol Med. 2001;74:75–87.
7. Hlatky MA, Boineau RE, Higginbotham MB, Lee KL, Mark DB, Califf RM, Cobb FR, Pryor DB. A brief self administered questionnaire to determine functional capacity (the Duke Activity Status Index). Am J Cardiol. 1989;64:651–4.
8. Fletcher GF, Balady GJ, Amsterdam EA, Chaitman B, Eckel R, Fleg J, Froelicher VF, Leon AS, Pina IL, Rodney R, Simons-Morton DA, Williams MA, Bazzarre T. Exercise standards for testing and training: a statement for healthcare professionals from the American Heart Association. Circulation. 2001;104:1694–740.
9. Goldman L, Caldera DL, Nussbaum SR, Southwick FS, Krogstad D, Murray B, Burke DS, O'Malley TA, Goroll AH, Caplan CH, Nolan J, Carabello B, Slater EE. Multifactorial index of cardiac risk in noncardiac surgical procedures. N Engl J Med. 1977;297(16):845.
10. Boersma E, Kertai MD, Schouten O, Bax JJ, Noordzij P, Steyerberg EW, Schinkel AF, van Santen M, Simoons ML, Thomson IR, Klein J, van Urk H, Poldermans D. Perioperative cardiovascular mortality in noncardiac surgery: validation of the Lee cardiac risk index. Am J Med. 2005;118:1134–41.
11. Ackland GL, Harris S, Ziabari Y, Grocott M. Revised cardiac risk index and postoperative morbidity after elective orthopaedic surgery: a prospective cohort. Br J Anaesth. 2010;105:744–52.
12. Fleisher LA, Beckman JA, Brown KA, Calkins H, Chaikof E, Fleischmann KE, Freeman WK, Froehlich JB, Kasper EK, Kersten JR, Riegel R, Robb JR. ACC/AHA guidelines on perioperative cardiovascular evaluation and care for noncardiac surgery: executive summary. J Am Coll Cardiol. 2007;50:1707–32.
13. Noorzij PG, Boersma E, Bax JJ, Feringa HH, Schreiner F, Schouten O, Kertai MD, Klein J, van Urk H, Elhendy A, Poldermans D. Prognostic value of routine preoperative electrocardiography in patients undergoing noncardiac surgery. Am J Cardiol. 2006;97:1103–6.
14. Kertai MD, Boersma E, Bax JJ, Heijenbrok-Kal MH, Hunink MG, L'Talien GJ, et al. A meta-analysis comparing the prognostic accuracy of six diagnostic tests for predicting perioperative cardiac risk in patients undergoing major vascular surgery. Heart. 2003;89:1327–34.
15. Etchelis E, Meade M, Tomlinson G, et al. Semiquantitative dipyridamole myocardial stress perfusion imaging for cardiac risk assessment before noncardiac vascular surgery: a metaanalysis. J Vasc Surg. 2002;36:534–40.
16. Shaw LJ, Eagle KA, Gersh BJ, et al. Meta-analysis of intravenous dipyridamole-thallium-201 imaging (1985 to 1994) and dobutamine echocardiography (1991 to 1994) for risk stratification before vascular surgery. J Am Coll Cardiol. 1996;27:787–98.
17. Elhendy A, Valkema R, van Domburg RT, et al. Safety of dobutamine-atropine stress myocardial perfusion scintigraphy. J Nucl Med. 1998;39:1662–6.
18. Nandalur KR, Dwamena BA, Choudhri AF, et al. Diagnostic performance of stress cardiac magnetic resonance imaging in the detection of coronary artery disease: a meta-analysis. J Am Coll Cardiol. 2007;50:1343–53.
19. Rerkpattanapipat P, Morgan TM, Neagle CM, Link KM, et al. Assessment of perioperative cardiac risk with magnetic resonance imaging. Am J Cardiol. 2002;90:416–9.
20. Hamon M, Biondi-Zoccai GG, Malagutti P, et al. Diagnostic performance of multi-slice spiral computed tomography of coronary arteries as compared with conventional invasive coronary angiography: a meta-analysis. J Am Coll Cardiol. 2006;48:1896–910.
21. Tsimikas S, Willerson JT, Ridker PM. C-reactive protein and other emerging blood biomarkers to optimize risk stratification in vulnerable patients. J Am Coll Cardiol. 2006;47(8 Suppl):C19–31.
22. Wang TJ, Larson MG, Levy D, et al. Plasma natriuretic peptide levels and the risk of cardiovascular events and death. N Engl J Med. 2004;350:655–63.
23. Bibbins-Domingo K, Gupta R, Na B, et al. N-terminal fragment of the prohormone brain type natriuretic peptide (NT-proBNP), cardiovascular events, and mortality in patients with stable coronary heart disease. JAMA. 2007;297:169–76.
24. Ferrringa HHH, Bax JJ, Elhendy A, et al. Association of plasma N-terminal pro-B-type natriuretic peptide with postoperative cardiac events in patients undergoing surgery for abdominal aortic aneurysm or leg bypass. Am J Cardiol. 2006;98:111–5.
25. Dernellis J, Panaretou M. Assessment of cardiac risk in noncardiac surgery: brain natriuretic peptide in 1590 patients. Heart. 2006;92:1645–50.
26. Cuthbertson BH, Card G, Croal BL, et al. The utility of B-type natriuretic peptide in predicting postoperative cardiac events and mortality in patients undergoing major emergency noncardiac surgery. Anaesthesia. 2007;62:875–81.
27. Devereaux PJ, Yang H, Yusuf S, et al. Effects of extended release metoprolol succinate in patients undergoing noncardiac surgery (POISE trial): a randomised controlled trial. Lancet. 2008;371:1839–47.
28. van Lier F, Schouten O, Hoeks SE, et al. Impact of prophylactic beta-blocker therapy to prevent strokes after noncardiac surgery. Am J Cardiol. 2010;105:43–7.
29. Mnagano DT, Layug EL, Wallace A, et al. Effect of atenolol on mortality and cardiovascular morbidity after noncardiac surgery. Multicenter Study of Perioperative Ischemia Research Group. N Engl J Med. 1996;335:1713–20.
30. Brady AR, Gibbs JS, Greenhalgh RM, et al. Perioperative beta-blockade (POBBLE) for patients undergoing infrarenal vascular surgery: results of a randomized double-blind controlled trial. J Vasc Surg. 2005;41:602–9.
31. Yang H, Raymer K, Butler R, et al. The effects of perioperative beta-blockade: results of the Metoprolol after Vascular Surgery (MaVS) study, a randomized controlled trial. Am Heart J. 2006;152:983–90.
32. Bangalore S, Wetterslev J, Pranesh S, et al. Perioperative B-blockers in patients having noncardiac surgery: a meta-analysis. Lancet. 2008;372:1962–76.

33. Beattie WS, Wijeysundera DN, Karkouti K, et al. Does tight heart rate control improve beta blocker efficacy? An updated analysis of the noncardiac surgical randomized trials. Anesth Analg. 2008;106:1039–48.
34. Oscarsson A, Gupta A, Fredrikson M, et al. To continue or discontinue aspirin in the perioperative period: a randomized controlled clinical trial. Br J Anaesth. 2010;104:305–12.
35. Burger W, Chemnitius JM, Kneissl GD, et al. Low dose aspirin for secondary cardiovascular protection-cardiovascular risks after its perioperative withdrawal versus bleeding risks with its continuation-review and meta-analysis. J Intern Med. 2005;257:399–414.
36. POISE-2 Investigators. Aspirin in patients undergoing noncardiac surgery. N Engl J Med. 2014;370:1494–503.
37. Costerga M, Voors AA, Pinto YM, et al. Effects of quinapril on outcome after coronary artery bypass grafting (the QUO VADIS Study). QUinapril on Vascular Ace and Determination of Ischemia. Am J Cardiol. 2001;87:542–6.
38. Wijeysundera DN, Beattie WS. Calcium channel blockers for reducing cardiac morbidity after noncardiac surgery: a systematic review. Anesth Analg. 2003;97:634–41.
39. Coriat P, Daloz M, Bousseau D, et al. Prevention of intraoperative myocardial ischemia during noncardiac surgery with intravenous nitroglycerine. Anesthesiology. 1984;61:193–6.
40. Oliver MF, Goldman L, Julian DG, et al. Effect of mivazerol on perioperative cardiac complications during noncardiac surgery in patients with coronary heart disease: the European Mivazerol Trial (EMIT). Anesthesiology. 2004;101:284–93.
41. Wijeysundera DN, Naik JS, Beattie WS, et al. Alpha-2 adrenergic agonists to prevent perioperative cardiac complications: a meta-analysis. Am J Med. 2003;114:742–52.
42. POISE-2 Investigators. Clonidine in patients undergoing noncardiac surgery. N Engl J Med. 2014;370:1504–13.
43. Schouten O, Boersma E, Hoeks S, et al. Fluvastatin and perioperative events in patients undergoing vascular surgery. N Engl J Med. 2009;361:980–9.
44. Durazzo AE, Machado FS, Ikeoka DT, et al. Reduction in cardiovascular events after vascular surgery with atorvastatin: a randomized trial. J Vasc Surg. 2004;39:967–75.
45. Hindler K, Shaw AD, Samuels J, et al. Improved post-operative outcomes associated with preoperative statin therapy. Anesthesiology. 2006;105:1260–72.
46. McFalls EO, Ward HB, Moritz TE, et al. Coronary artery revascularization before elective major vascular surgery. N Engl J Med. 2004;351:2795–804.
47. Poldermans D, Schouten O, Vidakovic R, et al. A clinical randomized trial to evaluate the safety of a non-invasive approach in high risk patients undergoing major vascular surgery: the DECREASE V Pilot Study. J Am Coll Cardiol. 2007;49:1763–9.
48. Gottlieb A, Banoub M, Sprung J, et al. Perioperative cardiac morbidity in patients with coronary artery disease undergoing vascular surgery after percutaneous transluminal coronary angioplasty. J Cardiothorac Vasc Anesth. 1998;12:501.
49. Brilakis ES, Orford JL, Fasseas P, et al. Outcome of patients undergoing balloon angioplasty in the two months prior to noncardiac surgery. Am J Cardiol. 2005;96:512.
50. Wilson SH, Fasseas P, Orford JL, et al. Clinical outcome of patients undergoing noncardiac surgery in the two months following coronary stenting. J Am Coll Cardiol. 2003;42:234.
51. van Kujik JP, Flu WJ, Schouten O, et al. Timing of noncardiac surgery after coronary artery stenting with bare metal or drug eluting stents. Am J Cardiol. 2009;104:1229–34.
52. Eagle KA, Rihal CS, Mickel MC, et al. Cardiac risk of noncardiac surgery: influence of coronary disease and type of surgery in 3368 operations. Circulation. 1997;96:1882–7.
53. Douketis JD, Berger PB, Dunn AS, et al. The perioperative management of antithrombotic therapy: American College of Chest Physicians Evidence Based Clinical Practice Guidelines. Chest. 2008;133(6 Suppl):299S–339.
54. Kertai MD, Bountioukos M, Boersma E, Bax JJ, Thomson IR, Sozzi F, Klein J, Roelandt JR, Poldermans D. Aortic stenosis: an underestimated risk factor for perioperative complications in patients undergoing noncardiac surgery. Am J Med. 2004;116 (1):8–13.
55. Torsher LC, Shub C, Rettke SR, Brown DL. Risk of patients with severe aortic stenosis undergoing noncardiac surgery. Am J Cardiol. 1998;81(4):448–52.
56. Sohn GH, Dae Hee S, Byun KM, et al. The incidence and predictors of postoperative atrial fibrillation after non-cardiothoracic surgery. Korean Circ J. 2009;39:100–4.
57. Kahn RL, Hargett MJ, Urquhart B, Sharrock NE, Peterson MG. Supraventricular tachyarrhythmias during total joint arthroplasty: incidence and risk. Clin Orthop Relat Res. 1993;296:265–9.
58. Hollenberg SM, Dellinger RP. Noncardiac surgery: postoperative arrhythmias. Crit Care Med. 2000;28(Suppl):N145–50.
59. Mayson SE, Greenspan AJ, Adams S, et al. The changing face of postoperative atrial fibrillation prevention: a review of current medical therapy. Cardiol Rev. 2007;15:231–41.
60. Vaporciyan AA, Correa AM, Rice DC, et al. Risk factors associated with atrial fibrillation after noncardiac thoracic surgery: analysis of 2588 patients. J Thorac Cardiovasc Surg. 2004;127:779–86.
61. Conwell C, Kamienski M, Memtsoudis S. Risk factors of new onset atrial fibrillation in the noncardiac orthopedic patient. 2011. Capstone Project Title.
62. Kowey PR, Stebbins D, Igidbashian L, et al. Clinical outcomes of patients who develop PAF after CABG surgery. Pacing Clin Electrophysiol. 2001;24:191–3.
63. Crystal E, Thorpe KE, Connolly SJ, et al. Metoprolol prophylaxis against postoperative atrial fibrillation increases length of hospital stay in patients not on preoperative beta blockers: the beta blocker length of stay (BLOS) trial. Heart. 2004;90:941–2.
64. Chong CP, van Gaal WJ, Savige J, et al. Cardiac injury and troponin testing after orthopedic surgery. Injury. 2011;42:855–63.
65. Urban MK, Jules-Elysee K, Loughlin C, et al. The one year incidence of postoperative myocardial infarction in an orthopedic population. HSS J. 2008;4:76–80.
66. Alpert JS, Thygesen K, Antman E, et al. Myocardial infarction redefined: a consensus document of the Joint European Society of Cardiology/American College of Cardiology Committee for the redefinition of myocardial infarction. J Am Coll Cardiol. 2000;36:959–69.
67. Jules-Elysee K, Urban MK, Urquhart B, et al. Troponin I as a diagnostic marker of postoperative myocardial infarction in the orthopedic population. J Clin Anesth. 2001;8:556–60.
68. Devereaux PJ, Goldman L, Yusuf S, et al. Surveillance and preservation of major perioperative ischemic cardiac events in patients undergoing noncardiac surgery: a review. CMAJ. 2005;173: 779–88.
69. Biondi-Zoccai GG, Lotrionte M, Agostoni P, et al. A systematic review and meta-analysis of the hazards on discontinuing or not adhering to aspirin among 50,279 patients at risk for coronary artery disease. Eur Heart J. 2006;27:2667–74.

# Perioperative Care of the Orthopedic Patient with Chronic Pulmonary Disease

12

Kethy M. Jules-Elysee

**Objectives**

- To appreciate the contribution of chronic pulmonary disease to the genesis of postoperative complications.
- To demonstrate the utility of such preoperative testing as serum albumin, arterial blood gases, and the spirometric assessment of pulmonary function.
- To demonstrate the importance of chronic pulmonary disease such as asthma, chronic obstructive lung disease, sleep apnea, and pulmonary hypertension in the perioperative context.
- To present a logical approach to the preoperative evaluation of patients with chronic pulmonary disease.

**Key Points**

- Chronic pulmonary disease is a potent contributor to problems of both a pulmonary and nonpulmonary nature in the postoperative setting.
- Pulmonary problems rival, if not exceed, the cardiac domain in their importance in the perioperative clinical setting.
- The preoperative evaluation should assess the following, including chronic pulmonary disease in its several variations, obstructive sleep apnea, pulmonary hypertension, congestive heart failure, and impairment in cognitive and functional capacity as risk factors.

K.M. Jules-Elysee (✉)
Department of Anesthesiology, Hospital for Special Surgery, 535 E70th Street, New York, NY 10021, USA
e-mail: JulesElyseeK@hss.edu

## Introduction

Although the prevention and management of postoperative cardiac complications have received more attention in the medical literature, postoperative pulmonary complications (PPC) have comparable mortality rates, result in similar prolongation in length of hospital stay, and indeed may be more frequent [1, 2]. One large study (1,055 patients) has reported a 2.7 % incidence of pulmonary complications in patients whose surgery is rated preoperatively to be low to moderate risk, for example orthopedic surgery; those with such postoperative problems had a markedly longer length of stay (27.9 vs. 4.5 days) [3]. Among PPC (Table 12.1) the most common occurring after noncardiac surgery are pneumonia (usually aspiration), respiratory failure, and atelectasis [4–6]. However, several additional problems are also relevant in the orthopedic setting where fat embolism syndrome [7] and venous thromboembolism [8] are more frequently seen, especially after total joint arthroplasty of the hip and knee. Further, obstructive sleep apnea (OSA), a problem associated with respiratory complications after surgery, is prevalent in the orthopedic patient population [9]. Finally, there is the underappreciated problem of pulmonary hypertension, a condition associated with several of the connective tissue diseases as well as with sleep apnea. Due to their relevance in the postoperative orthopedic setting, the chapter will focus on these major pulmonary conditions.

## The Preoperative Evaluation

### Identification of Conditions That Affect Postoperative Pulmonary Outcome

This begins with a history and physical examination, coupled with relevant laboratory investigations, an approach more fully developed in Chap. 1. A number of pulmonary specific considerations are noteworthy, however. For instance the

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_12, © Springer New York 2014

**Table 12.1** PCC

| General complications |
|---|
| Atelectasis |
| Infection |
| Bronchitis |
| Pneumonia |
| Bronchospasm |
| Pulmonary embolism |
| Exacerbation of underlying chronic lung disease |
| Respiratory failure and prolonged invasive or noninvasive ventilation |
| Fat embolism syndrome with Acute Respiratory Distress Syndrome (ARDS) |

Used with permission from Bapoje SR, Whitaker JF, et al. Preoperative evaluation of the patient with pulmonary disease. Chest. 2007;132 (5):1637–45

history should focus on such symptoms as wheezing, coughing, sputum production, exercise tolerance, orthopnea, and paroxysmal nocturnal dyspnea. The physical examination ascertains the presence of such pertinent findings as dyspnea, wheezing, cough, or sputum production or in more severe cases, cyanosis; other key findings include edema, raised jugular-venous pressure suggesting the presence of cor pulmonale or heart failure. Pulse oximetry to determine the resting oxygen saturation should be obtained as part of the routine examination. Such physical findings are important, as in one study, abnormal findings on lung examination were the strongest predictors of PPC.

The laboratory may also add important information. An elevated hematocrit in the patient with suspected pulmonary disease suggests chronic hypoxemia. Electrolytes are also helpful as bicarbonate elevations may be indicative of carbon dioxide retention. Less appreciated is the significance of a serum albumin as a low albumin level is not only a predictor of 30-day perioperative morbidity and mortality [10] but also a predictor of pulmonary complications. In one study, patients with levels of <36 g/L had a PPC rate of 27.6 % vs. 7 % in patients with normal levels [11].

Arterial blood gases may be performed in conjunction with pulmonary function testing and help in the estimation of the severity of underlying pulmonary disease. Hypoxia confirms the need for supplemental oxygen, whereas an elevated $CO_2$ suggests respiratory insufficiency and the need for urgent supportive measures (BiPAP, mechanical ventilation). As mentioned, a concomitant elevation in serum bicarbonate suggests chronic respiratory failure.

An electrocardiogram should be evaluated for signs of right heart strain including *P*-pulmonale, right ventricular strain (dominant R waves in the septal leads), or right bundle branch block. Chest radiography may confirm hyperinflated lungs consistent with chronic obstructive lung disease and

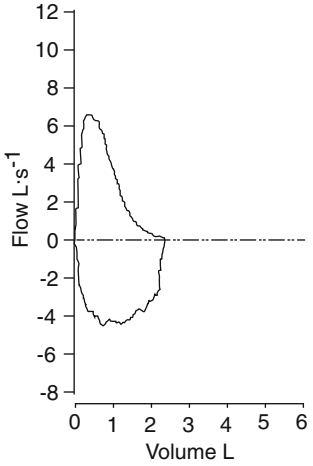


**Fig. 12.1** Flow-volume loop of a normal subject with end expiratory curvilinearity, which can be seen with aging. (Used with permission from Miller MR, Hankinson J, et al. Standardisation of spirometry. Eur Respir J. 2005;26(2): 319–38)

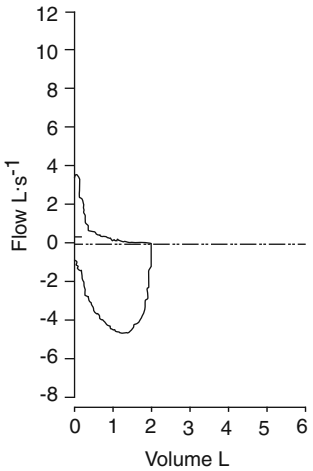


**Fig. 12.2** Severe airflow limitation in a subject with chronic obstructive pulmonary disease. (Used with permission from Miller MR, Hankinson J, et al. Standardisation of spirometry. Eur Respir J. 2005;26(2): 319–38)

rules out other lung pathology. Spirometry of the lung is the procedure by which lung function is evaluated. In order to facilitate an understanding of the role of such testing, a brief summary of the relevant spirometric patterns is justified.

Measurement of the $FEV_1$ is the best single measure of pulmonary function, a low $FEV_1$/FVC ratio being diagnostic of chronic obstructive pulmonary disease (COPD). More formal evaluations such as flow-volume loops are also useful and may distinguish respiratory versus cardiac dyspnea, and differentiate both obstructive versus restrictive lung diseases and reversible versus fixed pulmonary conditions (Figs. 12.1 and 12.2). The assessment of peak flow, a parameter

**Table 12.2** Risk factors for PPCs

| Preoperative risk factors |
|---|
| Chronic Obstructive Pulmonary Disease (COPD) |
| Age |
| Inhaled tobacco use |
| NYHA class II pulmonary hypertension |
| Obstructive Sleep Apnea (OSA) |
| Nutrition status |
| Congestive heart failure |
| ASA class |
| Functional dependence |

Used with permission from Bapoje SR, Whitaker JF, et al. Preoperative evaluation of the patient with pulmonary disease. Chest. 2007;132 (5):1637–45

analogous to the $FEV_1$, is easily measured using a simple, portable peak flow meter. It is useful both diagnostically and to follow the course of respiratory function in the postoperative setting.

While spirometric data can be helpful in planning for intrathoracic surgery, their benefit in extrathoracic surgery is not clear. Studies comparing spirometry to clinical data have not shown such testing to be diagnostically superior to the history and physical exam. Although McAlister found an FEV1 <1.0 L to be an adverse prognostic factor for PPC (OR 5.6) [3], spirometric assessment does not always predict PPC even in those with underlying lung disease [12]. As most patients identified as high risk by spirometry can be identified by clinical history, such testing should be performed mainly in patients with pulmonary symptoms but without a specific diagnosis. There is one orthopedic setting in which spirometric assessments are routinely employed, however: the patient undergoing complex spine surgery. The management of such patients is discussed in detail in Chaps. 10 and 26.

Exercise testing, whether formal treadmill or bicycle-based testing, or more simple measures such as the 6-min walk test, have been proposed for use in the preoperative environment. Nonetheless, the pain-related functional limitations in patients facing orthopedic surgery render these techniques of limited value.

With that background, this review now moves to a consideration of a number of chronic conditions known to contribute to the development of pulmonary complications after surgery (Table 12.2). These include chronic lung disease specifically emphysema, OSA, pulmonary arterial hypertension, and congestive heart failure. Further an impaired sensorium whether chronic or acute also contributes to an increased risk [13]. Although commonly implicated, conditions such as chronic stable asthma and obesity (even morbid obesity) do not increase the rate of pulmonary complications after noncardiac surgery.

## Chronic Pulmonary Disease

Chronic forms of pulmonary disease are the most commonly identified comorbidities contributing to the likelihood of PPC (OR 1.79) [11]. When conceptualized broadly, chronic pulmonary diseases are either reversible or irreversible.

Asthma is the prototypical reversible form and is a condition characterized by airway obstruction, inflammation, and hyperresponsiveness [14]. The severity of airway inflammation determines the degree of bronchial hyperresponsiveness and thus disease activity. Disease severity is assessed by the frequency and severity of attacks including hospital admissions, need for intubation, and by drug history, especially the use of corticosteroids. In patients with well-controlled asthma, the postoperative complication rate is relatively low [15]. Previously higher complication rates were reported with asthma [16, 17], though modern therapeutic strategies and anesthetic techniques have improved outcome. In the asymptomatic patient with history of asthma, the frequency of perioperative bronchospasm may approach that of the non-asthmatic 1.2 % [15]. Patients with active disease may develop a higher incidence of bronchospasm. These patients may benefit from a course of β2-agonists and systemic steroid pretreatment 5 days before surgery [18].

COPD is characterized by airflow limitation which is not fully reversible (Figs. 12.1 and 12.2). It is also associated with abnormal inflammatory response of the lungs to noxious stimuli, specifically cigarette smoking [19]. This remains the major risk factor of COPD [20]. COPD is the most commonly identified risk factor for PPC with an odd ratio of 1.9 [13]. Patients with COPD have a 2.7–4.7-fold increased risk of PPC [13, 21]. It is associated with atelectasis and pneumonia postoperatively. Studies have shown, however, that COPD alone does not predict the likelihood of PPC; other factors such as ASA physical status (Table 12.3), duration of surgery, and duration of anesthesia play a role [22]. In patients undergoing shoulder surgery the potential for respiratory decompensation should be assessed prior to administering interscalene or supraclavicular block. Both these blocks can lead to diaphragmatic paralysis further compromising lung mechanics [23, 24].

One important pulmonary subgroup frequently seen in the orthopedic setting, specifically with spinal surgery, is those patients with spinal deformities who are undergoing major corrective surgery. While such spinal and chest wall deformities as kyphoscoliosis may result in severely restrictive lung physiology, the estimation of the incremental surgical risk is imprecise and not fully appreciated by many perioperative physicians. Physicians experienced in the perioperative care of these patients intuitively understand

**Table 12.3** American society of anesthesiologists classification

| ASA class | Class definition | Rates of PPCs by class (%) |
|---|---|---|
| I | A normally health patient | 1.2 |
| II | A patient with mild systemic disease | 5.4 |
| III | A patient with systemic disease that is not incapacitating | 11.4 |
| IV | A patient with an incapacitating systemic disease that is a constant threat to life | 10.9 |
| V | A moribund patient who is not expected to survive for 24 h with or without operation | NA |

Data from Owens WD, Felts JA, Spitznagel EL Jr. ASA physical status classifications: a study of consistency of ratings. Anesthesiology. 1978;49:239–43

*ASA* American Society of Anesthesiologist; *NA* not applicable; *PPC* postoperative pulmonary complication

Used with permission from Qaseem A, Snow V, et al. Risk assessment for and strategies to reduce perioperative pulmonary complications for patients undergoing noncardiothoracic surgery: a guideline from the American College of Physicians. Ann Intern Med. 2006;144(8):575–80

and recognize the challenge they present in the perioperative context, however. Such patients are discussed in detail in Chaps. 10 and 26.

## Obstructive Sleep Apnea

Sleep disordered breathing occurs in 20 % of the adult population [25, 26]. Furthermore, although the prevalence of true OSA may be as high as 5–9 %, it may be even higher in surgical populations [27–29]. Up to 80 % of patients with OSA are unaware of the diagnosis and are thus untreated [26], so physicians performing preoperative evaluations need to consider this diagnosis in patients with known risk factors, usually morbid obesity.

OSA can be graded in severity from mild-apnea-hypopnea index (AHI) between 6-20, to severe with an AHI of greater than 40. Three types of sleep apnea are recognized—obstructive, central, and mixed—though the obstructive type is the most prevalent and problematic in the postoperative period [30]. In the obstructive form, a partial or complete upper airway obstruction occurs during sleep leading to oxygen desaturation and hypercapnea. In the postoperative setting the classic presentation is that of a sedated, morbidly obese patient, often with no documented history of OSA, who is observed to experience upper airway obstruction in the recovery room. Physical characteristics that correlate with the condition include a large neck circumference ($\geq$17 in.), craniofacial abnormalities, anatomic nasal obstruction, and tonsils that appose in the midline. Postoperatively snoring with airway obstruction leading to hypoxemia requiring chin lift provides the clinical suspicion for OSA [29].

Practice guidelines have been developed for the perioperative management of patients with OSA [31]. Fundamentally the diagnosis should be suspected, and indeed can be predicted with relative confidence, based on specific patient characteristics. These include increased body mass index, increased neck circumference, snoring, congenital airway abnormalities, daytime hypersomnolence, inability to visualize the soft palate, and tonsillar hypertrophy. Observed apnea usually by the patient's wife during sleep is also predictive. In addition, simple questionnaires have been developed for the screening of this condition. The Berlin questionnaire, an early example, was first validated in patients in primary care settings [32] and later in surgical patients [33]. More recently, the STOP (Snoring, Tiredness during daytime, Observed apnea, high blood Pressure), or the STOP-BANG questionnaire when body mass index, age, neck circumference, and gender are added, has been shown to be an effective screening methodology [34, 35].

Relatively prevalent in the orthopedic setting OSA poses risks on a number of fronts. First OSA immediately presents airway challenges to the anesthesiologist should general anesthesia be required. Although formal study of these patients in the orthopedic arena has been scant, one study of patients undergoing hip and knee replacement also suggests higher rates of reintubation, hypercapnia, and hypoxemia [36]. In addition these patients are at risk for postoperative atrial fibrillation and other cardiac arrhythmias, hypertension, heart failure, and even sudden death [37, 38]. This chronic condition is usually linked to morbid obesity and, in its advanced stages, with pulmonary hypertension. Likewise diabetes occurs in higher prevalence in patients with OSA; there may also be an increased risk of venous thrombosis.

## Pulmonary Arterial Hypertension

Another important but less appreciated problem in the perioperative setting is the patient with pulmonary arterial hypertension (PAH), defined as mean pulmonary arterial pressure >25 mmHg at rest or 30 mmHg during exercise. Owing to its association with a number of connective tissue diseases, this condition is well known not only to the pulmonologist but also to rheumatologists who do not infrequently confront its consequences in patients with such diseases as scleroderma, mixed connective tissue disease, and systemic

lupus erythematosus (Chap. 3). A pathophysiological state characterized by elevated right heart afterload, decreased venous return, reduced cardiac output, and deficient oxygen saturation, PAH is categorized according to its underlying etiology. Primary pulmonary hypertension arises as a consequence of left heart disease, hypoxic pulmonary disorders (for instance OSA), or from chronic thromboembolic phenomenon [39].

### Congestive Heart Failure

Congestive heart failure (CHF) increases the risk for PPC; Smetana in 2006 did a MEDLINE search looking at studies on PPC [40]. There were a total of 10,960 pulmonary complication events among 324,648 patients. CHF increased the risk of PPC with an odds ratio of 2.93. Examining an array of pulmonary risk factors, Arozullah has reported that among potential predictors related to cardiac states, only CHF was a significant predictor, OR 1.3 (95 % CI, 1.1–1.5) [41].

### Impairment in Cognitive and Functional Capacity

Lastly, there is evidence suggesting that various nonpulmonary conditions also correlate with adverse postoperative pulmonary events. For example an impaired sensorium, whether acute (delirium due to concomitant medical condition, alcohol withdrawal) or chronic (dementia), increases the rate of pulmonary complications after surgery [40, 41]. Such problems have other important and far-reaching consequences, interfering with the rehabilitative process and complicating discharge planning.

## The Optimization of Conditions Relevant to Postoperative Pulmonary Outcome

Turan et al. evaluated 635,265 patients from the American College of Surgeons National Surgical Quality Improvement Program database, and found higher mortality and serious postoperative complications in current smokers versus never smokers. The complications included pneumonia, higher intubation rates, cardiac arrest, myocardial infarction, and superficial and deep wound infection [42]. Of note, current smokers were defined as patients who reported smoking the year before admission while never smokers were patients who reported not smoking in the previous years and also reported zero lifetime pack years.

Some studies have implied a higher complication rate in patients who have stopped suddenly prior to surgery because of decreased cough and increased sputum production [43, 44]. In a meta-analysis of perioperative smoking cessation and outcomes, Myers et al. found no evidence that quitting smoking for less than 8 weeks before surgery had an impact on outcome [45]. Lindstrom in a group of patients undergoing general and orthopedic surgery found a statistically significant difference in complication rates in controls vs. an intervention group (41 % vs. 21 %) when smoking cessation started 4 weeks before surgery [46]. Complications were defined as any unexpected event that required treatment or prolonged care. A decreased need for postoperative ventilatory support has also been reported in a group of patients undergoing elective orthopedic surgery after enrolling in a smoking cessation program for 6–8 weeks [47]. In conclusion, the most effective time to stop smoking has not been well defined in the literature, but there is no evidence that quitting smoking less than 8 weeks prior to surgery leads to any harm.

Smoking is associated with hyperreactive airways with poor mucociliary clearance of secretions. Smokers are more prone to perioperative respiratory complications such as atelectasis or pneumonia even in the absence of underlying chronic lung disease [48, 49]. Besides pulmonary issues, smoking has many effects on bone health including accelerated bone mineral density loss, delayed fracture healing, and wound complications through its effect on immune function, all relevant in the orthopedic setting [50, 51].

Abstinence for 12 h before anesthesia allows time for nicotine clearance, a coronary vasoconstrictor. Nicotine also causes hypertension and tachycardia through its action on the sympathetic nervous system [52]. The presence of carbon monoxide leads to carboxyhemoglobin formation, shifting the oxygen-hemoglobin curve to the left and decreasing oxygen delivery to tissues [53]. Smoking cessation prior to surgery is usually recommended for improvement in ciliary action, macrophage activity, small airway function, as well as a decrease in sputum production. The correct timing for smoking cessation prior to surgery has been debated. Although it takes about 6 months for recovery of antimicrobial and alveolar macrophage formation [54], smoking cessation for 6–8 weeks improves pulmonary function and diminishes cardiovascular complications [47, 54]. Wound healing improves after 3 weeks of abstinence [55]. Nicotine has a half-life of 1 h while carboxyhemoglobin has a half-life of 4 h. One day of abstinence should result in much lower concentrations of these substances [55].

Prior to surgery, patients with COPD need to be assessed for quantity and quality of sputum production along with the frequency of their exacerbations. If a change in sputum is noted, the preoperative use of antibiotics may be helpful. A short course of preoperative steroids may also be indicated for severe COPD [56, 57].

Preoperative teaching focusing on techniques of lung expansion maneuvers and mobilization of secretions is

imperative. After major surgery, hypoxia may persist postoperatively, especially for patients on opioids [58]. Oxygen supplementation should be given in that time period. Every patient who may be at risk for PPC should use incentive spirometer and undergo deep breathing exercises. Other techniques such as coughing, postural drainage, percussion, vibration, suctioning, and ambulation should be used when indicated. Therapy with any of them is superior to no prophylaxis [59] in terms of fewer abnormalities on chest radiograph and tendency towards less complication. However, no specific one is better than the others [60]. Among the different modalities to maintain lung expansion postoperatively, continuous positive airway pressure (CPAP) may be helpful in the patient unable to perform deep breathing or incentive spirometry exercises [61]. The benefits of CPAP have included a decrease in intubation rates and a lower incidence of pneumonia in patients with postoperative hypoxemia after major abdominal surgery [62]. It has also been found to prevent pulmonary complications when used prophylactically.

## The Assessment of Perioperative Risk

With the exception of complex spine surgery and bilateral total joint arthroplasty, orthopedic procedures are generally considered to be of low to intermediate risk. All patients undergoing noncardiac surgery, however, should be evaluated for possible COPD; age older than 60 years, American Society of Anesthesiologists (ASA) class II or greater, functional dependency, and congestive heart failure all of which are known risk factors for PPC [13]. The higher the ASA class, the greater the risk [63]. Poor exercise tolerance and surgery lasting more than 3 h carry a higher risk of pulmonary complications [41, 64]. Age also plays an important role especially above 60 years, even after adjustment for comorbid conditions [40]. Even the healthy elderly is at increased risk of pulmonary complication [41, 64]. The odds that a patient experiences pulmonary complications increase statistically with age. Functional dependence has also been identified as a risk factor with total dependence being worse than partial dependence (being able to perform some activities of daily living) with an odd ratio of 2.51 vs. 1.65 [13, 41].

Pulmonary complication rates are more common in OSA patients [65]. The higher the number of desaturation episodes, the greater the complication rate. An oxygen desaturation index of $\geq 5$ was found to have a higher incidence of respiratory complication. Higher rates of reintubation, oxygen desaturation, hypercapnea, unplanned ICU transfers, and longer hospitalizations have been noticed [36]. Using the National Inpatient Sample of more than five million patients, Memtsoudis et al. confirmed the high rate of pulmonary complications in patients with OSA. In addition, an increased risk of pulmonary embolism was noted in the orthopedic patient population with sleep apnea.

Anesthesia tends to reduce pharyngeal musculature tone and diminish the ventilatory response to carbon dioxide. Opiates and benzodiazepines act as respiratory depressants [29]. The first night postoperatively, sleep is reduced and is highly fragmented [56, 57]. Surgical stress and pain can also affect OSA by leading to postoperative sleep deprivation, sleep fragmentation, and reduction in rapid eye movement sleep (REM). This is followed by rebound REM sleep in the second and third postoperative nights accompanied by increased susceptibility to airway obstruction and apnea lasting for days [55, 58, 59].

Perioperative use of CPAP reduces the complication rate seen in OSA patient. Its use improves upper airway patency, decreases myocardial ischemia, and stabilizes the blood pressure [62]. Kindgen-Milles et al. was able to show reduced pulmonary morbidity and length of stay in hospitalized patients after surgical repair of thoracoabdominal aortic aneurysms while using CPAP [65].

Many patients with OSA present to the OR without such diagnosis having been made. Postoperative CPAP should be empirically considered in these patients although this has not been studied. Of note, use of CPAP prior to surgery has been found to be beneficial in terms of decreasing complications rates postoperatively possibly from upper airway stabilization from CPAP [51]. Close postoperative monitoring of high-risk patients with either diagnosed or suspected OSA is recommended [36]. Data on management of these patients after surgery remain limited.

## Pulmonary Hypertension

In the surgical setting PAH is especially perilous, greatly challenging the medical consultant and anesthesiologist alike. In the setting of anesthesia, the sustained elevations in pulmonary vascular resistance and pulmonary arterial pressure, coupled with impaired vascular reactivity, may result in significant systemic hypotension. Further the negative inotropic effects of some anesthetic agents may exacerbate this tendency precipitating right heart failure. Simultaneously these adverse left-sided phenomena (systemic hypotension) are further exacerbated by concomitant right-sided responses resulting from hypoxia-mediated pulmonary vasoconstriction. In sum these events set in motion a cascade of adverse sequelae including hypercarbia, acidosis, and the release of catecholamines that, if progressing too far, may end in frank circulatory collapse. Reported experience supports these worrisome contentions. Ramakrishna et al. observed a 28 % incidence of respiratory failure and 7 %

**Table 12.4** Variables considered independent predictors in a multivariate logistic regression model of short-term morbidity after noncardiac surgery

| Characteristic | p value | OR (95 % CI) |
|---|---|---|
| History of pulmonary embolism | 0.01 | 7.3 (1.9–38.3) |
| New York Heart Association functional class ≥II | 0.02 | 2.9 (1.2–7.7) |
| Intermediate/high-risk surgery | 0.04 | 3.0 (1.1–9.4) |
| Duration of anesthesia >3 h | 0.04 | 2.9 (1.03–4.6) |

*CI* confidence interval, *OR* odds ratio
Used with permission from Ramakrishna G, Sprung J, et al. Impact of pulmonary hypertension on the outcomes of noncardiac surgery: predictors of perioperative morbidity and mortality. J Am Coll Cardiol. 2005;45(10):1691–9

mortality in patients with PAH ($n = 145$). Factors found to be independent predictors of short-term morbidity in noncardiac surgery have been described (Table 12.4) [66]. In another study, the rate of respiratory failure was 21 % in patients with PAH as compared to only 3 % of matched controls; in-hospital mortality was also higher in the PAH group [67]. Emergency surgery, coronary artery disease, and systolic pulmonary artery pressure were independent predictors of morbidity. Kaw et al. in a cohort study of 173 patients with PAH found higher incidence of congestive heart failure and respiratory failure [68]. They were more likely to require longer periods of ventilatory support.

Another concern in patients with pulmonary hypertension is further elevation of pulmonary pressures by either thrombotic events with pulmonary embolism or fat embolism (FES) leading to acute right heart failure. Cardiac arrest due to FES occurring during joint replacement has been reported [7]. Manifestations of FES include respiratory failure, change in mental status, cardiovascular collapse, petechiae rash, pyrexia, and thrombocytopenia [69]. Acutely, however, it may cause mechanical neurovascular obstruction further elevating pulmonary arterial pressures. This is followed by a chemical phase characterized by inflammatory damages in the lungs leading to acute respiratory distress syndrome [70].

In PAH, right heart afterload is elevated leading to decreased cardiac output, decreased venous return, and deficient oxygen saturation [71]. Intraoperatively, the vasodilating effects of anesthetics may help decrease the right ventricular preload and alleviate pulmonary pressures and ventricular ischemia. Postoperatively, however, anesthetic drugs are withdrawn and patients become more prone to decompensation due to surgical stress, pain, fluid shift increasing pulmonary vasculature, and compromising oxygenation and cardiac output [72]. There is an inverse relationship between survival and pulmonary arterial systolic arterial pressure [73, 74]. Anesthesia and surgery may lead to stress, pain, acidosis, and hypoxemia all causing further constriction of the pulmonary vasculature.

Patients with significant PAH should be evaluated for specific therapy prior to undergoing elective surgery. The need for therapeutic agents such as vasodilators, anticoagulants, anti-inflammatory, and vascular remodeling drugs should be considered [72]. Calcium channel blockers are first line agents if the patient has had a positive response to vasoreactive testing [75]. Prostanoids have also been used with improvement in exercise capacity and survival in patients with PAH. Phosphodiesterase inhibitors such as sildenafil are great vasodilators and have become first line agents. Endothelin receptor antagonists such as bosentan have improved performance in patients with PAH. Many patients, however, will present for surgery without such therapy having been initiated. If surgery cannot be postponed, an oral dose of sildenafil may be given prior to surgery. This agent has significant effects on pulmonary pressures while systemic pressures are not affected as much [76, 77]. Other drugs such as inhaled nitric oxide should be readily available. Phosphodiesterase inhibitors such as amrinone or milrinone should be in the operating room. They have an effect on both pulmonary and systemic pressures while increasing cardiac output [78]. Vasopressin may be used to maintain systemic pressure [79]. It has less of an effect on pulmonary pressures compared to other agents used for treatment of hypotension. Postoperatively, pain management, oxygenation, and perfusion should be optimized. These patients should be monitored closely, and respiratory acidosis avoided [80].

## Anesthesia Technique

General anesthesia may lead to decreased diaphragm activity from reflex inhibition of phrenic nerve and pain leading to decreased lung volume, alveolar collapse, airway closure, and ventilation/perfusion imbalance [81]. Regional anesthesia may avoid some of the pulmonary complications of general anesthesia. However, a high spinal/epidural anesthetic may result in impaired intercostal muscle function leading to a decrease in FRC, perioperative basal atelectasis, and hypoxia [81]. At lower concentrations of bupivacaine 0.25 %, however, ventilatory mechanics, inspiratory respiratory muscle strength, and airway flow are maintained even in patients with severe COPD [82, 83].

It is not clear whether neuraxial block leads to fewer respiratory complications compared to general anesthesia, although it may avoid the risk of bronchospasm seen with endotracheal intubation. For upper abdominal and thoracic surgery, epidural analgesia has been found to be helpful in reducing the risk of PPC [82, 83]. Meta-analysis on epidural analgesia for total hip and knee replacement surgery found insufficient number of patients to perform analysis of PPC [84]. Wu et al. found no difference in the incidence of pneumonia at 7 or 30 days in a group of patients undergoing total hip replacement with or without epidural analgesia [85]. Pedersen et al. found a higher incidence of PPC for orthopedic surgery performed under general anesthesia compared to regional anesthesia (11.5 % vs. 3.6 %) [86]. In a study looking at hip fracture repair, the rate of postoperative pneumonia was similar in the neuraxial group compared to the general group, 5.1 % vs. 5.5 % [87].

The major advantage to neuraxial block in orthopedic surgery is the reduction in the rate of DVT or pulmonary embolism (PE) seen after joint replacement surgery. In a meta-analysis by Hu, regional anesthesia decreased the incidence of thromboembolic disease (OR 0.45 DVT and OR 0.46 PE) in patients undergoing hip or knee arthroplasty [88]. In a meta-analysis of 141 trials of patients undergoing different types of surgery, neuraxial blockade reduced odds of DVT by 44 % and PE by 55 % [89].

## Postoperative Considerations

Effective postoperative analgesia is important since it allows deep breathing, adequate coughing, and clearance of secretions. Epidural analgesia gives superior analgesia compared to intravenous patient-controlled analgesia and may improve recovery by reducing respiratory muscle dysfunction and pain-related hypoventilation [81]. While epidural analgesia postoperatively has led to a significant reduction in respiratory failure in patients undergoing abdominal aortic surgery or in high-risk patients undergoing abdominal surgery, this has not been proven with joint surgery [82, 83]. Most of the epidurals in these studies were placed in the thoracic region. Peripheral nerve blockade with or without catheter placement also adds to the analgesic regimen and may reduce the need for opiate use [90–92].

Multimodal analgesia using nonsteroidal analgesic agents, acetaminophen and ketamine which all act through nonopioid pathways, should be considered. They have all been shown to reduce pain scores and opioid-related side effects [93–95]. In addition, in a systematic review of perioperative use of gabapentinoids (pregabalin and gabapentin) by Tiippana et al., they were shown to be effective at reducing postoperative pain, opioid-related adverse effects, and opioid use [96]. The optimal dose of these medications along with duration of treatment remains to be determined.

**Table 12.5** Pulmonary risk reduction strategy

| |
|---|
| *Preoperative* |
| • Encourage smoking cessation |
| • Treat airflow obstruction |
| • Antibiotic administration and delay of surgery if respiratory infection or worsening symptoms |
| • Begin education on postoperative lung expansion |
| • Consider preoperative use of CPAP in OSA patients |
| • If signs of RV strain or dysfunction on EKG consider echocardiogram to rule out pulmonary hypertension |
| *Intraoperative* |
| • Regional anesthesia |
| • Limit duration of surgery to <3 h |
| *Postoperative* |
| • Deep breathing exercises or incentive spirometry |
| • CPAP |
| • Epidural analgesia and peripheral nerve block |
| • Multimodal pain regimen |

## Summary

Chronic pulmonary disease is a potent contributor to problems of both a pulmonary and nonpulmonary nature in the postoperative setting. Although the perioperative literature has been highly focused, perhaps dominated, by concerns of a cardiac nature, pulmonary problems rival, if not exceed the cardiac domain in their importance in this clinical setting. The assessment and management of patients with chronic pulmonary disease in its several variants have long been the focus of an extensive literature. OSA and pulmonary hypertension, important because of their implications with respect to anesthesia, have been recently added to the discussion. This chapter reviews the role played by this panoply of conditions in the genesis of PPC. The mitigating role for such techniques as neuraxial is also introduced. See Table 12.5 for a summary of pulmonary risk reduction strategies in pre-, intra-, and postoperative settings.

**Summary Bullet Points**

- Chronic pulmonary disease is frequently encountered in the perioperative setting and place patients at significant risk postoperatively. The magnitude of this risk is comparable to that of existing cardiac disease.
- Obstructive sleep apnea and the associated pulmonary hypertension impose particular dangers and are relatively underappreciated preoperative comorbidities.

- Regional anesthesia, specifically neuraxial block, is often employed in orthopedic surgery and may avoid some pulmonary complications.
- A major advantage to regional anesthesia is the reduction in deep venous thrombosis after lower extremity joint replacement surgery.

## References


1. Lawrence VA, et al. Incidence and hospital stay for cardiac and pulmonary complications after abdominal surgery. J Gen Intern Med. 1995;10(12):671–8.
2. Lawrence VA, et al. Medical complications and outcomes after hip fracture repair. Arch Intern Med. 2002;162(18):2053–7.
3. McAlister FA, et al. Incidence of and risk factors for pulmonary complications after nonthoracic surgery. Am J Respir Crit Care Med. 2005;171(5):514–7.
4. Kozlow JH, et al. Epidemiology and impact of aspiration pneumonia in patients undergoing surgery in Maryland, 1999–2000. Crit Care Med. 2003;31(7):1930–7.
5. Ephgrave KS, et al. Postoperative pneumonia: a prospective study of risk factors and morbidity. Surgery. 1993;114(4):815–9. Discussion 819–21.
6. Mitchell CK, et al. Multivariate analysis of factors associated with postoperative pulmonary complications following general elective surgery. Arch Surg. 1998;133(2):194–8.
7. Donaldson AJ, et al. Bone cement implantation syndrome. Br J Anaesth. 2009;102(1):12–22.
8. Snow V, et al. Management of venous thromboembolism: a clinical practice guideline from the American College of Physicians and the American Academy of Family Physicians. Ann Intern Med. 2007;146(3):204–10.
9. Memtsoudis S, et al. Perioperative pulmonary outcomes in patients with sleep apnea after noncardiac surgery. Anesth Analg. 2011;112 (1):113–21.
10. Gibbs J, et al. Preoperative serum albumin level as a predictor of operative mortality and morbidity: results from the National VA Surgical Risk Study. Arch Surg. 1999;134(1):36–42.
11. Herrmann FR, et al. Serum albumin level on admission as a predictor of death, length of stay, and readmission. Arch Intern Med. 1992;152(1):125–30.
12. Kocabas A, et al. Value of preoperative spirometry to predict postoperative pulmonary complications. Respir Med. 1996;90(1): 25–33.
13. Qaseem A, et al. Risk assessment for and strategies to reduce perioperative pulmonary complications for patients undergoing noncardiothoracic surgery: a guideline from the American College of Physicians. Ann Intern Med. 2006;144(8):575–80.
14. Maddox L, Schwartz DA. The pathophysiology of asthma. Annu Rev Med. 2002;53:477–98.
15. Warner DO, et al. Perioperative respiratory complications in patients with asthma. Anesthesiology. 1996;85(3):460–7.
16. Gold MI, Helrich M. A study of complications related to anesthesia in asthmatic patients. Anesth Analg. 1963;42:238–93.
17. Shnider SM, Papper EM. Anesthesia for the asthmatic patient. Anesthesiology. 1961;22:886–92.
18. Silvanus MT, Groeben H, Peters J. Corticosteroids and inhaled salbutamol in patients with reversible airway obstruction markedly decrease the incidence of bronchospasm after tracheal intubation. Anesthesiology. 2004;100(5):1052–7.
19. Celli BR, MacNee W. Standards for the diagnosis and treatment of patients with COPD: a summary of the ATS/ERS position paper. Eur Respir J. 2004;23(6):932–46.
20. Saetta M, et al. CD8+ T-lymphocytes in peripheral airways of smokers with chronic obstructive pulmonary disease. Am J Respir Crit Care Med. 1998;157(3 Pt 1):822–6.
21. Trayner Jr E, Celli BR. Postoperative pulmonary complications. Med Clin North Am. 2001;85(5):1129–39.
22. Wong DH, et al. Factors associated with postoperative pulmonary complications in patients with severe chronic obstructive pulmonary disease. Anesth Analg. 1995;80(2):276–84.
23. Urmey WF, Talts KH, Sharrock NE. One hundred percent incidence of hemidiaphragmatic paresis associated with interscalene brachial plexus anesthesia as diagnosed by ultrasonography. Anesth Analg. 1991;72(4):498–503.
24. Mak PH, et al. Incidence of diaphragmatic paralysis following supraclavicular brachial plexus block and its effect on pulmonary function. Anaesth. 2001;56(4):352–6.
25. Young T, et al. Estimation of the clinically diagnosed proportion of sleep apnea syndrome in middle-aged men and women. Sleep. 1997;20(9):705–6.
26. Kapur V, et al. Underdiagnosis of sleep apnea syndrome in US communities. Sleep Breath. 2002;6(2):49–54.
27. Young T, Peppard PE, Gottlieb DJ. Epidemiology of obstructive sleep apnea: a population health perspective. Am J Respir Crit Care Med. 2002;165(9):1217–39.
28. Fidan H, et al. Prevalence of sleep apnoea in patients undergoing operation. Sleep Breath. 2006;10(3):161–5.
29. Kaw R, et al. Unrecognized sleep apnea in the surgical patient: implications for the perioperative setting. Chest. 2006;129(1):198–205.
30. Cartagena R. Preoperative evaluation of patients with obesity and obstructive sleep apnea. Anesthesiol Clin North America. 2005;23 (3):463–78. vi.
31. Gross JB, et al. Practice guidelines for the perioperative management of patients with obstructive sleep apnea: a report by the American Society of Anesthesiologists task force on perioperative management of patients with obstructive sleep apnea. Anesthesiology. 2006;104(5):1081–93. Quiz 1117–8.
32. Netzer NC, et al. Using the Berlin questionnaire to identify patients at risk for the sleep apnea syndrome. Ann Intern Med. 1999;131(7): 485–91.
33. Chung F, et al. Validation of the Berlin questionnaire and American Society of Anesthesiologists checklist as screening tools for obstructive sleep apnea in surgical patients. Anesthesiology. 2008; 108(5):822–30.
34. Chung F, et al. STOP questionnaire: a tool to screen patients for obstructive sleep apnea. Anesthesiology. 2008;108(5):812–21.
35. Vasu TS, et al. Obstructive sleep apnea syndrome and postoperative complications: clinical use of the STOP-BANG questionnaire. Arch Otolaryngol Head Neck Surg. 2010;136(10):1020–4.
36. Gupta RM, et al. Postoperative complications in patients with obstructive sleep apnea syndrome undergoing hip or knee replacement: a case-control study. Mayo Clin Proc. 2001;76 (9):897–905.
37. Liao P, et al. Postoperative complications in patients with obstructive sleep apnea: a retrospective matched cohort study. Can J Anaesth. 2009;56(11):819–28.
38. Hwang D, et al. Association of sleep-disordered breathing with postoperative complications. Chest. 2008;133(5):1128–34.
39. McGlothlin D, De Marco T. Preoperative risk assessment of pulmonary arterial hypertension patients undergoing general surgery. Adv Pulmon Hypertens. 2007;6(2):66–73.
40. Smetana GW, Lawrence VA, Cornell JE. Preoperative pulmonary risk stratification for noncardiothoracic surgery: systematic review for the American College of Physicians. Ann Intern Med. 2006;144 (8):581–95.

41. Arozullah AM, et al. Multifactorial risk index for predicting postoperative respiratory failure in men after major noncardiac surgery. The National Veterans Administration Surgical Quality Improvement Program. Ann Surg. 2000;232(2):242–53.
42. Turan A, et al. Smoking and perioperative outcomes. Anesthesiology. 2011;114(4):837–46.
43. Bluman LG, et al. Preoperative smoking habits and postoperative pulmonary complications. Chest. 1998;113(4):883–9.
44. Nakagawa M, et al. Relationship between the duration of the preoperative smoke-free period and the incidence of postoperative pulmonary complications after pulmonary surgery. Chest. 2001; 120(3):705–10.
45. Myers K, et al. Stopping smoking shortly before surgery and postoperative complications: a systematic review and meta-analysis. Arch Intern Med. 2011;171(11):983–9.
46. Lindstrom D, et al. Effects of a perioperative smoking cessation intervention on postoperative complications: a randomized trial. Ann Surg. 2008;248(5):739–45.
47. Moller AM, et al. Effect of preoperative smoking intervention on postoperative complications: a randomised clinical trial. Lancet. 2002;359(9301):114–7.
48. Dilworth JP, White RJ. Postoperative chest infection after upper abdominal surgery: an important problem for smokers. Respir Med. 1992;86(3):205–10.
49. Barrera R, et al. Smoking and timing of cessation: impact on pulmonary complications after thoracotomy. Chest. 2005;127(6): 1977–83.
50. McAllister-Sistilli CG, et al. The effects of nicotine on the immune system. Psychoneuroendocrinology. 1998;23(2):175–87.
51. W-Dahl A, Toksvig-Larsen S. Cigarette smoking delays bone healing: a prospective study of 200 patients operated on by the hemicallotasis technique. Acta Orthop Scand. 2004;75(3):347–51.
52. Narkiewicz K, et al. Cigarette smoking increases sympathetic outflow in humans. Circulation. 1998;98(6):528–34.
53. Rietbrock N, et al. Oxygen-dissociation kinetics in the blood of smokers and non-smokers: interaction between oxygen and carbon monoxide at the hemoglobin molecule. Naunyn Schmiedebergs Arch Pharmacol. 1992;345(1):123–8.
54. Buist AS, et al. The effect of smoking cessation and modification on lung function. Am Rev Respir Dis. 1976;114(1):115–22.
55. Warner DO. Perioperative abstinence from cigarettes: physiologic and clinical consequences. Anesthesiology. 2006;104(2):356–67.
56. Thompson WH, et al. Controlled trial of oral prednisone in outpatients with acute COPD exacerbation. Am J Respir Crit Care Med. 1996;154(2 Pt 1):407–12.
57. Smetana GW. Postoperative pulmonary complications: an update on risk assessment and reduction. Cleve Clin J Med. 2009;76 Suppl 4:S60–5.
58. Eichhorn JH. Pulse oximetry monitoring and late postoperative hypoxemia on the general care floor. J Clin Monit Comput. 1998; 14(1):49–55.
59. Chumillas S, et al. Prevention of postoperative pulmonary complications through respiratory rehabilitation: a controlled clinical study. Arch Phys Med Rehabil. 1998;79(1):5–9.
60. Hall JC, et al. Incentive spirometry versus routine chest physiotherapy for prevention of pulmonary complications after abdominal surgery. Lancet. 1991;337(8747):953–6.
61. Ferreyra GP, et al. Continuous positive airway pressure for treatment of respiratory complications after abdominal surgery: a systematic review and meta-analysis. Ann Surg. 2008;247(4):617–26.
62. Squadrone V, et al. Continuous positive airway pressure for treatment of postoperative hypoxemia: a randomized controlled trial. JAMA. 2005;293(5):589–95.
63. Owens WD, Felts JA, Spitznagel Jr EL. ASA physical status classifications: a study of consistency of ratings. Anesthesiology. 1978;49(4):239–43.
64. Johnson RG, et al. Multivariable predictors of postoperative respiratory failure after general and vascular surgery: results from the patient safety in surgery study. J Am Coll Surg. 2007;204(6):1188–98.
65. Kindgen-Milles D, et al. Nasal-continuous positive airway pressure reduces pulmonary morbidity and length of hospital stay following thoracoabdominal aortic surgery. Chest. 2005;128(2):821–8.
66. Ramakrishna G, et al. Impact of pulmonary hypertension on the outcomes of noncardiac surgery: predictors of perioperative morbidity and mortality. J Am Coll Cardiol. 2005;45(10):1691–9.
67. Lai HC, et al. Severe pulmonary hypertension complicates postoperative outcome of non-cardiac surgery. Br J Anaesth. 2007;99 (2):184–90.
68. Kaw R, Sharma P, Minai OA. What risks does a history of pulmonary hypertension present for patients undergoing noncardiac surgery? Cleve Clin J Med. 2007;74 Suppl 1:S20–1.
69. Mellor A, Soni N. Fat embolism. Anaesthesia. 2001;56(2):145–54.
70. Arthurs MH, Morgan OS, Sivapragasam S. Fat embolism syndrome following long bone fractures. West Indian Med J. 1993;42(3): 115–7.
71. Barst RJ. Medical therapy of pulmonary hypertension. An overview of treatment and goals. Clin Chest Med. 2001;22(3):509–15. ix.
72. Blaise G, Langleben D, Hubert B. Pulmonary arterial hypertension: pathophysiology and anesthetic approach. Anesthesiology. 2003;99 (6):1415–32.
73. Cottini SR, et al. Risk factors for reperfusion injury after lung transplantation. Intensive Care Med. 2006;32(4):557–63.
74. Krowka MJ, et al. Pulmonary hemodynamics and perioperative cardiopulmonary-related mortality in patients with portopulmonary hypertension undergoing liver transplantation. Liver Transpl. 2000; 6(4):443–50.
75. Rubin LJ. Pulmonary arterial hypertension. Proc Am Thorac Soc. 2006;3(1):111–5.
76. Hamdan MA, Abu-Sulaiman RM, Najm HK. Sildenafil in pulmonary hypertension secondary to unilateral agenesis of pulmonary artery. Pediatr Cardiol. 2006;27(2):279–81.
77. Michelakis E, et al. Oral sildenafil is an effective and specific pulmonary vasodilator in patients with pulmonary arterial hypertension: comparison with inhaled nitric oxide. Circulation. 2002; 105(20):2398–403.
78. Rauch H, Motsch J, Bottiger BW. Newer approaches to the pharmacological management of heart failure. Curr Opin Anaesthesiol. 2006;19(1):75–81.
79. Braun EB, Palin CA, Hogue CW. Vasopressin during spinal anesthesia in a patient with primary pulmonary hypertension treated with intravenous epoprostenol. Anesth Analg. 2004;99(1):36–7.
80. Fischer LG, Van Aken H, Burkle H. Management of pulmonary hypertension: physiological and pharmacological considerations for anesthesiologists. Anesth Analg. 2003;96(6):1603–16.
81. Warner DO. Preventing postoperative pulmonary complications: the role of the anesthesiologist. Anesthesiology. 2000;92(5): 1467–72.
82. Groeben H, et al. Lung function under high thoracic segmental epidural anesthesia with ropivacaine or bupivacaine in patients with severe obstructive pulmonary disease undergoing breast surgery. Anesthesiology. 2002;96(3):536–41.
83. Gruber EM, et al. The effects of thoracic epidural analgesia with bupivacaine 0.25 % on ventilatory mechanics in patients with severe chronic obstructive pulmonary disease. Anesth Analg. 2001;92(4):1015–9.
84. Choi PT, et al. Epidural analgesia for pain relief following hip or knee replacement. Cochrane Database Syst Rev. 2003;3:CD003071.
85. Wu CL, et al. Effect of postoperative epidural analgesia on morbidity and mortality after total hip replacement surgery in medicare patients. Reg Anesth Pain Med. 2003;28(4):271–8.
86. Pedersen T, Viby-Mogensen J, Ringsted C. Anaesthetic practice and postoperative pulmonary complications. Acta Anaesthesiol Scand. 1992;36(8):812–8.

87. Urwin SC, Parker MJ, Griffiths R. General versus regional anaesthesia for hip fracture surgery: a meta-analysis of randomized trials. Br J Anaesth. 2000;84(4):450–5.
88. Hu S, et al. A comparison of regional and general anaesthesia for total replacement of the hip or knee: a meta-analysis. J Bone Joint Surg Br. 2009;91(7):935–42.
89. Rodgers A, et al. Reduction of postoperative mortality and morbidity with epidural or spinal anaesthesia: results from overview of randomised trials. BMJ. 2000;321(7275):1493.
90. Allen HW, et al. Peripheral nerve blocks improve analgesia after total knee replacement surgery. Anesth Analg. 1998;87 (1):93–7.
91. Fowler SJ, et al. Epidural analgesia compared with peripheral nerve blockade after major knee surgery: a systematic review and meta-analysis of randomized trials. Br J Anaesth. 2008;100(2):154–64.
92. YaDeau JT, et al. The effects of femoral nerve blockade in conjunction with epidural analgesia after total knee arthroplasty. Anesth Analg. 2005;101(3):891–5. Table of contents.
93. Bell RF, et al. Perioperative ketamine for acute postoperative pain. Cochrane Database Syst Rev. 2006;1:CD004603.
94. Remy C, Marret E, Bonnet F. Effects of acetaminophen on morphine side-effects and consumption after major surgery: meta-analysis of randomized controlled trials. Br J Anaesth. 2005;94 (4):505–13.
95. Marret E, et al. Effects of nonsteroidal antiinflammatory drugs on patient-controlled analgesia morphine side effects: meta-analysis of randomized controlled trials. Anesthesiology. 2005;102(6):1249–60.
96. Tiippana EM, et al. Do surgical patients benefit from perioperative gabapentin/pregabalin? A systematic review of efficacy and safety. Anesth Analg. 2007;104(6):1545–56. Table of contents.

# Perioperative Care of the Orthopedic Patient with Renal Disease

13

James M. Chevalier

**Objectives**

- To realize the scope of chronic kidney disease in the United States
- To prepare patients with renal disease for orthopedic surgery
- To understand the perioperative needs of patients on dialysis or with a functioning renal transplant
- To evaluate, manage, and treat patients with acute kidney injury (AKI) and electrolyte disturbances, particularly hyponatremia
- To recognize medications known to be nephrotoxic, and in the patient with kidney disease, medications and their dosages must be chosen carefully and administered in dosages adjusted based on renal function

**Key Points**

- During the preoperative evaluation, a patient's renal risk should be assessed, and the patient should be prepared in such a way to lower that risk to the lowest possible level.
- A patient's hemodialysis or peritoneal dialysis schedule needs to be coordinated with the timing of surgery; renal transplant patients should avoid interruption of their immunosuppressive medications.
- After surgery, AKI and hyponatremia are common in patients with kidney disease; when encountered, specific testing can determine the cause of the abnormality and allow for appropriate treatment.
- Several medications are known to be nephrotoxic, and many others are renally excreted; in a patient with kidney disease, medications and their dosages must be chosen carefully.

## Introduction

Chronic kidney disease (CKD) is a pathological process encompassing a broad spectrum of conditions that adversely affect renal function. The hallmark of the condition, the progressive loss of nephrons, inevitably results in end-stage renal disease (ESRD). With a current prevalence of more than 30 million affected Americans (13 % of the US adult population), the incidence of CKD is expected to rise in the future [1]. Thus the frequency of this problem, coupled with the centrality of the kidney to normal homeostasis, makes the management of impaired renal function a common and challenging problem in the perioperative setting. This chapter reviews the range of common renal problems that arise in this context.

## Chronic Kidney Disease

CKD is defined by the National Kidney Foundation as either a glomerular filtration rate (GFR) $<60$ mL/min/1.73 $m^2$ or kidney damage for $\geq 3$ months. The term kidney damage denotes either anatomic abnormalities of the kidney or other markers of kidney damage, including abnormalities seen in the blood and urine or by imaging studies [2]. CKD is further graded along a continuum of severity from stage I, the earliest period of deterioration, to stage V, the most severe (Table 13.1). ESRD is defined as

J.M. Chevalier (✉)
Weill Cornell Medical College, New York Hospital, 505 E70th Street, HT-140, New York, NY 10021, USA
e-mail: jac9014@nyp.org

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_13, 

**Table 13.1** Stages of CKD

| Stage | Estimated GFR (mL/min/1.73 $m^2$) |
|---|---|
| I | >90[a] |
| II | 60–89[a] |
| III | 30–59 |
| IV | 15–29 |
| V | <15 |
| VI[b] | ESRD |

GFR <60 must be present for more than 3 months for a patient to be diagnosed with CKD
*CKD* chronic kidney disease, *GFR* glomerular filtration rate, *ESRD* end-stage renal disease. See text for details
[a]Patients with a GFR >60 have CKD if there is evidence of abnormal pathology, imaging, or renal laboratory tests such as proteinuria for more than 3 months
[b]Stage VI CKD is not part of the NKF guidelines but is used by many practicing nephrologists to distinguish patients with ESRD from patients with a GFR <15 who have not started dialysis or received a transplant (stage V)
Data from [2]

the need to replace the native kidney function via dialysis or transplantation.

CKD develops from a number of conditions including diabetes mellitus, hypertension, glomerulonephritis, and polycystic kidney disease. Regardless of the cause, such patients often have coronary artery disease and, in fact, have a higher lifetime risk of death from cardiovascular disease than of ever-reaching ESRD [1]. Since a serum creatinine ≥2 mg/dL is considered to be a risk factor for poor cardiac outcome after surgery [3], appropriate perioperative care of renal patients undergoing orthopedic surgery takes on added importance.

## The Preoperative Renal Evaluation

The patient with renal disease requires a comprehensive preoperative evaluation, one that often encompasses several organ systems. As such, the coordination of care between the orthopedic surgeon, nephrologist, anesthesiologist, and potentially other medical consultants, is imperative. Management of preexisting renal disease may involve treating its underlying cause; managing the blood pressure, fluids, and volume status; correcting electrolyte abnormalities; choosing which medications to continue, add, or hold; optimizing nutrition; and providing dialysis or transplant care. The ultimate goal is the assessment of the patient's risk for renal impairment with a given procedure and to institute measures directed at minimizing that risk.

## Renal Function and Postoperative Risk

During the preoperative evaluation, it is important to identify the risk factors for AKI and minimize them. Patients who suffer from an episode of AKI (regardless of whether they require dialysis) are at risk for a residual and progressive decline in kidney function, ESRD, and even death [4–6]. The greatest risk factor for such an outcome is preoperative CKD. Novis et al. in a systematic review of 28 heterogeneous studies have reported that preoperative CKD was the only consistent risk factor for postoperative AKI [7]. Several studies have also tried to define AKI predictors other than CKD in the setting of non-cardiac (and sometimes specifically orthopedic) surgery [8–13]. Putative risk factors differ slightly depending on the type of surgery, but the overlap is significant. A composite list of these risk factors is provided in Table 13.2. Unfortunately, in patients undergoing orthopedic surgery, CKD patients often have multiple risk factors for AKI. These include advanced age, obesity, as well as dysfunction in other major organ systems. Once identified, modifiable risk factors should be addressed to the degree possible, since preventing AKI after surgery will improve the patient's short- and long-term outcomes [14]. Cardiac function should also be optimized in patients with congestive heart failure, as should lung function in patients with chronic obstructive pulmonary disease. Nephrotoxins, hypotension, hypovolemia, and hypervolemia should be avoided.

The first step in establishing the patient's renal risk is to calculate the patient's estimated GFR. This allows for appropriate medication dosing and establishes the degree of risk for AKI, a risk that increases in step with a decreasing GFR. A 24-h urine collection is the traditional standard for the determination of the creatinine clearance; however, an acceptable and simple alternative is the Modification of Diet in Renal Disease (MDRD) formula for the estimation of GFR [15]. The formula can be found online at several websites including www.nkdep.nih.gov. This formula has not been validated in patients with stage I or II CKD and is applicable only when the serum creatinine is stable. In the setting of AKI, when the serum creatinine is rising, the estimated GFR is presumed to be <15 mL/min/1.73 $m^2$. Once the GFR has been established, recommendations are made to dose the patient's medications based on this value.

The preoperative creatinine relative to historical values is also important. Patients with stable renal disease are at lower risk for worsening serum creatinine after surgery. Thus, in the patient with a progressively rising serum creatinine, elective procedures should be delayed until the cause of deteriorating renal function is identified and has stabilized.

**Table 13.2** Risk factors for perioperative acute kidney injury

| |
|---|
| **Advanced age** |
| Anemia |
| **Chronic kidney disease** |
| Chronic obstructive pulmonary disease |
| **Congestive heart failure** |
| Coronary artery disease |
| **Diabetes mellitus** |
| Elevated BMI |
| Emergent surgery |
| **Hypertension** |
| Liver disease |
| Male gender |
| Peripheral vascular disease |
| **Use of nephrotoxic medications**: ACE, ARB, **NSAID**, **diuretic** |
| Volume depletion |
| **Worse American Society of Anesthesiologists score** |

Bold items represent risk factors found in more than one study of orthopedic patients. *BMI* body mass index, *ACE* angiotensin-converting enzyme inhibitor, *ARB* angiotensin receptor blocker, *NSAID* nonsteroidal anti-inflammatory drug. See text for details
Data from [15–20]

## Medication Management

Choosing which medications to hold prior to surgery in order to decrease the chance of AKI remains controversial; however, several classes of medications are believed to be especially problematic, particularly in the patient with kidney disease. Nonsteroidal anti-inflammatory agents (NSAIDs) are a paradigmatic example. NSAIDs, even the cyclooxygenase-2 inhibitors, impair renal autoregulation by inhibiting prostaglandin-mediated dilation of the afferent arteriole in the glomerulus [16]. It is via this mechanism that these drugs are thought to produce their adverse influence on the kidney. Therefore, due to their nephrotoxic potential, all NSAIDs should be avoided in the perioperative setting, using alternative analgesics to control pain instead.

Angiotensin-converting enzyme (ACE) inhibitors and angiotensin receptor blockers (ARBs) diminish the ability of the efferent arteriole to constrict [16] and are reported to cause hypotension during induction of anesthesia [17, 18]. A meta-analysis confirmed this finding but found insufficient data to draw conclusions about other outcomes, such as AKI [19]. However, in one study [20], ACE inhibitor or ARB therapy combined with diuretics increased the risk of hypotension; in contrast similar rates of AKI in the patients with and without the ACE inhibitor or ARB therapy have also been reported although in bariatric surgery the use of such medications increased the risk of AKI in one study [21]. Reasonable recommendations from a review on perioperative medication management [22] suggest holding ACE inhibitors and ARBs for patients who take these medications for hypertension and have acceptably controlled blood pressure. For patients who require the medication for congestive heart failure, an individualized approach may be needed.

In summary, prior to orthopedic surgery, CKD patients should generally hold NSAIDs, ACE inhibitors, ARBs, and diuretics on the morning of surgery. Patients who take such treatment for control of heart failure may need to continue their medication perioperatively, and in such circumstances the opinion of the patient's cardiologist should be sought. All medications held preoperatively should be considered for re-initiation postoperatively once hemodynamic stability and euvolemia are achieved.

## Blood Pressure, Fluid, and Volume Management

Perioperative blood pressure management is discussed elsewhere, but it should be noted that most patients with CKD have volume-mediated hypertension and are often treated with diuretics. Volume status should be assessed during the preoperative evaluation. Hypovolemic and hypervolemic patients are treated with volume and diuresis, respectively, to achieve a euvolemic state. Some patients with long-standing congestive heart failure and kidney disease often have a "best" volume, i.e., a volume at which heart and kidney function have achieved balance, allowing the highest level of function. While this may not reflect true euvolemia, this is an assessment best left to physicians who care for the patient longitudinally.

Lactated Ringer's solution is generally avoided, given renal patients' propensity for hyperkalemia [23]. Patients with CKD also have difficulty excreting excess fluid and need lower intravenous (IV) fluid rates than patients without kidney disease. Similarly, patients currently on dialysis with no significant urine output require smaller volumes of IV fluid during surgery. Since CKD patients are at risk for both volume depletion and volume overload, maintenance IV fluid rate should account for insensible losses, residual urine output, and anticipated blood loss with additional IV fluid boluses as needed [23]. If central venous access is in place, central venous pressure (CVP) monitoring can guide fluid management, especially in dialysis patients who have little or no urine output [23].

## Electrolyte Disturbances

Hyponatremia and hyperkalemia are sometimes encountered during preoperative lab testing. The cause should be determined and appropriate treatment administered, based on the

results of the work-up. While there are no values of serum sodium or potassium that are considered totally "safe" prior to surgery, some observations can be made. The safety of any given serum sodium is likely related to the cause of the hyponatremia, its chronicity, and the patient's symptoms (if any). Clinical experience also suggests that patients with CKD, especially ESRD, tolerate hyperkalemia better than the general population. Indeed, in one study, electrocardiographic changes occurred only at a serum potassium level of >6.5 mmol/L [24]. The full evaluation, management, and treatment of hyponatremia and hyperkalemia are discussed in the postoperative section.

## Hematologic Issues: Anemia

The kidneys are responsible for the production of erythropoietin, so as renal function declines, the prevalence of anemia increases [25]. Associated with an increased mortality in CKD [26], the presence of anemia also correlates with a higher mortality in patients undergoing cardiac [27, 28] and non-cardiac surgery [29]. In one orthopedic study, however, the patients' comorbidities rather than their preoperative anemia correlated best with postoperative complications and mortality [30].

Prior to the widespread use of erythropoietin-stimulating agents (ESAs), patients with CKD required transfusions to treat their anemia. Such transfusions increase the risk of hyperkalemia and lead to antibody formation, ultimately decreasing the odds of successful kidney transplant in the future. For nearly two decades, ESAs were used freely to increase a patient's hematocrit, improve quality of life, and decrease the need for transfusion.

Three trials, CREATE [31], CHOIR [32], and TREAT [33], have called in to question the safety of such therapy as well as the concept of a target hematocrit when using ESAs. CREATE and CHOIR each randomized patients to a target hemoglobin of 11 g/dL versus 13 g/dL. In each study, normalization of the patient's hemoglobin failed to decrease cardiovascular events and suggested an increased risk of cardiovascular events and death. In contrast, TREAT randomized patients to a hemoglobin of 13 g/dL versus rescue therapy to prevent a hemoglobin <9 g/dL. Again no decrease in cardiovascular events resulted from a correction of anemia. Further, an increased incidence of stroke in the normalized hemoglobin group was noted, though the increased risk of other cardiovascular events and death seen in CREATE and CHOIR was not demonstrated. The National Kidney Foundation currently recommends a target hemoglobin of 11–12 g/dL [50], although this may change. The FDA, however, has already added a boxed warning to the package insert of all ESAs, warning of the risk of cardiovascular deaths and recommending individualized dosing to avoid transfusion, targeting a hemoglobin of 10–11 g/dL.

Besides anemia of CKD, the renal patient is often iron deficient. The evaluation of iron deficiency is more difficult in a patient with CKD due to the chronic inflammation associated with the disease. Accordingly, iron parameters have different targets in CKD: transferrin saturation >20 % and ferritin >100 ng/mL are recommended thresholds in a CKD patient [34]. Because the ferritin may be elevated secondary to inflammation, the low transferrin saturation dictates treatment, despite an elevated ferritin. Patients with iron deficiency should still be referred for GI evaluation to rule out intestinal sources of bleeding. Iron can be supplemented orally or intravenously. Current formulations of IV iron can be a safe alternative to oral iron and have been used successfully prior to orthopedic surgery [35].

In summary, patients currently receiving peritoneal or hemodialysis should receive supplemental iron and ESAs according to their dialysis center protocols, usually to maintain a hematocrit of at least 30, especially if surgery is anticipated. Patients with CKD who are not yet on dialysis should be treated with iron to correct iron deficiency. ESAs can be added to achieve a hematocrit >30 % prior to surgery if iron repletion alone did not achieve such a hematocrit. These recommendations are not dissimilar to those for the treatment of preoperative anemia before elective surgeries such as joint replacements [36]. Anticipatory planning is especially necessary in the patient with CKD. Postoperatively non-autologous blood transfusions should be limited or avoided since transfusions from other donors will increase antibody production and decrease the chances of a successful renal transplant in the future.

## Hematologic Issues: Uremic Bleeding

Uremia causes platelet dysfunction and can increase the chance of perioperative bleeding. Desmopressin acetate can enhance hemostasis in general [37] and specifically improves the platelet dysfunction in uremia [38]. It has been studied widely from patients with CKD undergoing renal biopsy [39] to patients with normal renal function undergoing cardiac surgery [40]. Despite an extensive published record, the use of desmopressin for uremic patients undergoing surgery remains controversial. All of the randomized controlled trials were small. One review article [37] and a Cochrane review [41] did not support the use of desmopressin to reduce blood loss and decrease transfusion requirements. However, another meta-analysis [42]

did find a small but statistically significant reduction in blood loss and blood transfusion requirement though the percentage of patients who received transfusions was not changed. Desmopressin acetate is not FDA approved for hemostasis; however, when given for this indication, the dose is usually 0.3 μg/kg IV, with a maximum of 20 μg. Side effects include flushing, hyponatremia, myocardial infarction or other thrombotic events, and hypotension; however, in the meta-analysis by Crescenzi et al. [42], only clinically insignificant hypotension occurred more often in patients receiving desmopressin as compared to the placebo group. It should be noted that in most studies patients were included regardless of severity of kidney disease, so it is possible that desmopressin may be more beneficial in the uremic patient. Therefore in order to mitigate the platelet dysfunction associated with the uremic state, patients with advanced CKD (GFR <20 mL/min/1.73 $m^2$) are often considered for treatment with desmopressin or are dialyzed prior to surgery.

## Renal Replacement Therapy: Dialysis and Transplantation

Before discussing the preparation of ESRD patients for surgery, some statistics about the dialysis population are in order. The Medicare Payment Advisory Commission reports that as of 2007, there were more than 368,000 Americans receiving dialysis (mostly in-center hemodialysis (HD)) and more than 158,000 Americans with a functioning kidney transplant [43]. The 1-, 3-, and 5-year survival rate for an incident dialysis patient is only 79 %, 52.8 %, and 34.9 %, respectively [44]. As of 2007, 36 % of dialysis patients were aged 65 or over [43]. Given their age and background mortality rate, a few studies have analyzed the risk–benefit ratio of total hip arthroplasty in HD patients. Sakalkale et al. [45] reported a high short-term mortality rate (58 %) and an average survival of 31 months. Further the success rate of total hip arthroplasty in HD patients has been mixed though most studies found a lower success in HD patients. Therefore it appears prudent to reserve joint replacement surgery for dialysis patients with a longer life expectancy, possibly those who qualify for renal transplant.

When preparing a patient with ESRD for a surgical procedure, special attention must be given to the patient's dialysis or transplant needs. A nephrologist must be involved in coordinating this care. For a comprehensive review of the perioperative management of the HD patient, the reader is referred to a review of the subject [46], the most pertinent aspects of which are reviewed here.

### Hemodialysis Patients

Conventionally, an HD patient should receive dialysis the night before surgery, whether as an inpatient or an outpatient, even if this requires a change in the patient's regular three-times-per-week schedule. Doing so renders the blood as "clean" as possible for surgery. One session should be sufficient. Repeat labs should not be drawn within the first few hours following dialysis, as the electrolytes may be falsely low, having not yet re-equilibrated. For this reason, supplemental potassium should never be given based on labs drawn in the immediate post-dialysis period. The well-dialyzed patient should also experience fewer uremic complications such as poor platelet function and delayed wound healing. In addition, preoperative dialysis usually delays the need for dialysis after surgery. This is particularly beneficial in those patients who are not hemodynamically stable in the early postoperative period [23].

If a patient is well dialyzed and regularly attending his or her dialysis sessions three times per week, it is unclear if additional (daily) HD sessions prior to surgery will improve surgical outcome, unless the patient is significantly over his or her target weight and requires more fluid removal than can be achieved with the normal schedule. Sufficient fluid is generally removed to make the patient euvolemic and achieve the patient's dry weight (i.e., the patient's target weight at the end of dialysis). Traditionally, a dialysis prescription without heparin is used during the final presurgical HD session. The use of heparin with dialysis is also avoided for at least 1–2 days following major orthopedic surgery. However, many orthopedic procedures, particularly total joint arthroplasty, require anticoagulation after surgery and thus would require patients to receive heparin-free dialysis anyway.

Vascular access is required to perform HD. Examples of such access include an arteriovenous fistula (AVF), arteriovenous graft (AVG), or a tunneled HD catheter. Since maintaining a functioning vascular access is critically important, special attention must be given to the access. All blood pressures, blood draws, and IVs should be performed in the extremity contralateral to the functioning AVF or AVG [46] as using the arm with the HD access risks thrombosis and loss of the fistula or graft. In fact, IV placement should be limited to only what is absolutely necessary in order to preserve the patient's other veins for future HD access placement.

Any required central venous catheter should be placed in the side contralateral to the HD access; otherwise, the HD access may not function as well [23]. The internal jugular location for catheters is preferred over the subclavian location due to the risk of subclavian stenosis and decreased function of the current (or future) access in the ipsilateral arm. Providers obtaining central venous access in an HD

patient should be aware that patients with a long-standing history of HD may have one or more occluded central veins from current or previous central venous catheters, cardiac pacemakers, or other injuries and procedures.

An existing tunneled dialysis catheter should not be used during surgery unless no other IV access can be obtained. The catheter traditionally has an anticoagulant (usually heparin) dwelling in the tubing in order to decrease the chance of thrombosis. In patients with advanced CKD who are approaching ESRD and the need for dialysis, one should avoid using the non-dominant arm for blood pressure readings, blood draws, and IVs, if possible, as HD access will likely be created in this arm in the future.

## Peritoneal Dialysis Patients

Peritoneal dialysis (PD) is a form of renal replacement therapy in which the clearance of toxins and ultrafiltration of water take place via the peritoneal membrane by exchanging substances from blood to PD fluid and vice versa. The patient either manually exchanges fluid in the peritoneal cavity an average of four times per day or uses a machine, called a cycler, to exchange the fluid at night while sleeping. When a PD patient undergoes a surgical procedure, alterations in the dialysis schedule are also needed. Some nephrologists recommend performing PD exchanges more frequently prior to surgery, but the beneficial effect of this strategy on surgical outcomes is not clear. PD patients should be advised to drain the fluid from their abdomen on the morning of surgery. A dry abdomen during surgery should be tolerated by a regularly dialyzed patient and will have only a small effect on electrolyte and fluid balance. In contrast, leaving PD fluid in the abdomen increases intra-abdominal pressure [23] and leads to the absorption of fluid during surgery, thus risking fluid overload. Assuming that the peritoneum was not compromised during surgery, PD can usually be resumed the morning after surgery (barring any emergent electrolyte or fluid issues requiring earlier initiation), when the patient is more alert and able to assist with the fluid exchanges. Nursing staff should feel comfortable with PD if performing the exchanges without the assistance of the patient. Patients on the cycler at home can be converted to manual PD postoperatively if the hospital does not have cycler machines available. PD patients do not have the same dietary restrictions as patients receiving hemodialysis. For example, while phosphorus and total fluid intake should be limited, potassium restriction is usually not necessary due to the nearly continuous removal of potassium provided by this form of dialysis. However, PD patients should still have their potassium level followed; if low, they can be encouraged to increase oral potassium intake or receive small doses of potassium repletion.

## Renal Transplant Patients

Understandably, renal transplant patients have a keen interest in keeping their renal transplant functioning, as it is the sole buffer between their current lifestyle and a life of regular dialysis. Renal transplant patients should continue their regular immunosuppressive medications up to, and including, the morning of surgery. As soon as feasible after surgery, the patient should be allowed to continue taking his or her regular transplant medications by mouth. More tenuous transplant patients, who are unable to take their medications by mouth and are therefore at risk for missing their immunosuppressive medications, should be considered for administration via a nasogastric tube. If the transplant medication cannot be given enterally, IV formulations may be given, although the dosing conversion is not always 1:1 and occasionally requires continuous infusion. A nephrologist or a pharmacist experienced with transplant medications should assist with the conversion of outpatient medications to an IV equivalent.

Calcineurin inhibitors, such as tacrolimus and cyclosporine, are common transplant medications that interact with many other medications. Care must be taken when starting or discontinuing any medication in a patient taking these agents, as the serum level may be affected. Levels should be monitored and appropriate dosage adjustments made. Of particular relevance to orthopedic surgery, especially total joint arthroplasty, is the concurrent use of warfarin and cyclosporine, as together these medications can lead to decreased anticoagulant and cyclosporine effectiveness [47]. In such circumstances the levels of both warfarin and cyclosporine should be followed closely with dose adjustments made as needed. Many patients with a functioning kidney transplant also take low-dose prednisone chronically. These patients may require stress-dose steroids prior to surgery.

Finally, patients on chronic immunosuppression are at increased risk for infections, including opportunistic infections. Work-up for the cause of fever should have a broader differential in the transplant patient. Those with a recent kidney transplant are at the highest risk. Should a transplant patient develop a life-threatening infection, the immunosuppressive agents may need to be held until the infection resolves, despite the risk of rejection and transplant failure.

## Postoperative Renal Considerations

Postoperatively, patients with CKD are at risk for a broad range of complications including difficult-to-control hypertension, proteinuria, hematuria, volume overload, electrolyte disturbances, as well as AKI and thus may require nephrology consultation.

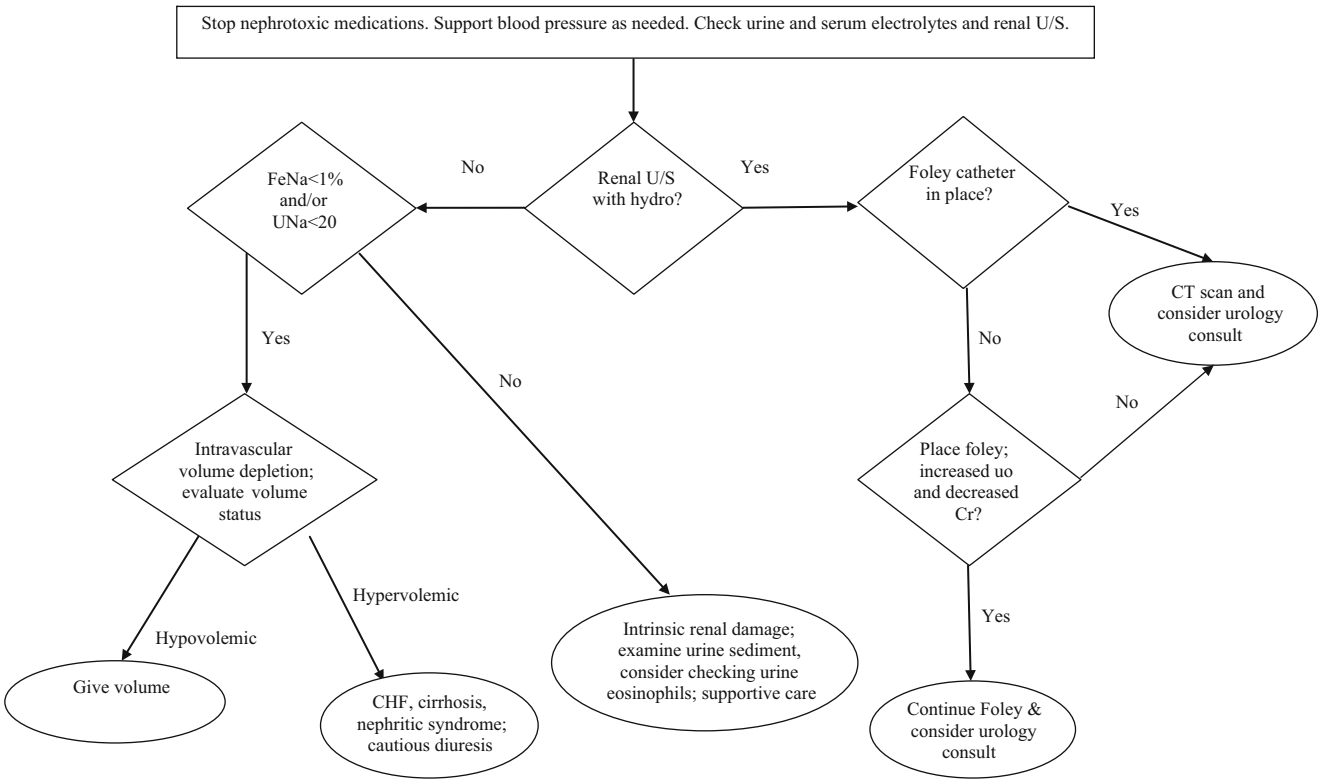


**Fig. 13.1** Evaluation and management of oliguric acute kidney injury. *U/S* ultrasound, *FeNa* fractional excretion of sodium, *UNa* urine sodium, *uo* urine output, *Cr* creatinine, *CHF* congestive heart failure. See text for details

## Acute Kidney Injury

AKI, formerly known as acute renal failure, is a potential complication of surgery, especially in the CKD population. AKI during hospitalization increases morbidity, mortality, length of stay, and cost of care [14]. Although the literature is difficult to interpret because of the wide-ranging definitions of AKI in the past, efforts are being made to standardize the definition. Currently the most commonly used criteria are the RIFLE criteria [48], which stand for risk, injury, failure, loss, and end-stage kidney disease (ESKD). The severity of kidney dysfunction increases across the letters of the acronym, from risk to ESKD. The categorization of the patient's renal dysfunction is based on urine output and the change in serum creatinine/percent decrease in GFR from baseline.

In the general population, the incidence of AKI after noncardiac surgery is low, and after orthopedic surgery the incidence is even lower, with reported rates often <1 % [8, 11, 49]. Risk scores exist to predict the risk of AKI after cardiac surgery [50], the risk of needing dialysis after cardiac surgery [51], the risk of AKI in patients undergoing general surgery [52], and the risk of AKI following liver resection [53]. Unfortunately, no such risk scores exist specifically for orthopedic surgeries.

A review by Thadhani et al. [54] discusses the rationale supporting the standard evaluation and management of AKI by nephrologists. After conducting a history and physical examination, the first parameter considered is the urine output as non-oliguric AKI has a better prognosis than the oliguric form. Further the differential diagnosis differs [54]. The placement of a Foley catheter is then considered, especially in patients with oliguric AKI, as this maneuver may be both diagnostic and therapeutic.

The cause of oliguric AKI is most often divided into pre-renal, intrinsic renal, and post-renal (obstructive) causes [54]. Pre-renal causes account for 60 %, intrinsic renal for 30 %, and post-renal for 10 % of AKI [10]. Pre-renal and post-renal causes are the most reversible, and prompt diagnosis leads to early intervention and attenuation of the effects of the AKI. Serum and urine electrolytes can help rule in or out a pre-renal cause of AKI, while a renal ultrasound can help rule in or out a post-renal cause (Fig. 13.1).

To differentiate between these entities, a urinalysis and serum and urine electrolytes (specifically random urine sodium and creatinine) are ordered, and a fractional excretion of sodium (FeNa) is calculated. The FeNa is defined as the patient's urine sodium times the serum creatinine divided by the serum sodium times the urine creatinine (FeNa = UNa × SCr/SNa × UCr). When the FeNa is <1 % and/or

the urine sodium is <20 mmol/L, the patient is likely volume depleted. In contrast a FeNa >20 mmol/L and a FeNa >1 % in the oliguric patient argue against intravascular volume depletion, suggesting intrinsic renal damage. If the patient has received diuretics, the FeNa may be inaccurate because of the sodium wasting effect of these medications. In such circumstances, a serum BUN and urine urea can be used to calculate a fractional excretion of urea (FeUrea), using the formula for FeNa, replacing sodium with urea. A FeUrea <30 (or 35) % suggests a pre-renal cause. Patients with pre-renal AKI are treated according to their volume status. Hypovolemic patients should receive volume. Hypervolemic patients should be diuresed.

A renal ultrasound is performed in order to determine whether or not hydronephrosis is present. Hydronephrosis denotes an obstruction along the course of the urinary tract, from the urethra to the kidneys, implying post-renal AKI. The likelihood of post-renal AKI increases in such circumstances as the older man with an enlarged prostate, or any patient with a history of cancer, enlarged lymph nodes, scarring, or other abnormalities in the lower abdomen or the pelvis [54]. Of note, a renal ultrasound with Doppler may sometimes reveal a pre-renal cause of AKI such as an abnormality in renal blood flow (aortic dissection) or bilateral renal vein thrombosis. Inserting a Foley catheter in this clinical setting may improve both urine output and serum creatinine. If the AKI does improve after insertion of a Foley catheter, further urologic evaluation regarding treatment of the blockage and timing of catheter removal is warranted. If no improvement ensues, a CT scan of the abdomen and pelvis and urologic consultation are required.

If the work-up reveals neither a pre-renal nor a post-renal cause of AKI, further testing for intrinsic renal causes of AKI should be sought. The differential diagnosis is based on the anatomic portion of the kidney affected, namely, the tubules, interstitium, glomeruli, or blood vessels [54]. Acute tubular injury (ATI), formerly known as acute tubular necrosis, accounts for 85 % of the cases of intrinsic AKI. Ischemia, such as that seen after surgery, causes 50 % of ATI cases, and toxins, such as iodinated IV contrast, cause the remaining 35 % [54]. Examination of the urine sediment may reveal granular casts in ATI, white blood cell casts in allergic interstitial nephritis (AIN), or red blood cell casts in glomerulonephritis, all of which require different treatments. Checking the urine for eosinophils or cholesterol may also help establish the diagnosis of AIN or cholesterol emboli, although their absence does not rule out either diagnosis.

Unfortunately, there is no reliable way to reverse ATI, which is why prevention is so important. Treatment is merely supportive: decreasing the stress on the kidneys by avoiding hypotension and volume depletion, stopping nephrotoxic medications, correcting electrolyte imbalances and fluid overload, and monitoring for the need for dialysis.

Several preventive and therapeutic interventions for AKI have been studied, mostly in cardiac surgery and ICU patients, with mixed success. Dopamine, furosemide, and the combination of these two drugs failed to prevent AKI [55]. Indeed the group receiving furosemide may have had an increased risk of AKI. Neither has *N*-acetylcysteine been shown to prevent AKI in patients undergoing cardiac surgery [56]. Early treatment with erythropoietin after the development of AKI did not change the outcome [57]. In contrast, there is some evidence that fenoldopam decreases the incidence of AKI in patients undergoing cardiac surgery [58] and that natriuretic peptides may prevent and ameliorate the effects of AKI in patients undergoing cardiac surgery [59].

A significant loss of renal function must ensue before the serum creatinine rises. This late reaction to kidney injury may represent a point of "no return" and explain the lack of efficacy of treatments in recent trials. In the future, more sensitive biomarkers may replace serum creatinine in the diagnosis of AKI [16]. Biomarkers such as cystatin C, neutrophil gelatinase-associated lipocalin (NGAL), kidney injury molecule-1 (KIM-1), and others are currently being studied and may eventually enter clinical practice [60].

## Hyponatremia

Hyponatremia is relatively common after surgery, with 4–5 % of patients developing a serum sodium <130 mmol/L [61, 62], and virtually all postoperative patients experience some drop in their serum sodium. Multiple mechanisms may be at play, including the release of antidiuretic hormone (ADH) secondary to postoperative intravascular volume depletion, nausea, and pain [61]; use of hypotonic IV fluids; poor oral intake; etc. ADH concentrates the urine and decreases urine volume by reabsorbing water from the urine back into the blood. During ordinary conditions, when ADH levels are appropriately suppressed by hypotonicity, a patient should be able to excrete up to 12–15 L of free water per day and prevent hyponatremia [63].

Hyponatremia is caused by an imbalance of several factors. Elevated ADH levels, increased free water intake, decreased free water excretion, and decreased intake of osmoles can all contribute to hyponatremia. Because patients with CKD have a decreased GFR, and therefore less water filtered for excretion, they are at higher risk for hyponatremia, especially when combined with a large intake (or administration) of free water [63].

Many medications may cause hyponatremia, so the patient's medication list should be reviewed and cross-referenced with a resource such as Micromedex [64], which lists more than 120 medications that can potentially cause hyponatremia. Liamis et al. provide a review of the

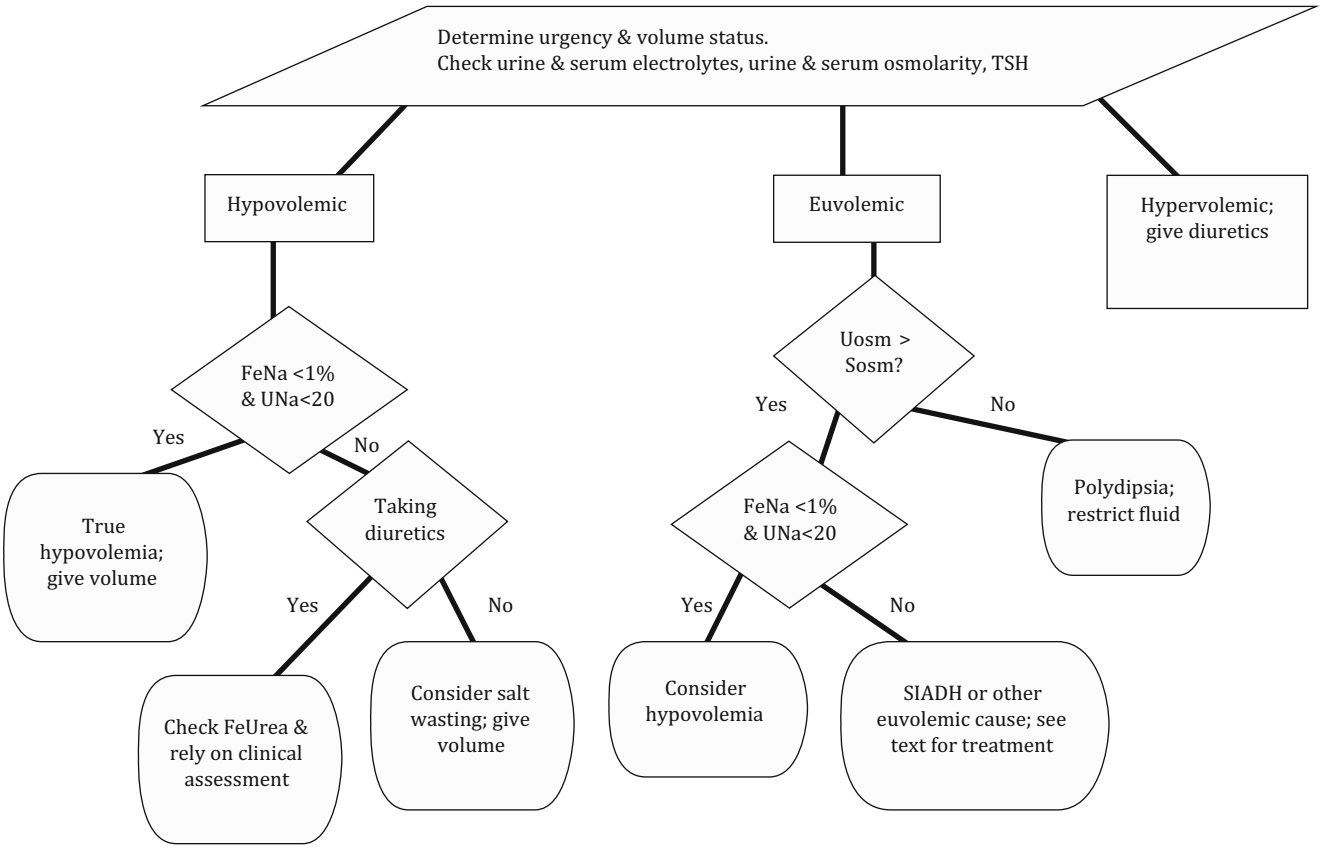


**Fig. 13.2** Evaluation and management of hyponatremia. *TSH* thyroid-stimulating hormone, *FeNa* fractional excretion of sodium, *UNa* urine sodium, *FeUrea* fractional excretion of urea, *Uosm* urine osmolarity, *Sosm* serum osmolarity, *SIADH* syndrome of inappropriate antidiuretic hormone. See text for details

mechanisms of drug-induced hyponatremia, including an extensive list of medications known to cause hyponatremia [65]. Any medication that may cause hyponatremia should be held or changed to another agent if possible. Hydrochlorothiazide should be held or switched to a loop diuretic if a patient is volume overloaded, especially in elderly female patients with a low body mass, since they are at increased risk for thiazide-induced hyponatremia [66]. Selective serotonin reuptake inhibitors are also known to cause hyponatremia but may not be as easily discontinued because of potential side effects with discontinuation. Hypotonic IV fluids in the setting of little or no solid food intake can also lead to hyponatremia.

Whatever the cause, the urgency of the hyponatremia (i.e., symptoms) and the patient's volume status should be determined first, as the answer to these two factors will determine further diagnostic and treatment strategies. Symptoms can present at any serum sodium level. Mild hyponatremia (serum sodium 126–134), previously thought of as benign, is now recognized to be associated with decreased cognitive function, gait instability, falls, osteoporosis, fractures, and inpatient mortality [67]. More overt symptoms present at lower sodium levels or when the serum sodium falls quickly. Hyponatremic patients with neurologic symptoms need urgent treatment with hypertonic saline to quickly raise the serum sodium and resolve symptoms. Asymptomatic patients can undergo a more deliberate diagnostic evaluation followed by treatment directed at the underlying cause. Patients with postoperative hyponatremia should be monitored closely with frequent lab draws and evaluations for symptoms.

Determining the volume status and checking a few laboratory tests narrow the cause of the patient's hyponatremia (Fig. 13.2). Laboratory evaluation of hyponatremia includes serum and urine electrolytes, specifically sodium, potassium, and creatinine; urine and serum osmolarity; TSH; and possibly other endocrine tests depending on the clinical situation. Volume-depleted patients (see section on pre-renal acute kidney injury) from any cause should increase solute and fluid intake. Hypervolemic patients should receive diuretics.

Euvolemic hyponatremia is most often due to an excess of free water and not a deficiency of sodium [68]; therefore, treatment is aimed at increasing the urine output so that it exceeds fluid intake. If urine osmolarity (Uosm) is $<$ serum

osmolarity (Sosm), such as with primary polydipsia, then fluid restriction alone is usually sufficient. When Uosm > Sosm and the urine sodium and fractional excretion of sodium (see section "Acute Kidney Injury") are elevated, the diagnosis of syndrome of inappropriate antidiuretic hormone (SIADH) is most likely. Treatments include restriction of total fluid intake to about 1 L per day, ideally avoiding free water as much as possible and choosing fluids with osmoles such as milk, oral supplements, and tomato soup; increasing the intake of osmoles in the diet with sodium, including salt tablets, protein, and possibly potassium; and loop diuretics. If the hyponatremia remains refractory to these interventions, an AVP receptor antagonist or a hypertonic saline may be considered.

### Hyperkalemia

Since the kidneys are responsible for the vast majority of potassium excretion, hyperkalemia is frequently seen in patients with renal disease. The serum potassium level generally increases postoperatively as a consequence of blood transfusions, cell death, certain medications, and certain IV fluids.

In patients with an elevated serum potassium but no obvious cause, ruling out "pseudohyperkalemia" by checking a concurrent plasma potassium is reasonable. Once confirmed, all patients with an elevated serum potassium level should be instructed to follow a strict low-potassium diet. A review of the patient's medication list and cross-referencing the list with a resource such as Micromedex [69] may reveal medications that can raise the patient's potassium. Such medications should be held or changed to another agent if possible.

Acutely, calcium gluconate is given if electrocardiogram changes are present. Agents to transiently shift potassium intracellularly include albuterol, bicarbonate, and dextrose with insulin. Use of a loop diuretic or a cation-exchange resin leads to potassium excretion.

Using a cation-exchange resin to lower potassium remains controversial. While frequently employed, data in support of the use of cation-exchange resins to lower the potassium are lacking and reports of intestinal necrosis thought to be secondary to the sorbitol employed in the resin (or the resin itself) continue to accumulate, prompting a commentary about the use of such therapy [70, 71].

## Medications and Nephrotoxins

Choosing a medication in patients with renal disease requires a consideration of two key principles: whether there is a potential for nephrotoxicity and whether the medication is renally excreted. While certain medications carry the potential for nephrotoxicity when used in the general population, most euvolemic patients with normal renal function do not develop AKI as a result of such medications. Nephrotoxicity increases in the presence of specific risk factors: advanced age, CKD, intravascular volume depletion, vascular disease, and number of concurrent nephrotoxic agents [54]. Medications with significant nephrotoxic potential in patients with CKD include ACE inhibitors, ARBs, NSAIDs, calcineurin inhibitors, aminoglycoside antibiotics, cisplatin, methotrexate, foscarnet, amphotericin B, and iodinated IV contrast agents, to name a few.

Because impaired renal function can alter the metabolism and excretion of numerous agents [72], renally excreted medications must be dosed according to the patient's estimated GFR or creatinine clearance in order to avoid supra-therapeutic levels. Individual medications should be looked up on a case-by-case basis in references such as the medication's package inserts or a handbook of CKD [72], since the estimated GFR at which dose adjustments need to be made varies by medication. Drug levels should guide management whenever available.

### The Use of Contrast When Imaging Patients with Renal Disease

Patients undergoing orthopedic surgery often require imaging prior to surgery or during hospitalization. In patients with normal renal function, the choice of the imaging modality is generally the technique providing the optimal diagnostic information. However, imaging a patient with renal disease often presents difficulty, particularly when the radiologic procedure requires contrast. Ultrasound, CT scan without IV contrast, and MRI without gadolinium, are non-nephrotoxic. Dilemmas arise when a radiologic study with contrast is required in the patient with CKD. In such instances the clinician must weigh the potential risk of contrast-induced nephrotoxicity (CIN) associated with the iodinated contrast of a CT scan versus the potential risk of nephrogenic systemic fibrosis (NSF) from gadolinium-enhanced MRI. This recently described systemic condition is characterized by fibrosis and thickening of the skin and other organs. Because of the risk and severity of these conditions, a serum creatinine and estimation of GFR should be determined in all patients undergoing radiologic studies with contrast. Two reviews discussing the risks of CIN and NSF in CKD patients [73, 74] are summarized below.

In addition to CKD, several other risk factors have been identified which increase the risk of CIN after interventional cardiac procedures [75]. These include advanced age, diabetes mellitus, congestive heart failure, hypotension, hypovolemia, and anemia. Since the adverse consequences

appear to be a direct effect of the contrast agent itself, it can be inferred that these risk factors apply equally to CIN after CT scan with contrast. One method to mitigate CIN is the use of low-osmolar contrast media (<915 mOsm/kg) instead of high-osmolar (>1,500 mOsm/kg) agents. Iso-osmolar (290 mOsm/kg) contrast agents have also been studied, though it remains unclear if these agents reduce the risk further than that seen with the low-osmolar preparations [76, 77]. The dose of contrast should be minimized as much as possible [77, 78], and repeat doses should be avoided. The patient should receive IV fluid prior to contrast administration unless volume overloaded or otherwise contraindicated [77]. The fluid should be isotonic, such as normal saline. According to the REMEDIAL I and REMEDIAL II trials, isotonic sodium bicarbonate-based fluids may or may not be superior to normal saline [79, 80], possibly depending on the patient's GFR and the precise therapy received by the control group. Results from studies describing the pericontrast treatment with *N*-acetylcysteine remain mixed. Given the relatively low cost and side effect profile of the oral preparation, many nephrologists use *N*-acetylcysteine as prophylaxis. The dose of 1,200 mg rather than 600 mg twice daily on the day prior to and day of contrast may be more effective in preventing CIN [81]. The IV formulation of the medication has been used in patients who cannot tolerate oral administration but is more expensive and carries the risk of allergic reaction.

The risk of NSF is highest with the use of gadolinium contrast agents that are nonionic and linear based [73, 82], and if possible these agents should be avoided in CKD patients. The dose of gadolinium should be limited to the smallest dose needed, and repeat gadolinium administration should be avoided. Patients with ESRD, AKI, or CKD stages IV and V (GFR <30 mL/min/1.73 $m^2$) are at the highest risk, with only one reported case of NSF in a patient with a GFR >30 mL/min/1.73 $m^2$ (the GFR was 34 mL/min/1.73 $m^2$). Other putative risk factors include high-dose ESAs, IV iron, hypercalcemia, and hyperphosphatemia [82]. All potentially reversible risk factors should be corrected. Besides NSF, gadolinium also carries a small risk of AKI, much smaller than that of iodinated contrast with CT scans.

In summary, in patients with AKI, imaging with contrast should be delayed until renal function improves, if at all possible. In patients with stable CKD and a GFR >30 who require contrast to achieve adequate imaging, an MRI with gadolinium is preferred over a CT scan with contrast, as the risk of CIN with contrast-enhanced CT scan would be significantly higher than the risk of NSF with gadolinium. In patients on dialysis with no significant residual renal function, a CT scan with contrast is preferred over an MRI with gadolinium since the risk of NSF is significant, and the risk of CIN is essentially nonexistent. In patients with a GFR <30 and who still have significant renal function, the risks and benefits of the imaging must be taken on a case-by-case basis; if non-contrast options are available, they should be used. Whenever a contrast modality must be used, steps should be taken to minimize the risk of complications, as noted previously. If a hemodialysis patient must receive gadolinium, then increased (daily) dialysis is often performed for at least three treatments after the gadolinium exposure. This usually means planning to give the gadolinium prior to a regularly scheduled HD session and the addition of at least one extra dialysis session to the usual three-times-per-week schedule. Repeat gadolinium should be avoided in any patient with a GFR <30. Peritoneal dialysis patients may have a higher risk of NSF [74], in addition to more reliance on their residual renal function, than their HD counterparts, so the risks and benefits of imaging with contrast in these patients must be carefully discussed with the patient's nephrologist. In any CKD patient whose risk of toxicity from the contrast outweighs the benefits of the radiologic study, contrast should be avoided.

## Analgesia in Patients with Renal Disease

Ketorolac and other NSAIDs should be avoided in CKD patients, especially those with other risk factors for AKI. In circumstances where NSAIDs must be given, the dosage should be limited. Meperidine and propoxyphene should also be avoided due to the toxic effects of their metabolites which accumulate in CKD patients [83]. The pharmacologically active metabolites of morphine also have a prolonged half-life, and the dose of morphine required to achieve pain relief in CKD patients is usually lower than in patients with normal renal function. One source [84] has recommended fentanyl and methadone as the opiates of choice in CKD and dialysis patients, although these narcotics are the least dialyzable if a patient develops untoward side effects [85].

## Anesthesia in Patients with Renal Disease

Choice of anesthetic agents is clearly important for any type of surgery, including orthopedics. The ideal anesthetic agent in the patient with renal disease should be one that is reliably cleared and non-nephrotoxic. Based on the experience during surgery in humans and animals, propofol [46, 86], sevoflurane [46, 86], possibly isoflurane [86], atracurium [23, 46], and cisatracurium [23, 46] have been successfully used in CKD and dialysis patients. Succinylcholine may raise the serum potassium and should generally be avoided in patients with preoperative hyperkalemia. Since the rise in serum potassium may be no worse in patients with ESRD than in patients with normal kidney function, it may be an acceptable choice

in patients without preoperative hyperkalemia [23, 24]. The following agents are best avoided: ketamine, suxamethonium, mivacurium, vecuronium, rocuronium, gallamine, metocurine, pancuronium, pipecuronium, and tubocurarine [23, 46, 86].

## Miscellaneous

Several laboratory tests are known to be abnormal in patients with CKD, especially patients on dialysis, despite a lack of pathology [87]. The abnormalities are assumed to be secondary to alterations in clearance of the substance from the circulation because of the patient's decreased renal function. While the aspartate aminotransferase (AST) can be decreased, most enzymes are elevated including troponin, amylase, lipase, lactate dehydrogenase, and alkaline phosphatase. If plans exist to follow one or more of these labs postoperatively, then baseline levels should be established at the time that the preoperative labs are drawn. Relative changes should still be considered significant.

Good nutrition, important for wound healing and overall good outcome after surgery, is discussed elsewhere. Renal patients should receive the renal formulation of oral supplements, with the exception of PD patients, who can usually get the regular formulation. Any patient receiving dialysis should be dialyzed sufficiently to meet adequacy goals in order to decrease the anorexia associated with uremia.

Preoperative antibiotics are generally given according to standard surgical protocol. Prophylaxis to prevent endocarditis should be given in certain dialysis patients [23]. Before epithelialization occurs, patients with newly placed synthetic AVG [88], and possibly peritoneal dialysis catheters [89], may have bacterial seeding of these foreign bodies without antibiotics.

Some patients require bowel cleansing prior to orthopedic surgery. Phosphate-based cleansing regimens should be avoided because of the potential for AKI from acute phosphate nephropathy [90], especially in older female patients with hypertension who are taking diuretics, ACE inhibitors, or ARBs. Likewise, during hospitalization, if an enema is required for the treatment of constipation, tap water or mineral oil enemas are preferable to phosphate-based enemas.

Occasionally a patient develops supra-therapeutic levels of a medication that lead to unwanted clinical side effects. Some, but not all, medications can be removed from the blood by dialysis. For a determination of whether or not a given medication is dialyzable, the reader is referred to the Dialysis of Drugs handbook [85].

## Summary

With the gradual aging of the US population, and the increasing number of patients with CKD and ESRD on dialysis or with a functioning kidney transplant, orthopedic surgeons will surely encounter renal patients in their practice. When evaluating and preparing a patient with renal disease for an orthopedic surgery, many factors are considered. With careful attention to the patient's degree of renal insufficiency/failure, need for renal replacement therapy, anemia, electrolytes, medications, etc., the patient can be appropriately assessed for risk, and recommendations can be made to reduce that risk.

The patient with renal disease may often appear to be quite ill and have numerous laboratory abnormalities, sometimes seeming quite overwhelming to manage. Careful preoperative evaluation and perioperative management reduce the risk of long-term renal complications after surgery. With appropriate care, most patients with renal disease can have a successful orthopedic procedure.

**Summary Bullet Points**

- As many as 40 million Americans may have CKD with over half a million Americans either receiving dialysis or living with a functioning kidney transplant.
- Preoperative evaluation and assessment of perioperative renal complications should include assessment of renal function, adjustment of medications, recommendations for volume status, and treatment of abnormalities in the labs, as needed.
- Patients who are currently receiving hemodialysis, receiving peritoneal dialysis, or living with a functioning renal transplant require coordination with a nephrologist to ensure continued delivery of their dialysis or transplant medications.
- Patients with AKI should have urine and serum electrolytes (including sodium and creatinine) and a renal ultrasound checked. Further management is then determined, based on whether the results suggest a pre-renal, intrinsic renal, or post-renal cause of the AKI.
- Patients with hyponatremia should have serum and urine electrolytes (including sodium and creatinine) and serum and urine osmolarity checked; a TSH is often ordered as well. Based on the results of these tests and the patient's volume status, further management is determined.

- Check the patient's medication list to ensure that medications are appropriately dosed for the patient's estimated GFR; if a patient develops AKI, adjust renally excreted medications to prevent supra-therapeutic levels; in patients with pre-existing renal disease, alternative medications which are less or non-nephrotoxic should be used in place of medications which are known to increase the risk of AKI.

## Case Studies

Case studies for this chapter are included in Appendix I at the end of this book.

## References


1. Coresh J, Selvin E, Stevens LA, Manzi J, Kusek JW, Eggers P, Van Lente F, Levey AS. Prevalence of chronic kidney disease in the United States. JAMA. 2007;298(17):2038–47.
2. National Kidney Foundation. K/DOQI clinical practice guidelines for chronic kidney disease: evaluation, classification, and stratification. Am J Kidney Dis. 2002;39(2 Suppl 1):3–4.
3. Lee TH, Marcantonio ER, Mangione CM, Thomas EJ, Polanczyk CA, Cook EF, Sugarbaker DJ, Donaldson MC, Poss R, Ho KK, Ludwig LE, Pedan A, Goldman L. Derivation and prospective validation of a simple index for prediction of cardiac risk of major noncardiac surgery. Circulation. 1999;100(10):1043–9.
4. Lo LJ, Go AS, Chertow GM, McCulloch CE, Fan D, Ordonez JD, Hsu CY. Dialysis-requiring acute renal failure increases the risk of progressive chronic kidney disease. Kidney Int. 2009;76(8):893–9.
5. Hsu CY, Chertow GM, McCulloch CE, Fan D, Ordonez JD, Go AS. Nonrecovery of kidney function and death after acute on chronic renal failure. Clin J Am Soc Nephrol. 2009;4(5):891–8.
6. Lafrance JP, Miller DR. Acute kidney injury associates with increased long-term mortality. J Am Soc Nephrol. 2010;21(2):345–52.
7. Novis BK, Roizen MF, Aronson S, Thisted RA. Association of preoperative risk factors with postoperative acute renal failure. Anesth Analg. 1994;78(1):143–9.
8. Kheterpal S, Temper KK, Englesbe MJ, O'Reilly M, Shanks AM, Fetterman DM, Rosenberg AL, Swartz RD. Predictors of postoperative acute renal failure after noncardiac surgery in patients with previously normal renal function. Anesthesiology. 2007;107(6):892–902.
9. Aveline C, Leroux A, Vautier P, Cognet F, Le Hetet H, Bonnet F. Risk factors for renal dysfunction after total Hip arthroplasty (French). Ann Fr Anesth Reanim. 2009;28(9):728–34.
10. Kellerman PS. Perioperative care of the renal patient. Arch Intern Med. 1994;154(15):1674–88.
11. Jafari SM, Huang R, Joshi A, Parvizi J, Hozack WJ. Renal impairment following total joint arthroplasty: who is at risk? J Arthroplasty. 2010;25 Suppl 6:49–53.
12. Bennet SJ, Berry OM, Goddard J, Keating JF. Acute renal dysfunction following hip fracture. Injury. 2010;41(4):335–8.
13. Abelha FJ, Botelho M, Fernandes V, Barros H. Determinants of postoperative acute kidney injury. Crit Care. 2009;13(3):R79.
14. Josephs SA, Thakar CV. Perioperative risk assessment, prevention, and treatment of acute kidney injury. Int Anesthesiol Clin. 2009;47(4):89–105.
15. Levey AS, Bosch JP, Lewis JB, Greene T, Rogers N, Roth D. A more accurate method to estimate glomerular filtration rate from serum creatinine: a new prediction equation. Modification of diet in renal disease study group. Ann Intern Med. 1999;130(6):461–70.
16. Borthwick E, Ferguson A. Perioperative acute kidney injury: risk factors, recognition, management, and outcomes. BMJ. 2010;341:85–91.
17. Coriat P, Richer C, Douraki T, Gomez C, Hendricks K, Giudicelli JF, Viars P. Influence of chronic angiotensin-converting enzyme inhibition on anesthetic induction. Anesthesiology. 1994;81(2):299–307.
18. Bertrand M, Godet G, Meersschaert K, Brun L, Salcedo E, Coriat P. Should the angiotensin II antagonists be discontinued before surgery? Anesth Analg. 2001;92(1):26–30.
19. Rosenman DJ, McDonald FS, Ebbert JO, Erwin PJ, LaBella M, Montori VM. Clinical consequences of withholding versus administering renin-angiotensin-aldosterone system antagonists in the perioperative period. J Hosp Med. 2008;3(4):319–25.
20. Kheterpal S, Khodaparast O, Shanks A, O'Reilly M, Tremper KK. Chronic angiotensin-converting enzyme inhibitor or angiotensin receptor blocker therapy combined with diuretic therapy is associated with increased episodes of hypotension in noncardiac surgery. J Cardiothorac Vasc Anesth. 2008;22(2):180–6.
21. Thakar CV, Kharat V, Blanck S, Leonard AC. Acute kidney injury after gastric bypass surgery. Clin J Am Soc Nephrol. 2007;2(3):426–30.
22. Whinney C. Perioperative medication management: general principles and practical applications. Cleve Clin J Med. 2009;76 Suppl 4:S126–32.
23. Palevsky PM. Perioperative management of patients with chronic kidney disease or ESRD. Best Pract Res Clin Anaesthesiol. 2004;18(1):129–44.
24. Ahmed J, Weisberg LS. Hyperkalemia in dialysis patients. Semin Dial. 2001;14(5):348–56.
25. Kohagura K, Tomiyama N, Kinjo K, Takishita S, Iskei K. Prevalence of anemia according to stage of chronic kidney disease in a large screening cohort of Japanese. Clin Exp Nephrol. 2009;13(6):614–20.
26. Voormolen N, Grootendorst DC, Urlings TA, Boeschoten EW, Sijpkens YW, Huisman RM, Krediet RT, Dekker FW. Prevalence of anemia and its impact on mortality and hospitalization rate in predialysis patients. Nephron. 2010;115(2):c133–41.
27. Karkouti K, Wijeysundera DN, Beattie WS. Reducing Bleeding in Cardiac surgery (RBC) investigators. Risk associated with preoperative anemia in cardiac surgery: a multicenter cohort study. Circulation. 2008;117(4):478–84.
28. De Santo L, Romano G, Della Corte A, de Simone V, Grimaldi F, Cotrufo M, de Feo M. Preoperative anemia in patients undergoing coronary artery bypass surgery grafting predicts acute kidney injury. J Thorac Cardiovasc Surg. 2009;138(4):965–70.
29. Beattie WS, Karkouti K, Wijeysundera DN, Tait G. Risk associated with perioperative anemia in noncardiac surgery: a single-center cohort study. Anesthesiology. 2009;110(3):574–81.
30. Mantilla CB, Wass CT, Goodrich KA, Johanns CJ, Kool ML, Zhu X, Corredor JA, Warner DO, Joyner MJ, Berry DJ, Schroeder DR, Sprung J. Risk of perioperative myocardial infarction and mortality in patients undergoing hip or knee arthroplasty: the role of anemia. Transfusion. 2011;51(1):82–91.
31. Drueke TB, Locatelli F, Clyne N, Eckardt KU, Macdougall IC, Tsakiris D, Burger HU, Scherhag A. CREATE investigators. Normalization of hemoglobin level in patients with chronic kidney disease and anemia. N Engl J Med. 2006;355(20):2071–84.
32. Singh AK, Szczech L, Tang KL, Barnhart H, Sapp S, Wolfson M, Reddan D. CHOIR investigators. Correction of anemia with epoetin

Alfa in chronic kidney disease. N Engl J Med. 2006;355(20): 2085–98.
33. Pfeffer MA, Burdmann EA, Chen CY, Cooper ME, de Zeeuw D, Eckardt KU, Feyzi JM, Ivanovich P, Kewalramani R, Levey AS, Lewis EF, McGill JB, McMurray JJ, Parfrey P, Parving HH, Remuzzi G, Singh AK, Solomon SD, Toto R. TREAT investigators. A trial of darbepoetin alfa in type 2 diabetes and chronic kidney disease. N Engl J Med. 2009;361(21):2019–32.
34. KDOQI. KDOQI clinical practice guideline and clinical practice recommendations for anemia in chronic kidney disease: 2007 update of hemoglobin target. Am J Kidney Dis. 2007;50(3): 471–530.
35. Theusinger OM, Leyvraz PF, Schanz U, Seifert B, Spahn DR. Treatment of iron deficiency anemia in orthopedic surgery with intravenous iron: efficacy and limits—a prospective study. Anesthesiology. 2007;107(6):923–7.
36. Kumar A. Perioperative management of anemia: limits of blood transfusion and alternatives to it. Cleve Clin J Med. 2009;76 Suppl 4:S112–8.
37. Mannucci PM, Levi M. Prevention and treatment of major blood loss. N Engl J Med. 2007;356(22):2301–11.
38. Lee HK, Kim YJ, Jeong JU, Park JS, Chi HS, Kim SB. Desmopressin improves platelet dysfunction measured by in vitro closure time in uremic patients. Nephron. 2010;114(4):c248–52.
39. Manno C, Bonifati C, Torres DD, Campobasso N, Schena FP. Desmopressin acetate in percutaneous ultrasound-guided kidney biopsy: a randomized controlled trial. Am J Kidney Dis. 2011;57 (6):850–5.
40. Salzman EW, Weinstein MJ, Weintraub RM, Ware JA, Thurer RL, Robertson L, Donovan A, Gaffney T, Bertele V, Troll J, Smith M, Chute LE. Treatment with desmopressin acetate to reduce blood loss after cardiac surgery. A double blind randomized trial. N Engl J Med. 1986;314(22):1402–6.
41. Carless PA, Henry DA, Moxey AJ, O'Connell D, McClelland B, Henderson KM, Sly K, Laupacis A, Fergusson D. Desmopressin for minimising perioperative allogeneic blood transfusion. Cochrane Database Syst Rev. 2004;1:CDC001884.
42. Crescenzi G, Landoni G, Biondi-Zoccai G, Pappalardo F, Nuzzi M, Bignami E, Fochi O, Maj G, Calabro MG, Ranucci M, Zangrillo A. Desmopressin reduces transfusion needs after surgery: a meta-analysis of randomized controlled trials. Anesthesiology. 2008; 109(6):1063–76.
43. Medicare Payment Advisory Commission (MEDPAC). A data book: healthcare spending and the medicare program. 2010; 199–205.
44. U S Renal Data System. USRDS 2008 annual data report: atlas of chronic kidney disease and end-stage renal disease in the United States, section I: patient survival. National Institutes of Health, National Institute of Diabetes and Digestive and Kidney Diseases, Bethesda, MD; 2008.
45. Sakalkale DP, Hozack WJ, Rothman RH. Total hip arthroplasty in patients on long-term renal dialysis. J Arthroplasty. 1999;14(5): 571–5.
46. Trainor D, Borthwick E, Ferguson A. Perioperative management of the hemodialysis patient. Semin Dial. 2011;24(3):314–26.
47. Drug interactions, search for "cyclosporine" and "warfarin". http://www.thomsonhc.com/micromedex2/librarian. Accessed 28 Sep 2011.
48. Bellomo R, Ronco C, Kellum JA, Mehta RL, Palevsky P. Acute dialysis quality initiative workgroup. Acute renal failure: definition, outcome measures, animal models, fluid therapy and information technology needs: the second international consensus conference of the Acute Dialysis Quality Initiative (ADQI) group. Crit Care. 2004;8(4):R204–12.
49. Pavone V, Johnson T, Saulog PS, Sculco TP, Bottner F. Perioperative morbidity in bilateral one-stage total knee replacements. Clin Orthop Relat Res. 2004;421:155–61.
50. Thakar CV, Arrigain S, Worley S, Yared JP, Paganini EP. A clinical score to predict acute renal failure after cardiac surgery. J Am Soc Nephrol. 2005;16(1):162–8.
51. Wijeysundera DN, Karkouti K, Dupuis JY, Rao V, Chan CT, Granton JT, Beattie WS. Derivation and validation of a simplified predictive index for renal replacement therapy after cardiac surgery. JAMA. 2007;297(16):1801–9.
52. Kheterpal S, Tremper KK, Heung M, Rosenberg AL, Englesbe M, Shanks AM, Campbell Jr DA. Development and validation of an acute kidney injury risk index for patients undergoing general surgery: results from a national data set. Anesthesiology. 2009; 110(3):505–15.
53. Slankamenac K, Breitenstein S, Held U, Beck-Schimmer B, Puhan MA, Clavien PA. Development and validation of a prediction score for postoperative acute renal failure following liver resection. Ann Surg. 2009;250(5):720–8.
54. Thadhani R, Pascual M, Bonventre JV. Acute renal failure. N Engl J Med. 1996;334(22):1448–60.
55. Lassnigg A, Donner E, Grubhofer G, Presterl E, Druml W, Hiesmayr M. Lack of renoprotective effects of dopamine and furosemide during cardiac surgery. J Am Soc Nephrol. 2000;11(1): 97–104.
56. Nigwekar SU, Kandula P. N-acetylcysteine in cardiovascular-surgery-associated renal failure: a meta-analysis. Ann Thorac Surg. 2009;87(1):139–47.
57. Endre ZH, Walker RJ, Pickering JW, Shaw GM, Frampton CM, Henderson SJ, Hutchison R, Mehrtens JE, Robinson JM, Schollum JB, Westhuyzen J, Celi LA, McGinley RJ, Campbell IJ, George PM. Early intervention with erythropoietin does not affect the outcome of acute kidney injury (the EARLYARF trial). Kidney Int. 2010;77(11):1020–30.
58. Landoni G, Biondi-Zoccai GG, Marino G, Bove T, Fochi O, Maj G, Calabro MG, Sheiban I, Tumlin JA, Ranucci M, Zangrillo A. Fenoldopam reduces the need for renal replacement therapy and in-hospital death in cardiovascular surgery: a meta-analysis. J Cardiothorac Vasc Anesth. 2008;22(1):27–33.
59. Nigwekar SU, Hix JK. The role of natriuretic peptide administration in cardiovascular surgery-associated renal dysfunction: a systematic review and meta-analysis of randomized controlled trials. J Cardiothorac Vasc Anesth. 2009;23(2):151–60.
60. Waikar SS, Liu KD, Chertow GM. Diagnosis, epidemiology, and outcomes of acute kidney injury. Clin J Am Soc Nephrol. 2008;3 (3):844–61.
61. Upadhyay A, Jaber BL, Madias NE. Incidence and prevalence of hyponatremia. Am J Med. 2006;119(7 Suppl 1):S30–5.
62. Gluck GS, Lachiewicz PF. Symptomatic hyponatremia in patients undergoing total hip and knee arthroplasty. A report of three cases. J Bone Joint Surg Am. 2008;90(3):634–6.
63. Gardner LB, Preston RA. University of Miami division of clinical pharmacology therapeutic rounds: the water-intolerant patient and perioperative hyponatremia. Am J Ther. 2000;7(1):23–30.
64. Medications that can cause hyponatremia, search for "hyponatremia". http://www.thomsonhc.com/micromedex2/librarian. Accessed 26 Sep 2011.
65. Liamis G, Milionis H, Elisaf M. A review of drug-induced hyponatremia. Am J Kidney Dis. 2008;52(1):144–53.
66. Chow KM, Szeto CC, Wong TY, Leung CB, Li PK. Risk factors for thiazide-induced hyponatremia. QJM. 2003;96(12):911–7.
67. Sterns RH, Hix JK, Silver S. Treatment of hyponatremia. Curr Opin Nephrol Hypertens. 2010;19(5):493–8.
68. Androgue HJ, Madias NE. Hyponatremia. N Engl J Med. 2000;342 (21):1581–9.
69. Medications that can cause hyperkalemia, search for "hyperkalemia". http://www.thomsonhc.com/micromedex2/librarian. Accessed 26 Sep 2011.

70. Sterns RH, Rojas M, Bernstein P, Chennupati S. Ion-exchange resins for the treatment of hyperkalemia: are they safe and effective? J Am Soc Nephrol. 2010;21(5):733–5.
71. Watson M, Abbott KC, Yuan CM. Damned if you do, damned if you don't: potassium binding resins in hyperkalemia. Clin J Am Soc Nephrol. 2010;5(10):1723–6.
72. Olyaei AJ, Roberta G. Drug dosing in chronic kidney disease. In: Daugirdas JT, editor. Handbook of chronic kidney disease management. 1st ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2011. p. 376–431.
73. Manjunath V, Perazella MA. Imaging patients with kidney disease in the era of NSF: can it be done safely? Clin Nephrol. 2011;75 (4):279–85.
74. Perazella MA, Reilly RF. Imaging patients with kidney disease: how do we approach contrast-related toxicity? Am J Med Sci. 2011;341(3):215–21.
75. Kagan A, Sheikh-Hamad D. Contrast-induced kidney injury: focus on modifiable risk factors and prophylactic strategies. Clin Cardiol. 2010;33(2):62–6.
76. Thomsen HS. Imaging patients with chronic kidney disease: CIN or NSF? Radiol Med. 2007;112(5):621–5.
77. Barrett BJ, Parfrey PS. Preventing nephropathy induced by contrast medium. N Engl J Med. 2006;354(4):379–86.
78. Gurm HS, Dixon SR, Smith DE, Share D, Lalonde T, Greenbaum A, Moscucci M. BMC2 (blue cross blue shield of Michigan cardiovascular consortium) registry. J Am Coll Cardiol. 2011;58(9): 907–14.
79. Briguori C, Airoldi F, D'Andrea D, Bonizzoni E, Morici N, Focaccio A, Michev I, Montofano M, Carlino M, Cosgrave J, Ricciardelli B, Colombo A. Renal insufficiency following contrast media administration trial (REMEDIAL): a randomized comparison of 3 preventive strategies. Circulation. 2007;115 (10):1211–7.
80. Briguori C, Visconti G, Focaccio A, Airoldi F, Valgimigli M, Sangiorgi GM, Golia B, Ricciardelli B, Condorelli G, REMEDIAL II Investigators. Renal insufficiency after contrast media administration trial II (REMEDIAL II): RenalGuard system in high-risk patients for contrast-induced acute kidney injury. Circulation. 2011;124:1260–9.
81. Briguori C, Colombo A, Violante A, Balestrieri P, Manganelli F, Paolo Elia P, Golia B, Lepore S, Riviezzo G, Scarpato P, Focaccio A, Librera M, Bonizzoni E, Ricciardelli B. Standard vs. double dose of N-acetylcysteine to prevent contrast agent associated nephrotoxicity. Eur Heart J. 2004;25(3):206–11.
82. Perazella MA. Advanced kidney disease, gadolinium and nephrogenic systemic fibrosis: the perfect storm. Curr Opin Nephrol Hypertens. 2009;18(6):519–25.
83. Kurella M, Bennett WM, Chertow GM. Analgesia in patients with ESRD: a review of available evidence. Am J Kidney Dis. 2003;42(2):217–28.
84. Dean M. Opioids in renal failure and dialysis patients. J Pain Symptom Manage. 2004;28(5):497–504.
85. Bailie GR, Mason NA. 2011 Dialysis of drugs. 2011th ed. Saline, MI: Renal Pharmacy Consultants, LLC; 2011.
86. Weil AB. Anesthesia for patients with renal/hepatic disease. Top Companion Anim Med. 2010;25(2):87–91.
87. Vaziri ND, Kayichian D. Serum enzyme levels. In: Daugirdas JT, Blake PG, Ing TS, editors. Handbook of dialysis. 4th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2007. p. 482–9.
88. Krishnan M. Preoperative care of patients with kidney disease. Am Fam Physician. 2002;66(8):1471–6.
89. Bender FH, Bernardini J, Piraino B. Prevention of infectious complications in peritoneal dialysis: best demonstrated practices. Kidney Int Suppl. 2006;103:S44–54.
90. Markowitz GS, Perazella MA. Acute phosphate nephropathy. Kidney Int. 2009;76(10):1027–34.

# Perioperative Care of the Orthopedic Patient with Diabetes Mellitus

14

C. Ronald MacKenzie and Naina Sinha Gregory

**Objectives**

- To emphasize the challenge of caring for the patient with diabetes in the perioperative setting
- To present a stepwise approach to the preoperative assessment of the patient with diabetes
- To review the array of diabetes medications now employed in diabetic care
- To present a physiologically based method for perioperative glucose control

**Key Points**

- Care of the patient with diabetes in the perioperative period is one of the most common and challenging problems of clinical medicine.
- This setting is marked by higher rates of infection, wound breakdown, and other adverse events.
- Management of these patients taxes all levels of medical and nursing care.
- Approaches to the evaluation and management of such patients warrant attention at all levels of inpatient and outpatient care.

C.R. MacKenzie (✉)
Department of Medicine, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA
e-mail: MacKenzier@hss.edu

N.S. Gregory
Division of Endocrinology, Department of Medicine, Weill Cornell College of Medicine, New York, NY, USA
e-mail: sinhana@med.cornell.edu

## Introduction

We are in the midst of an epidemic of type 2 diabetes. Both its incidence and prevalence continue to increase across the world hand in hand with the epidemic of obesity. It continues to be a leading cause of cardiovascular disease, end-stage renal disease, and blindness. Associated with this epidemic is an increase in the number of hospitalizations related to diabetes. The management of diabetes has become even more complex with the introduction of new classes of medications that have become available over the past decade. This complexity is related to the complex pathogenesis of type 2 diabetes which includes a combination of both insulin resistance and insulin deficiency which leads to hyperglycemia. The pathogenesis is not limited to one organ system but involves a dizzying interaction of the pancreas, muscle, fat, liver, brain, and most recently the gastrointestinal tract.

Diabetes mellitus is amongst the most common of chronic diseases, currently affecting approximately 8 % of the US population [1]. In those over 60 years of age the prevalence is now estimated at almost 25 %. Of even greater concern is the quadrupling of prevalence of this disease over the last 30 years with approximately 1.6 million new adult cases added annually. More than 90 % have type 2 diabetes with one in four not aware they even have it.

As the fourth most common reason for consulting a physician and a leading cause of mortality and disability in the US population, it follows that diabetes is frequently encountered in the perioperative setting where its management challenges the internist, anesthesiologist, and surgeon alike. Indeed in the orthopedic setting it has been estimated that >8 % of patients undergoing primary and revision total hip and knee arthroplasty carry a diagnosis of diabetes and that these patients experience higher postoperative complications and mortality [2]. Furthermore a substantial literature demonstrates that hyperglycemia in hospitalized patients is associated with multiple poor outcomes including infection,

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_14, 

cognitive deficits, increased mortality, and prolonged length of hospital stay. It is even more surprising that those patients with no known history of hyperglycemia or diabetes fare more poorly than those with a known history of diabetes [3–6]. Thus diabetes is destined to remain a major challenge to all involved in the care of patients undergoing surgery.

## Preoperative Evaluation of the Diabetic Patient

Given the higher prevalence of significant comorbidities in patients with diabetes, the history and physical examination must be broad and focused on a number of relevant organ systems, specifically the heart, kidney, and peripheral nervous system. As the preoperative evaluation of patients from the cardiac, renal, and neurological perspectives is dealt with in their organ-specific chapters in this book, this discussion focuses on an evaluation of glycemic control. Optimizing glycemic control is the main goal in the perioperative management of the diabetes patient. Moreover the high prevalence of coronary artery disease which includes a significant number of asymptomatic patient deserves specific attention, and thus the assessment of cardiac risk is essential in this population.

The key elements of the preoperative evaluation of the diabetic are summarized in Table 14.1 [7]. The determination of the type of diabetes, specifically type 1 or 2, is important because in type 1 diabetes there is little to no endogenous insulin secretion. This places the type 1 patient at higher risk for life-threatening diabetic ketoacidosis in the setting of insufficient insulin administration. They are also at higher risk for erratic glycemic control and hypoglycemic unawareness. For all patients with diabetes a clear and thorough assessment of the patients' control, including the presence, frequency, and degree of hypoglycemia, is critical. A detailed history including the frequency of glucose monitoring, range of blood glucose values, recent A1C levels, and type of insulin or other diabetes medications should be obtained. Further relevant issues are the nature and type of surgical procedure the patient is to undergo, the time of day the surgery is to be performed, and its anticipated duration. The type of anesthesia to be employed is also important as the impact of anesthesia on glucose metabolism and insulin resistance varies with the technique employed. For instance, epidural anesthesia, so often employed in total joint arthroplasty, has minimal metabolic effects [8].

Preoperative investigations are justifiably broader when compared to the patient without diabetes and should include baseline renal function, an ECG, and an assessment of the patient's glucose control. If not previously assessed within the past 2–3 months a blood sugar and hemoglobin A1C should be obtained [9]. Not only there is evidence suggesting that elevated blood sugars (>200 mg/dl) and A1C (>7.0 %) correlate with postoperative complications including an increased mortality [10–13], but also the hemoglobin A1C informs decision making, especially insulin dosing. There is convincing evidence that if the A1c is >9.0 % then basal insulin should be initiated and continued upon discharge if the patient was only on oral or GLP-1 agents prior to surgery [9]. Of particular relevance to the orthopedic population, one study of the risk of surgical site infection following spine surgery supports the view that poor diabetic control portends problems postoperatively [14].

**Table 14.1** Preoperative evaluation of the diabetes patient

| |
|---|
| • Type of diabetes |
| • Diabetic complications |
| • Glycemic control |
| • Hypoglycemia |
| • Diabetic therapy |
| • Other pharmacology |
| • Surgical procedure |
| • Anesthetic |

## Optimization of the Diabetic Patient

Surgery leads to a neuroendocrine stress response which results in hyperglycemia. This response is mediated by the release of many counter-regulatory hormones including epinephrine, glucagon, cortisol, and growth hormone. There are also inflammatory cytokines including interleukin-6 and tumor necrosis factor-alpha that are released. These hormones and cytokines together lead to a cascade of effects including increased peripheral insulin resistance, decreased glucose utilization, impaired insulin secretion, increased lipolysis, and protein catabolism with resultant hyperglycemia. Ketone production is possible in states of insulin deficiency and relative starvation. The magnitude of these changes varies with each patient and is also influenced by the type of anesthesia employed with general anesthesia resulting in larger metabolic effects. Other significant influences include the magnitude of the surgical procedure and other perioperative factors such as steroid use and the patient's nutritional status. Table 14.2 summarizes the primary goals of perioperative diabetes management.

Poorly controlled diabetes can lead to volume depletion and in severe circumstances such threatening conditions as diabetic ketoacidosis (DKA) or a nonketotic hyperosmolar state (NKH). The mechanism is largely due to the osmotic diuresis associated with hyperglycemia. The renal threshold of glucose reabsorption is exceeded at glucose levels greater than 215 mg/dL; therefore, at higher levels glucosuria results with resultant polyuria and dehydration [15]. Although rare, and usually a consequence of suboptimal management, these metabolic complications can be life threatening. Thus, in the

**Table 14.2** Goals of perioperative diabetic management

| |
|---|
| • Maintenance of fluid and electrolyte balance |
| • Prevention of ketoacidosis |
| • Avoidance of severe hyperglycemia |
| • Avoidance of hypoglycemia |

preoperative phase of management of the diabetes patient, securing optimal control is important in warding off potential metabolic complications postoperatively. No prospective controlled trial demonstrating that controlling glucose or decreasing HgbA1c improves the outcome before elective surgery has been reported. Further it is remarkable that many of the obvious questions concerning diabetic management remain unanswered [16]. These include such considerations as the following:

- Is there a preoperative glucose level (or A1C) above which surgery should be delayed?
- How should oral hypoglycemic agents be managed prior to surgery?
- How should insulin therapy be managed preoperatively?
- Should the insulin-naïve, poorly controlled patient be started on insulin preoperatively?

These are just a few of the unresolved but key management issues. In the absence of such information generally accepted approaches to diabetes treatment in the perioperative hospital setting have been developed through consensus of the practicing community [17, 18].

Preoperatively, most diabetes patients require limited laboratory testing, as a fasting blood sugar (supplemented with home glucose determinations if available), a HgbA1c (an index of control over the preceding 3-month period), and a history of hypoglycemia will provide a sufficient picture of the patient's preoperative glycemic control. In patients with severe, insulin-dependent disease, additional measures including renal function may be useful.

Given the described association between perioperative hyperglycemia and postoperative complications, measures should be taken in the preoperative period to decrease this risk. Time is often short, however, and there will be circumstances in which the prudent course of action is to cancel surgery to allow for the implementation or the modification of appropriate therapy. Defensible criteria for use in preoperative decision making are as follows. A preoperative HgbA1c of $<7$ % is considered satisfactory diabetes control, while a level of $>10$ % (correlates with an average blood sugar of 250 mg/dl) provides grounds for cancellation of elective surgery. For HgbA1c levels of an intermediate degree, clinical judgment is required. Reasonable therapeutic responses include the institution of oral agents with quick action including sulfonylureas if daytime hyperglycemia is the patient's pattern or basal insulin if morning hyperglycemia is the more the issue. This can be started 1 week before surgery. Efforts should be made to schedule the patient's surgery early in the day, thereby avoiding prolonged fasting periods. For patients who are on insulin pumps, the basal infusion rate should be maintained preoperatively and throughout the surgical procedure.

Once the decision is made to proceed with surgery, decision making is then oriented around the patients' mode of therapy, mainly how to manage patients on oral and injectable non-insulin-based agents versus those treated with insulin.

## Non-insulin Hypoglycemic Agents

For the patient receiving non-insulin-based therapies, the topic has become much more complex in recent years with a substantially expanded list of available agents including newer injectable non-insulin medications. At least six different classes of oral hypoglycemic agents are now available, each differing in its mechanism of action. The list includes insulin secretagogues (sulfonylureas or glinides), biguanides, thiazoladinediones, alpha-glucosidase inhibitors, DPP-4 inhibitors, and injectable GLP-1 receptor agonists. Despite their efficacy and safety in the outpatient setting, these are difficult agents to use in the hospital. The main reason is the rapidly changing clinical picture where patients are under stress, not eating well, or missing meals because of procedures and may be on new medications that temporarily could impact glucose control. These medications cannot be withdrawn after daily dosing and can increase the risk for in-hospital hypoglycemia. It is for this reason that all oral agents are usually held preoperatively. Metformin particularly has been a focus of concern due to the propensity to produce lactic acidosis, particularly in patients who have developed serious complications such as shock, hypoxemia, or renal failure. The validity of this apparent complication has been challenged, however [19]. Nevertheless metformin is generally held for 24 h preoperatively. For various reasons related to their specific pharmacology, the other classes of oral hypoglycemic agents are also held prior to surgery mainly to prevent hypoglycemia in patients whose oral intake has been temporarily held or decreased (Table 14.3).

Two injectable non-insulin medications, symlin and exenatide, are now commonly employed in diabetic management. Although new, most clinicians approach these medications as they do the oral hypoglycemic agents, holding them on the day of surgery and restarting once the patient is tolerating oral intake postoperatively.

**Table 14.3** Preoperative management of non-insulin hypoglycemic agents

| Oral hypoglycemic agents | |
|---|---|
| *Insulin secretagogues* | |
| • Sulfonylureas (Diabeta, Amaryl) | Hold on the day of surgery and while patient is fasting |
| • Glinides (Prandin, Starlix) | Hypoglycemia may occur in the absence of carbohydrate intake |
| *Biguanides* | |
| • Metformin (Glucophage) | Hold 24 h preoperatively |
| | Putative cause of lactic acidosis |
| *Thiazolidinediones* | |
| • Rosiglitazone (Avandia) | Hold on the day of surgery and as long as the patient is fasting |
| • Pioglitazone (Actos) | Minor concern due to slow onset of action and long half-life; these agents rarely cause hypoglycemia |
| *α-glucosidase inhibitors* | |
| • Acarbose (Precose) | Hold on the day of surgery and as long as the patient is fasting |
| • Miglitol (Glyset) | Only effective when the patient is taking carbohydrates |
| *Dipeptidyl peptidase inhibitors* | |
| • Sitagliptin (Januvia) | Hold on the day of surgery, restart when oral intake is resumed |
| • Saxagliptin (Onglyza) | Do not produce hypoglycemia |
| *Injectable agents* | |
| *Glucagon-like peptide inhibitors* | |
| • Exenatide (Byetta) | Hold on the day of surgery, restart when oral intake is resumed |
| *Amylin mimetics* | |
| • Pramlintide (Symlin) | Hold on the day of surgery, restart when oral intake is resumed |

Adapted with permission from Wesorick D. Assessing and managing endocrine disorders. Chapter 11. In: Jaffer AK, Grant PJ, editors. Perioperative medicine: medical consultation and co-management. Hoboken, NJ: Wiley-Blackwell, 2012

## Insulin

In the absence of evidence concerning what constitutes appropriate preoperative insulin management, recommendations to patients should be based on safety considerations. The primary goal should be the avoidance of hypoglycemia with the secondary one being stability of blood glucose values. The glycemic targets in the hospital should be tailored to the individual clinical situation with generally more liberal control in the inpatient setting when compared to outpatient goals. The glycemic targets for inpatient non-ICU settings extended to the preoperative setting include a pre-meal glucose $<140$ mg/dL or a random blood glucose level of $<180$ mg/dL. There are certain groups of patients, particularly the cardiac and surgical ICU patients, where there is evidence that even lower glycemic targets may provide morbidity and mortality benefit [5, 6].

## The Assessment of Perioperative Risk in the Diabetic Patient

The reason that patients with diabetes are at higher risk for postoperative complications is not just a function of the hyperglycemia but also the increased risk of cardiovascular disease and immune dysfunction. Acute hyperglycemia has a number of adverse effects and contributes to poor postoperative outcome [20]. Figure 14.1 schematically depicts the relationship of perioperative injury, hyperglycemia, and adverse outcome of surgery. Hyperglycemia may suppress immune function via a number of mechanisms and increase the release of circulating inflammatory cytokines. Decreased nitrous oxide production and increased angiotensin II alter vascular resistance and reactivity. Finally the resulting osmotic diuresis may lead to dehydration and electrolyte and acid–base imbalances. In its most severe form, the resultant hyperosmolarity may result in central nervous system dysfunction and even cerebral edema.

Insulin resistance and its resultant hyperglycemia are directly related to the magnitude of the surgical procedure as well as concomitant therapies (i.e., steroids, epinephrine, and dextrose-containing IV fluids). Anesthetic technique is also of concern. With respect to procedures involving the lower regions of the body such as spine, hip, and knee, the physiologic consequences of surgery are blunted by the use of epidural anesthesia and when feasible peripheral nerve blocks. Thus preoperative consultation with the anesthesiologist is often useful.

Most of the discourse concerning the diabetes patient undergoing noncardiac surgery focuses on the glycemic-related complications of infection and wound healing, both believed to be favorably influenced by better metabolic control. Indeed the current recommendation to maintain a perioperative glucose concentration of $<200$ mg/dL is mainly because of the influence of serum glucose on

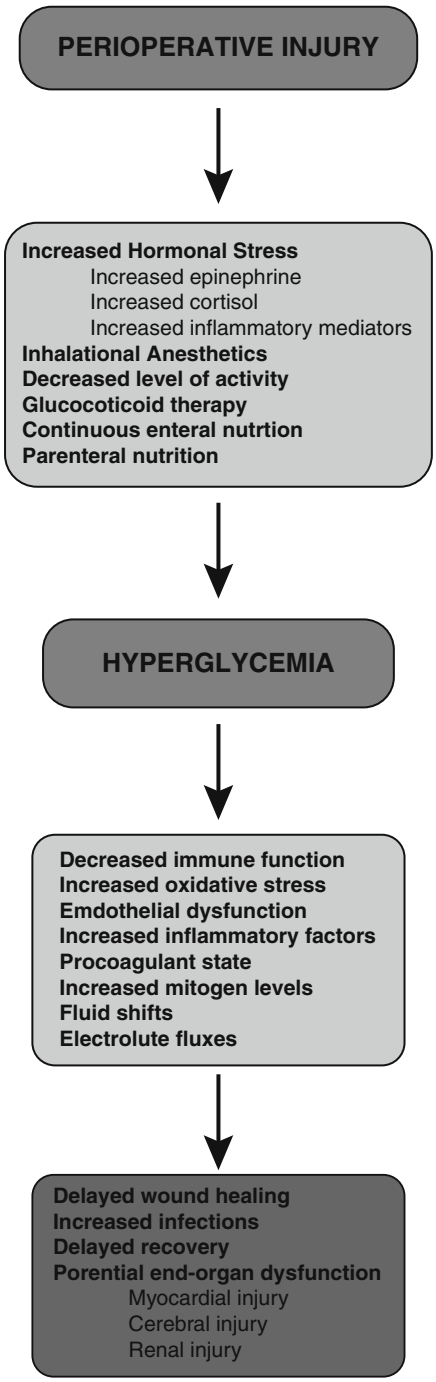


**Fig. 14.1** The relationship amongst perioperative injury, hyperglycemia, and outcomes (used with permission from Akhtar S, Barsh PG, Inzucchi SE. Scientific principles and clinical implications of perioperative glucose regulation and control. Anesth Analg 2010;110 (2):478–97)

postoperative infection [3]. Other complications are important, however, though the literature concerning outcomes in diabetes patients undergoing noncardiac surgery is remarkably limited. An increase in long-term mortality amongst patients with diabetes undergoing noncardiac surgery was noted in an early *beta*-blocker trial [21] as well as in another extensive retrospective review in which the overall postoperative mortality was 24 % [22]. In the latter investigation, preoperative ischemic heart disease augmented the mortality significantly (44 %) underscoring the importance of this prevalent comorbidity in the diabetic. Indeed, of the evaluable preoperative comorbid diseases, coronary artery disease, often occult, should be assiduously sought in this patient population. The evaluation of such cardiac disease follows the dictums and practices outlined in Chap. 11 of this book.

One further important complication relevant to the diabetes patient is that of cerebral injury. Hyperglycemia in the presence of cerebral ischemia may increase neuronal damage and worsen the severity of the neurologic injury incurred. A variety of mechanisms are responsible for this association including the development of lactic acidosis, hemorrhagic transformation of ischemic infarcts, and decreased cerebral blood flow to name a few. Of particular note in the noncardiac surgical setting are observations demonstrating a relationship with blood glucose levels and outcome of acute stroke. While not common after orthopedic surgery, such neurologic injury can have devastating and long-lasting consequences, fully undoing the usually positive impact of the surgical procedure. That elevated blood sugars may increase the severity of such injury should serve as a strong impetus for the optimization of the blood sugar in the perioperative period. Glucose levels $>$200 mg/dL appear to have unfavorable effects in the setting of cerebral injury, an observation that adds support for the setting of glycemic targets.

## Patient Education and Preventive Practices

Patients with diabetes are often well informed and meticulous in their approach to their condition. As such they are important allies in securing optimal management of their condition, intuitively understanding the importance of the maintenance of good metabolic control. Further they have a good sense of their own system, including their responses to diet and to certain medications. Thus it is helpful to include them actively in the decision making concerning the perioperative management of their disease. Such discussion should begin at the preoperative visit when specific recommendations will be made as to the medication protocol to be employed prior to surgery.

As outlined earlier, a number of alterations in the patient's usual medical regimen are usually necessary in the 24 h preceding the procedure. The specific nature of these medication changes, their rationale, the postoperative medication strategy, and estimates concerning when the patient is likely to return to his or her usual routine should be fully discussed and negotiated with the patient prior to admission.

## Postoperative Management

Decision making in the postoperative period requires consideration of a number of factors amongst which include the patient's general condition, their nutritional status, the magnitude of the surgical procedure, and the patient's type of diabetes and its control. The medically stable patient, undergoing surgery of a minor-to-intermediate magnitude, does not experience major surges in their counter-regulatory hormones and typically have their diet resumed soon after the procedure. In such circumstances, common in the orthopedic population, the usual medical regimen can be restarted almost immediately.

In those undergoing major procedures, more significant glycemic responses can occur and the management becomes more challenging. Indeed in such circumstances, oral and non-insulin injectable hypoglycemic agents are often avoided and patients are managed with insulin, usually via the subcutaneous route. Occasionally, in critical surgical settings, intravenous insulin infusions may be required although evidence of the safety and efficacy of such intensive glycemic control is lacking. Indeed meta-analyses of the major clinical trials addressing this issue failed to demonstrate benefit from such strategies [23, 24]. Further an increase of five- to sixfold in the incidence of significant hypoglycemia has been reported [25, 26]. Thus the value of tight glycemic control in the intra- and postoperative period has not been established nor generally advocated [27]. Expert opinion, however, does support achieving reasonable degrees of glycemic control in the perioperative setting. Several professional organizations have provided guidelines defining "glycemic "targets" for the non-critically ill, hospitalized patient. These recommendations make clear that uncontrolled hyperglycemia is an unacceptable standard of care [28, 29]. Recommendations for inpatient (non-ICU) glycemic control are fasting and maximal glucoses of 110 mg/dL and 180 mg/dL, respectively. Recognizing the difficulty in achieving these goals consistently, coupled with the dangers of hypoglycemia, some leeway is generally accepted. How can these targets be consistently achieved in practice?

## Postoperative Insulin Management

Diabetes management in the postoperative period can be challenging due to the variety of influences that can arise. The treatment regimen employed needs to be flexible and responsive to changes arising in the patient's clinical condition. Subcutaneous insulin is the drug of choice for the majority of hyperglycemic patients after surgery. Its advantages include its quick onset of action and its ability to be titrated immediately based on the patients' glucose control. Insulin therapy is indicated for all patients who are on insulin prior to surgery as well as those whose postoperative glucoses remain out of the desired range.

In the stable patient, with reasonable intake of nutrition and satisfactory blood sugars, simply resuming their usual diabetes regimen after surgery is appropriate. Nonetheless when such therapy proves unsatisfactory in the postoperative setting and insulin supplementation is required, employing a methodology that uses exogenous insulin to mimic normal physiologic insulin secretion is indicated. This regimen is built upon three distinct components: *basal* insulin, *nutritional* (prandial/meal) insulin, and *correction*-dose (supplemental) insulin [15, 16]. A patient's total daily insulin requirement (total daily dose, TDD) is the total of these and is the amount of insulin required in 24 h when taking adequate nutrition. Basal insulin is secreted continuously and suppresses hepatic glucose production and ketone production. Nutritional insulin is secreted in response to the ingestion of food and is responsible for the normalization of glucose following a meal. Correction insulin is that given to correct the hyperglycemia that can occur from the increase in counter-regulatory hormones during stress, illness, and surgery. Approximately one-half of the total daily insulin secreted is basal insulin, while the other half is a response to nutritional intake. Remembering this "50/50" rule is helpful in developing insulin regimens in the postoperative setting.

Basal insulin can be provided using a long-acting, low-peaking insulin that results in stable insulin levels, such as glargine or detemir. NPH insulin dosed twice daily can also serve as a basal insulin although the risk of hypoglycemia is higher because of its erratic peak; therefore, the dosage should be reduced by 30–50 %. Nutritional insulin must be provided according to the postoperative nutritional program ordered for the patient. Thus patients receiving nutrition in a bolus fashion (regular meals, bolus tube feeding) should be given rapid-acting insulin at the time of their meal to cover the glycemic peak that will follow. Short-acting insulin analogs such as aspart, glulisine, and lispro are common examples. Regular insulin has fallen out of favor as it has an effect up to 6–8 h, and consecutive dosing can lead to accumulation of insulin and an increased risk of hypoglycemia, a phenomenon known as "insulin stacking."

Correction-dose insulin refers to the small supplemental dosages given to patients intermittently to correct hyperglycemia. Using similar insulin preparations as those used to meet nutritional requirements the purpose of this additional therapy is to return the blood glucose back to the target range. Correction dosages are usually administered at the

**Table 14.4** Weight-based insulin dosing

| Patient characteristics | Dosing estimate (units/kg/day) |
|---|---|
| Insulin sensitivity (elderly, lean/malnourished, chronic kidney disease) | 0.3 |
| Clinically normal | 0.4 |
| Insulin resistance (obese, high-dose steroids) | ≥0.5 |

Adapted with permission from Wesorick D, O'Malley C, Rushakoff R, et al. Management of diabetes and hyperglycemia in the hospital: a practical guide to subcutaneous insulin use in the non-critically Ill, adult patient. J Hosp Med 2008;3(5)Suppl 5:S17–S28

same time as the nutritional component or every 4–6 h in patients who are not eating. In patients requiring correction-dose insulin on a consistent basis, the basal and/or nutritional regimen will need to be modified. Estimates for the increase in dosing are based on the total number of units of correction insulin that was required in the preceding 24 h. This is then divided up and added to the basal and nutritional components of the overall insulin coverage. Note that the previous, physiologically based, approach has replaced the familiar "sliding scale" methodology, a reactive generally ineffective strategy that was found to result in more erratic glycemic control with increased rates of both hypo- and hyperglycemia [30, 31].

In situations where correction dosages are required frequently or in high doses, the basal and nutritional insulin component may need to be increased. In these circumstances the total daily corrective insulin is incorporated into the basal and nutritional insulin requirement for the next day. The goal of management is to achieve glycemic targets, without the need for large supplemental correction insulin. It is important to attempt to keep the 50:50 ratio of basal insulin to nutrition + correction insulin when adjusting the regimen; this will decrease the risk of hypoglycemia.

Having provided a physiologic framework for the approach to perioperative insulin therapy, certain dosing guidelines and rules are useful. Dosing estimates should take into account risk factors for hypoglycemia. These include various comorbidities including renal or hepatic dysfunction, low body weight, heart failure, adrenal insufficiency, alcoholism and dialysis. Other considerations include elderly or thin patients, patients with poor nutritional intake and a history of hypoglycemia. The following represents a basic approach:

- Estimate a patient's daily insulin requirement (TDD) when taking adequate nutrition, either using his or her outpatient TDD or employing a weight-based estimation of TDD (Table 14.4), dosing that may require adjustment according to certain patient characteristics.
- The TDD should then be divided into the basal and nutritional components, generally according to a 50:50 distribution. Note that nutritional insulin is held in patients not taking nutrition.
- Table 14.5 summarizes the recommended insulin regimens for varying nutritional situations.
- In order to cover periods of hyperglycemia, a correction-dose insulin scale using bedside glucose monitoring should be established.

The last category of therapy has to do with patients who are managed with an insulin pump which continuously infuses subcutaneous insulin. This approach provides basal insulin at rates that have been adjusted to meet the 24-h needs of the patient. Insulin pumps are still not a common treatment but are more prevalent in the type 1 diabetes population. Hospital staff, in contrast to the patients, is often not comfortable with the management of an insulin pump. Reaching an agreement with the patient to engage so directly in their own therapy (a unique form of co-management) may be reasonable in some circumstances though it requires close communication with and oversight by the medical-nursing staff. Alternatively, if such conditions cannot be achieved, or the hospital personnel are not comfortable with this degree of patient therapeutic autonomy, patients on insulin pumps at home can be converted temporarily to the standard subcutaneous approaches just outlined. Other situations in which insulin pump therapy is not recommended include surgeries where fluid overload may occur as edema may interfere with the absorption of subcutaneous insulin or if the patients may temporarily lose their ability either cognitively or physically to manage the pump postoperatively [32].

Finally, hospital discharge presents a challenging transition in care for the diabetes patient as their glycemic control may have been disrupted by the circumstances of their surgery. The Joint Commission recognizes this problem as an important quality domain citing the need for patient education with respect to finger-stick glucose monitoring, glycemic targets, and recognition and treatment of hyper- and hypoglycemia; communication with the patient's primary physician concerning any changes in diabetic care is also emphasized in their decrees [33].

## Summary

In conclusion, the care of the patient with diabetes in the perioperative period is one of the most common and challenging problems of clinical medicine. In addition to being plagued with higher rates of infection, wound breakdown,

**Table 14.5** Society of Hospital Medicine Glycemic Control Task Force recommendation-preferred insulin regimens for different nutritional situations

| Nutritional situation | Necessary insulin components | Preferred regimen[a] |
|---|---|---|
| NPO (or clear liquids) | Basal insulin: 50 % of TDD Nutritional insulin: None | Basal insulin: Glargine given once daily or detemir given twice daily. Nutritional insulin: None. Correctional insulin: Regular insulin q 6 h or RAA insulin q 4 h. Other comments: Dextrose infusion (e.g., D5 containing solution at 75–150 cc/h) recommended when nutrition is held. An IV insulin infusion is preferred for management of prolonged fasts or fasting type 1 diabetes patients |
| Eating meals | Basal insulin: 50 % of TDD, Nutritional insulin: 50 % of TDD divided equally before each meal | Basal insulin: Glargine given once daily or detemir given twice daily. Nutritional insulin: RAA insulin with meals. Correctional insulin: RAA insulin q AC and HS (reduced dose at HS) |
| Bolus tube feeds | Basal insulin: 40 % of TDD. Nutritional insulin: 60 % of the TDD, divided equally before each bolus feed | Basal insulin: Glargine given once daily or detemir given twice daily. Nutritional insulin: RAA insulin with each bolus. Correctional insulin: RAA insulin with each bolus |
| Continuous tube feeds | Basal insulin: 40 % (conservative) of TDD. Nutritional insulin: 60 % of the TDD in divided doses | Basal insulin: Glargine given once daily or detemir given twice daily. Nutritional insulin: RAA insulin q 4 h or regular insulin q 6 h. Correctional insulin: Should match nutritional insulin choice |
| Parenteral nutrition | Insulin is usually given parenterally with the nutrition | Initially, a separate insulin drip allows for accurate dose finding. Then, 80 % of the amount determined as TDD using drip is added to subsequent TPN bags as regular insulin. Use correctional subcutaneous insulin doses cautiously, in addition |

Used with permission from Wesorick D, O'Malley C, Rushakoff R, et al. Management of diabetes and hyperglycemia in the hospital: a practical guide to subcutaneous insulin use in the non-critically Ill, adult patient. J Hosp Med 2008;3(5)Suppl 5:S17–S28

*HS,* at bedtime; *IV* intravenous, *NPO* nothing by mouth, *q 4 h* every 4 h, *q 6 h* every 6 h, *q AC* before every meal, *RAA* rapid-acting analog, *TDD* total daily dose, *TPN* total parenteral nutrition

[a]These are the preferred regimens for most patients in these situations by consensus of the SHM Glycemic Control Task Force. Alternate regimens may appropriately be preferred by institutions or physicians to meet the needs of their own patient population. RAA insulins include lispro, aspart, and glulisine

and other adverse events, the management of these patients taxes all levels of medical and nursing care. As such, approaches to the evaluation and management of such patients warrant attention at all levels of inpatient and outpatient care.

**Summary Bullet Points**

- Diabetes mellitus is a frequently encountered and challenging condition in the perioperative setting.
- Patients with Diabetes are at additional risk after surgery due to their high prevalence of comorbidities, most importantly cardiovascular disease.
- A systematic approach to the preoperative assessment of the patient with diabetes is required emphasizing such considerations as the degree of glucose control, medications, and anticipation of postoperative insulin resistance.
- Postoperative "glycemic targets" should be established preoperatively.
- The concepts of basal, nutritional, and correction-dose insulin therapy must be appreciated.
- Glycemic related postoperative complications, specifically infection and impaired wound healing, must be anticipated.

## References


1. Centers for Disease Control and Prevention. National diabetes fact sheet: national estimates and general information on diabetes and prediabetes in the United States. (2011). http://www.cdc.gov/diabetes/pubs/pdf/nkfs_2011.pdf.
2. Bolognesi MP, Marchant MH, Viens NA, et al. The impact of diabetes mellitus on perioperative patient outcomes after total hip and knee arthroplasty in the United States. J Arthroplasty. 2008;23 (6 Suppl 1):92–8.
3. Golden SH, Peart-Vigilance C, Kao WH, Brancati FL. Perioperative glycemic control and the risk of infectious complications in a cohort of adults with diabetes. Diabetes Care. 1999;22(9):1408–14.
4. Zerr KJ, Furnary AP, Grunkemeier GL, Bookin S, et al. Glucose control lowers the risk of wound infection in diabetics after open heart operation. Ann Thorac Surg. 1997;63(2):356–61.
5. Furnary AP, Gao G, Grunkemeier GL, et al. Continuous insulin infusions reduces mortality in patients with diabetes undergoing coronary artery bypass grafting. J Thorac Cardiovasc Surg. 2003; 125(5):1007–21.
6. den Berghe V, Wouters P, Weekes F, et al. Intensive insulin therapy in the critically ill patients. NEJM. 2001;345(19):1359–67.
7. Khan NA, Ghali W, Cagliero E. Perioperative management of diabetes mellitus. UpToDate. (2012). www.uptodate.com.
8. Brandt M, Kehlet H, Binder C, et al. Effect of epidural analgesia on the glycoregulatory endocrine response to surgery. Clin Endocrinol (Oxf). 1976;5:107.
9. Umpierrez GE, Hellman R, Korytkowski MT, et al. Management of hyperglycemia in hospitalized patients in non-critical care settings: an endocrine society clinical practice guideline. J Clin Endocrinol Metab. 2012;97:16–38.

10. Trick WE, Scheckler WE, Tokars JI, et al. Modifiable risk factors associated with deep sternal site infection after coronary artery bypass grafting. J Thorac Cardiovasc Surg. 2000;119:108.
11. Dronge AS, Perkal S, Kancir S, et al. Long-term glycemic control and postoperative infectious complications. Arch Surg. 2006; 141:375.
12. Noordzij PG, Ooersman E, Schreiner F, et al. Increased preoperative glucose levels are associated with perioperative mortality in patients undergoing noncardiac, nonvascular surgery. Eur J Endocrinol. 2007;156:137–42.
13. Yendamuri S, Fulda GJ, Tinkoff GH. Admission hyperglycemia as a prognostic indicator in trauma. J Trauma. 2003;55:33–8.
14. Olsen MA, Nepple JJ, Riew KD, et al. Risk factors for surgical site infection following orthopaedic spinal operations. J Bone Joint Surg Am. 2008;90:62–9.
15. Mesotten D, Van den Berghe G. Glycemic targets and approaches to management of patient with critical illness. Curr Diab Rep. 2012;12(1):101–7.
16. Joshi GP, Chung F, Vann MA, et al. Society for ambulatory anesthesia consensus statement on perioperative blood glucose management in diabetic patients undergoing ambulatory surgery. Anesth Analg. 2010;111(6):1378–87.
17. Clement S, Braithwaite SS, Magee MF, et al. Management of diabetes and hyperglycemia in hospitals. Diabetes Care. 2004;27 (2):533–91.
18. Wesorick D, O'Malley C, Rushakoff R, et al. Management of diabetes and hyperglycemia in the hospital: a practical guide to subcutaneous insulin use in the non-critically ill adult patient. J Hosp Med. 2008;3(5 Suppl):S17–28.
19. Salpeter SR, Greyber E, Pasternak GA, et al. Risk of fatal and nonfatal lactic acidosis with metformin use in type 2 diabetes mellitus. Cochrane Database Syst Rev. 2009;1, CD002967.
20. Akhtar S, Barsh PG, Inzucchi SE. Scientific principles and clinical implications of perioperative glucose regulation and control. Anesth Analg. 2010;110(2):478–97.
21. Mangano DT, Layug EL, Wallace A, et al. Effect of atenolol on mortality and cardiovascular morbidity after noncardiac surgery. Multicenter Study of Perioperative Ischemia Research Group. N Engl J Med. 1996;335:1713–20.
22. Juul AB, Wetterslev J, Kofoed-Enevoldsen A. Long-term postoperative mortality in diabetic patients undergoing major non-cardiac surgery. Eur J Anaesthesiol. 2004;21:523–9.
23. Pittas AG, Siegel RD, Lau J. Insulin therapy for critically ill hospitalized patients: a meta-analysis of randomized controlled trials. Arch Intern Med. 2005–2011;2004:164.
24. Gandhi GY, Murad MH, Flynn DN, et al. Effect of perioperative insulin infusion on surgical morbidity and mortality: systemic review and meta-analysis of randomized trials. Mayo Clin Proc. 2008;83:418–30.
25. Wiener RS, Wiener DC, Larson RJ. Benefits and risks of tight glucose control in critically ill adults: a meta-analysis. JAMA. 2008;300:933–44.
26. Griesdale DR, de Souza RJ, van Dam RM, et al. Intensive insulin therapy and mortality among critically ill patients: a meta-analysis including NICE-SUGAR study data. CMAJ. 2009;180:821–7.
27. Watkinson P, Barber MS, Young JD. Strict glucose control in the critically ill. BMJ. 2006;322:865–6.
28. American College of Endocrinology Task Force on Inpatient Diabetes and Metabolic Control. American College of Endocrinology position statement on inpatient diabetes and metabolic control. Endocr Pract. 2004;10:77–82.
29. American Diabetes Association. Standards of medical care in diabetes. Diabetes Care. 2006;29(Supp 1):s4–42.
30. Queale WS, Seidler JA, Brancati FL. Glycemic control and sliding scale use in medical inpatients with diabetes mellitus. Arch Intern Med. 1997;157:545–52.
31. Umpierrez GE, Andres P, Smiley D, et al. Randomized study of basal-bolus insulin therapy in the inpatient management of patients with type 2 diabetes (Rabbitt 2 trial). Diabetes Care. 2007; 30:2181–6.
32. Bailon RM, Partlow BJ, Miller-Cage V. Continuous subcutaneous insulin infusion (insulin pump) therapy can be safety used in the hospital in select patients. Endocr Pract. 2009;15(1):24–9.
33. Inpatient Diabetes Certification. Joint Commission. http://www.jointcommission.org/CertificationPrograms/Inpatient + Diabetes (2008) Accessed Apr 2008

# Perioperative Care of the Orthopedic Patient with Gastrointestinal and Liver Issues

15

Melissa H. Rosen and Charles Maltz

**Objectives**

- To present an approach to the perioperative evaluation and management of the patient with known or newly presenting GI/liver disease
- To explore approaches to the prevention and management of postoperative GI bleeding
- To present an approach to the diagnosis and treatment of postoperative abdominal distention

**Key Points**

- The most effective preoperative optimization of the patient with abnormal liver function tests/cirrhosis and GI disease is required.
- The evaluation of new postoperative liver function abnormalities is essential.
- The prevention and management of postoperative GI bleeding are critical.
- The evaluation and management of postoperative abdominal distention are critical.

## Introduction

The majority of patients undergoing orthopedic surgery will have an uncomplicated postoperative course, experiencing no or only minor problems of a gastrointestinal or a hepatological nature. In circumstances when such clinical issues arise pre- or postoperatively, the gastroenterologist may be called for advice. Common problems such as postoperative nausea, vomiting, or constipation are most often managed by the general medical consultant. However, more threatening problems associated with significant morbidity and mortality do occur and constitute the primary emphasis of this chapter. Key to their management is early identification and preemptive treatment. Common examples range from the evaluation of abnormal liver function studies to more severe clinical challenges including the preoperative recognition of alcoholic liver disease, a condition that often portends alcohol withdrawal in the postoperative period; postoperative ileus, an often difficult problem arising as a consequence of bed rest and narcotics; infectious complications such as *Clostridium difficile* colitis; and gastrointestinal bleeding, all of which are reviewed herein.

## The Preoperative Evaluation

### Identification of Conditions That Affect Postoperative Gastroenterological Outcome

As always, the preoperative evaluation begins with a thorough history, a physical examination, laboratory studies, and, if necessary, radiographic assessments. With a few important exceptions, the majority of gastroenterologic diseases do not require special consideration prior to surgery. Thus the preoperative evaluation should primarily focus on conditions associated with actual mortality risk in the surgical patient, particularly liver disease. The other gastroenterologic conditions arising in the surgical setting tend to occur postoperatively and usually cannot be predicted prior to surgery.

M.H. Rosen
Division of Gastroenterology, New York University Langone Medical Center, 207 E 84th Street, New York, NY 10028, USA

C. Maltz (✉)
Division of Gastroenterology and Hepatology, Weill Cornell Medical College, 1305 York Ave., New York, NY 10021, USA
e-mail: chm2022@med.cornell.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_15, © Springer New York 2014

## Elevated Transaminases Without Cirrhosis

Owing to the still widespread performance of routine laboratory studies prior to surgery, the finding of abnormal liver function tests (LFTs) in the preoperative setting is a common phenomenon. Indeed, broadly observed, such findings are seen in 9 % of the US population [1]; thus, such abnormalities can be expected in a significant proportion of patients evaluated before surgery. The differential diagnosis of asymptomatic LFT elevations is broad and includes numerous, often benign, conditions (Table 15.1); the perioperative implications of such findings are dependent on their etiology and chronicity. The most common causes for chronically elevated LFTs are nonalcoholic fatty liver disease, alcoholic liver disease, chronic viral hepatitis (usually hepatitis C), and medications. Finally one would be remiss in not considering alcoholism and the possibility of postoperative alcohol withdrawal in any patient with hepatic dysfunction [2]. In addition to the presence of liver disease, the history of unexplained multiple fractures should raise the suspicion for alcoholism.

**Table 15.1** Causes of mild increases in ALT or AST levels

| |
|---|
| *Hepatic: Predominantly ALT elevations* |
| Chronic hepatitis B |
| Chronic hepatitis C |
| Acute viral hepatitis (A–E, Epstein–Barr virus, cytomegalovirus) |
| Steatosis/steatohepatitis |
| Hemochromatosis |
| Medications |
| Toxins |
| Autoimmune hepatitis |
| Alpha-1-antitrypsin deficiency |
| Wilson's disease |
| Celiac sprue |
| *Hepatic: Predominantly AST elevations* |
| Alcohol-related liver injury |
| Steatosis/steatohepatitis |
| Cirrhosis |
| *Extrahepatic* |
| Gallstone disease |
| Thyroid disease |
| Hypernephroma |
| Hodgkin's lymphoma |
| Muscle injury |
| Anorexia nervosa |
| Adrenal insufficiency |

## Cirrhosis and Chronic Liver Disease

In the preoperative evaluation of the patient with potential hepatic dysfunction one seeks to determine the severity of any chronic liver disease, as well as the degree of hepatic inflammation, and to consider how these processes might affect the ability of the patient to tolerate surgery and anesthesia. Clues regarding the presence of cirrhosis may be found in the patient's history, through physical exam, or via ancillary testing. A history of alcoholism, prior illicit drug use, a history of hepatitis B or C, ascites, or prior variceal bleeding or encephalopathy has obvious meanings. The physical examination findings of cirrhosis include abdominal ascites, spider angiomas on the chest, and gynecomastia in a male patient. Asterixis, altered sleep patterns, or slowing of mentation suggests encephalopathy.

The most common lab findings of cirrhosis are an elevated INR, low albumin, and decreased platelet count. If suspicion of cirrhosis exists, the most cost-effective test is a sonogram of the liver. Suggestive sonographic findings, coupled with the history and laboratory values, should be sufficient to alert the examiner to this diagnosis. The presence of cirrhosis results in an increased susceptibility to infections as well as decrease in liver reserve in the setting of perioperative circulatory changes. Such hepatic functional compromise may result in postoperative liver and/or renal failure. The stratification of the patient as to the risk of the procedure from a hepatic standpoint depends on the procedure under consideration, the elective or the emergent nature of the procedure, and the underlying condition of the liver.

## Optimization of Gastroenterological and Hepatic Conditions That May Affect Postoperative Outcome

For virtually all of the benign conditions mentioned previously, surgery can proceed without delay. However, nonemergent surgery should be avoided in the patient with acute viral or alcoholic hepatitis, as such conditions are associated with a substantial mortality even in the absence of surgery [3]. Further, in other patients, who exhibit no evidence of cirrhosis, surgery can also be safely performed. In some instances such as with an offending medication or excessive alcohol ingestion, the etiology can be removed, surgery deferred, and the responsible factors eliminated so as to allow for improvement of liver function. In patients with chronic hepatitis C or nonalcoholic fatty liver disease, surgery can be safely performed if there is no cirrhosis.

As will be discussed later, postoperative outcome is closely linked to the optimization of hepatic processes in patients with more severe forms of liver disease. Thus in the cirrhotic patient, with clinical evidence of hepatic decompensation (elevated INR, low albumin, ascites, encephalopathy), surgery should be delayed with efforts directed at achieving better control of the hepatic dysfunction. Relevant treatment approaches may include platelet transfusions to correct severe thrombocytopenia (<50,000) and vitamin K to correct an elevated INR, thereby reducing the resultant

bleeding tendency. Transfusions of plasma or blood should be avoided unless absolutely necessary so as not to increase portal pressure and provoke variceal bleeding. A high suspicion of infection postoperatively should be kept in mind with a low threshold for diagnostic paracentesis. This is particularly true of the cirrhotic with ascites as such patients are at risk for spontaneous bacterial peritonitis. Similarly, blood cultures should be drawn in the postoperative patient with clinical deterioration. In the advanced cirrhotic with ascites, albumin should be used rather than saline in an effort to increase renal perfusion and avoid hepatorenal syndrome. NSAIDS and other potentially nephrotoxic medications should be avoided perioperatively in these patients.

## The Assessment of Postoperative Risk

In patients identified with acute or chronic hepatic disease, the Child–Turcotte–Pugh (CTP) score (Table 15.2) has traditionally been used to stratify patients as to the severity of their liver disease. Despite its long track record, weaknesses in the predictive capacity of the CTP methodology have been recognized and ascribed to two subjective components of the classification, namely, encephalopathy and ascites. Thus recently an alternative approach employed in liver transplant allocation has been more broadly employed in surgical risk stratification [4, 5]. The formula, the so-called model for end-stage liver disease (MELD), uses only objective laboratory data and may be the best predictor of 30- and 90-day mortality (Table 15.3) which is calculated as follows:

MELD = 3.78 (serum bilirubin [mg/dl]) + 11.2(ln INR) + 9.57 (creatinine [mg/dl]) + 6.43.[1]

In comparing the two systems, a CTP class A correlates with a MELD score of ≤8, CTP class B to a MELD score of 9–16, and CTP class C similar to a MELD score of >16 [4]. Using either a Child's score or the MELD reveals that worsening liver function results in increased perioperative mortality and morbidity [6]. The overall rates of significant complications were 14.3 %, 28.6 %, and 100 % in cirrhotic patients with CTP class A, B, and C; the associated mortality rates were 4.7 %, 14.3 %, and 100 % for CTP classes A, B, and C, respectively [7]. A study from Korea reviewing hip arthroplasty in cirrhotic individuals found that a higher CPT score ($p = 0.0001$) and a high level of creatinine ($p = 0.0499$) were associated with significantly increased perioperative complications or death [8].

[1] Numerous Internet sites which allow calculation of the MELD score are available.

**Table 15.2** The Child–Turcotte–Pugh (CTP) score

| | 1 | 2 | 3 |
|---|---|---|---|
| Encephalopathy | None | Mild | Severe |
| Bilirubin | <2 | 2–4 | >4 |
| Ascites | None | Small | Large |
| Albumin | >3.5 | 2.8–3.4 | <2.8 |
| PT prolongation | <2 s | 2–6 s | >6 s |

CTP A5–6, CTP B6–9, CTP C10–15

## Elevated Liver Function Tests Without Cirrhosis

As mentioned earlier, patients with elevated LFTs without evidence of cirrhosis may require further investigation to identify the etiology of their abnormal laboratory parameters. Typically, mild elevations in transaminases, such as those arising from chronic hepatitis C or from nonalcoholic fatty liver disease, are not a contraindication to surgery. Alternatively it would be unwise to proceed with nonemergent surgery in the setting of acute alcoholic or viral hepatitis. Elevations in transaminases from chronic alcohol abuse should prompt monitoring for alcohol withdrawal in the perioperative period. Not all patients who abuse alcohol suffer from alcohol withdrawal, and a thorough history should provide such details. A history of prior alcohol withdrawal is most worrisome. Symptoms include hypertension, tachycardia, tremors, nausea, and/or vomiting. If alcohol withdrawal is not addressed with administration of benzodiazepine therapy and hydration, patients can rapidly progress to a state of delirium tremens (DTs), a condition characterized by confusion, tachycardia, fever, and a mortality of 5 %.

# The Postoperative Period

The GI consultant often first becomes involved postoperatively, since the majority of gastroenterologic complications arise as a result of anesthesia, from antibiotics, and/or narcotic therapy. The remainder of this chapter focuses on the common gastroenterologic complications in this setting.

## Postoperative Nausea and Vomiting

Postoperative nausea and vomiting (PONV) is a frequent problem in the postoperative setting. Approximately one-third of surgical patients experience nausea and/or vomiting after general anesthesia [9]. An outcome rated by patients to be amongst the ten most undesirable consequences of surgery [10], PONV is believed to be multifactorial in etiology with such risk factors as female sex, nonsmoker status, and a previous history of postoperative nausea, vomiting, or motion sickness; postoperative opiate use is also a risk factor

**Table 15.3** Relationship between MELD score and postoperative mortality

| Mortality, % (No. of patients at risk) | | | | | | |
|---|---|---|---|---|---|---|
| MELD score | 7 days | 30 days | 90 days | 1 year | 5 years | 10 years |
| 0–7 ($n = 351$) | 1.9 (314) | 5.7 (301) | 9.7 (287) | 19.2 (253) | 50.7 (123) | 72.6 (57) |
| 8–11 ($n = 257$) | 3.3 (236) | 10.3 (219) | 17.7 (200) | 28.9 (170) | 58.5 (83) | 78.1 (35) |
| 12–15 ($n = 106$) | 7.7 (94) | 25.4 (78) | 32.3 (69) | 45.0 (56) | 69.5 (24) | 87.2 (10) |
| 16–20 ($n = 35$) | 14.6 (29) | 44.0 (19) | 55.8 (15) | 70.5 (10) | 94.1 (2) | 94.1 (2) |
| 21–25 ($n = 13$) | 23.0 (7) | 53.8 (4) | 66.7 (3) | 84.6 (2) | 92.3 (1) | 100 (0) |
| $\geq$26 ($n = 10$) | 30.0 (6) | 90.0 (1) | 90.0 (1) | 100 (0) | 100 (0) | 100 (0) |

*MELD* model for end-stage liver disease
Used with permission from Teh SH, Nagorney DM, Stevens SR, et al. Risk factors for mortality after surgery in patients with cirrhosis. Gastroenterology 2007;132:1261–9 [4]

[11]. The presence of none, one, two, three, or four such risk factors is associated with an incidence of 10 %, 21 %, 61 %, and 79 %, respectively [12]. Such problems often herald the onset of more significant problems to come, specifically postoperative abdominal ileus.

When evaluating a patient with PONV a thorough review of the medication list is important, since medications are often the culprit. Examples of medications used in the postoperative patient that may cause nausea and subsequent vomiting are analgesics, including aspirin, nonsteroidal anti-inflammatory drugs (NSAIDs), and opiates. Additionally, disorders of the gastrointestinal tract should be considered. Mechanical obstruction, such as a small bowel obstruction, can also cause acute-onset nausea and vomiting; similarly an intestinal pseudo-obstruction can bring about these symptoms. Other underlying conditions existing prior to surgery, such as gastroparesis and migraine headaches, can likewise manifest in this manner and should be considered as potential etiologies. Central nervous system causes, such as tumor, or meningitis may be considerations in the appropriate clinical setting but are uncommon.

Evaluation of the patient with new-onset postoperative nausea and vomiting involves a thorough history, addressing the previously mentioned issues, as well as a physical exam. If there is concern for obstruction or pseudo-obstruction, an abdominal X-ray should be obtained and work-up should proceed as discussed later in this chapter.

Treatment involves both addressing the presumed etiology and the use of antiemetics. If it becomes apparent that the nausea may be medication related, try to minimize or eliminate the use of that medication. Both antiemetic and pro-kinetic medications can be helpful. Given that postoperative nausea is felt to be associated with the neurotransmitter dopamine, metoclopramide, the dopamine antagonist can be used [13]. Metoclopramide, with its antiemetic and pro-kinetic properties, can also be associated with extrapyramidal side effects. Similarly, prochlorperazine, a dopamine antagonist, can be used for postoperative nausea and vomiting. Like metoclopramide, it is associated with extrapyramidal side effects. Ondansetron, a serotonin antagonist, can also be an effective antiemetic. One should be careful not to continue these medications at discharge, however.

If the nausea and vomiting persist despite a thorough work-up, elimination of offending medications, an unremarkable abdominal X-ray, and proper use of antiemetics, one should consider an evaluation by a gastroenterologist. Endoscopy may need to be considered in order to rule out such conditions as partial outlet gastric obstruction due to peptic ulcer disease or erosive esophagitis.

## Postoperative Abdominal Distention

Abdominal distention is not uncommon in the postoperative period. Usually this resolves as the patient is weaned from narcotic analgesia and becomes more ambulatory. Occasionally, however, it can persist or progress to marked distention, a condition referred to as postoperative ileus or *Ogilvie's* syndrome. Further megacolon, arising from *Clostridium difficile colitis*, is also in the differential diagnosis, particularly when the diarrhea accompanies the distention. Acute intestinal pseudo-obstruction, called *Ogilvie's* syndrome, is an acute ileus occurring in the postoperative state after procedures that do not involve manipulation of the abdominal viscera [14]. This was originally described after the caesarean section and can be seen after cardiac surgery as well as after orthopedic procedures such as spine and hip surgery. Ileus was found to occur in 0.7–4.0 % of patients after total joint arthroplasty and up to 5.6 % in patients who underwent revision total hip arthroplasty [13]. This portion of the chapter focuses on the diagnosis and management of a postoperative distention.

Although there are no specific criteria for the diagnosis of *Ogilvie's* syndrome, the symptoms may include abdominal distention and bloating, diffuse abdominal pain, nausea and/or vomiting, obstipation, or delayed transit of flatus. This can be accompanied by the inability to tolerate any oral intake with symptoms persisting for more than 3–5 days after surgery. On physical exam, patients typically have abdominal distention, absence of or hypoactive bowel

sounds, and tympani to percussion and may have abdominal tenderness.

Initial radiographic evaluation should include an abdominal X-ray, both supine and upright, to confirm that the symptoms can be attributed to a postoperative ileus and to rule out mechanical obstruction. A mechanical obstruction must be considered prior to proceeding with management of the ileus. The differential for a mechanical obstruction includes volvulus (colonic torsion), diverticulitis, carcinoma, and a small bowel obstruction with the management of these depending on the diagnosis. A volvulus may be managed colonoscopically. The date of the last screening colonoscopy is vital when contemplating a colonic carcinoma. Similarly, the patient history is necessary, since a history of previous abdominal surgeries can suggest adhesions and thus small bowel obstruction. Feculent emesis, severe abdominal pain, and peritoneal signs are more suggestive of a small bowel obstruction than paralytic ileus, and management often involves surgery. Acute urinary retention may present with similar features, but a careful exam should be able to detect a distended bladder.

If a small bowel obstruction or other causes of mechanical obstruction cannot sufficiently be ruled out with the patient presentation and abdominal X-rays, then computed tomography (CT) scan of the abdomen and pelvis should be done for further evaluation. Prior studies have found CT to have high sensitivity and specificity for distinguishing paralytic ileus from small bowel obstruction. If there is concern for obstruction of the left colon, a gastrografin enema may be used as a diagnostic imaging modality.

Once a mechanical obstruction has been excluded and it has been determined that a postoperative paralytic ileus is the correct diagnosis, the initial management involves determining the etiology of the ileus since certain causes may be reversible. Laboratory tests including an electrolyte panel, including sodium, potassium, and magnesium, should be checked. Hypokalemia and hypomagnesemia are easily correctable reversible causes of a paralytic ileus. The goal of repletion should be a potassium level of 4 mEq/L and a magnesium level of 2 mEq/L. Of note, the potassium should be repleted prior to the magnesium when both electrolytes are deficient. Another common, yet often reversible, cause of a paralytic ileus is one that is secondary to opiate use. It is not uncommon for patients to be on either intravenous or oral opiate regimens for pain control in the postoperative period. Opioids contribute to postoperative gastrointestinal dysmotility by decreasing the normally coordinated movement of the gastrointestinal tract. This may be prevented, or abated, by minimizing the use or stopping the use of narcotic medications or by substituting non-opiate medications for pain management, such as NSAIDs. Alternatively, the use of methylnaltrexone, a peripherally acting μ-opioid receptor antagonist, by subcutaneous injection, can mitigate the effects of opiates and help to promote a bowel movement. Further management techniques for postoperative paralytic ileus involve making the patient "nil per os" NPO or insertion of a nasogastric tube if the patient is suffering from vomiting. The use of rectal enemas and suppositories will also stimulate the bowel; the use of the rectal tube is controversial. If the patient is bed bound, frequent turning is necessary. Otherwise, the patient should be encouraged to get out of the bed to sit in a chair or ambulate, since movement will aid in the recovery of bowel motility.

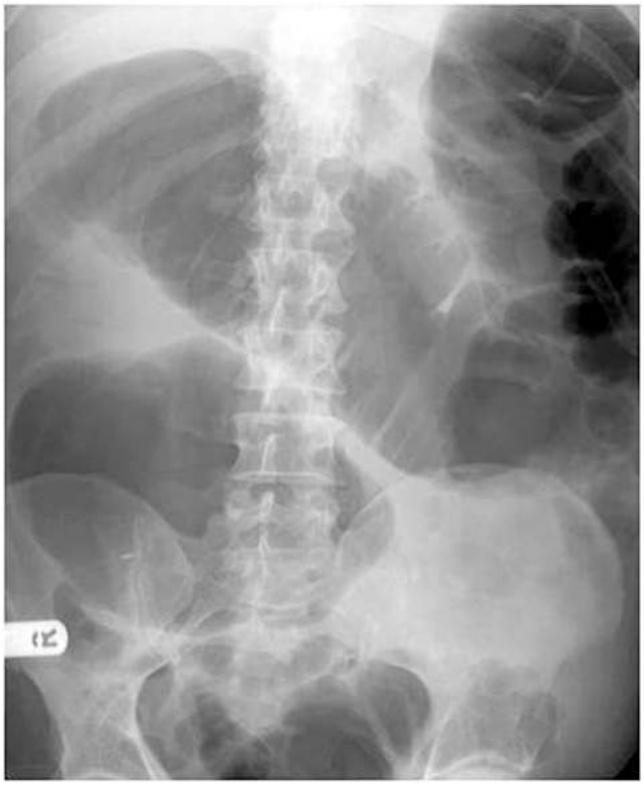

**Fig. 15.1** Massive colonic distention

The abdominal X-rays should indicate the severity of the ileus. If there is massive colonic distention on the abdominal X-ray (Fig. 15.1), the differential includes acute intestinal pseudo-obstruction, or *Ogilvie's* syndrome (toxic megacolon), often secondary to *Clostridium difficile* infection. If *C. difficile* has been excluded with a stool sample, and if a mechanical obstruction has been ruled out with CT imaging, then one should proceed with management of the *Ogilvie's* as discussed previously. It should be noted that with *Ogilvie's* syndrome, there is a 3 % perforation rate; 40 % of such patients die [14]. Morbidity depends on both the diameter of the distended colon as well as the length of time the colon remains distended. The perforation risk increases with a cecal diameter of $<10$ cm, so that pharmaceutical or colonoscopic decompression should be considered in those cases. Similarly, decompression is often

necessary in cases where the cecal diameter does not decrease with 72 h of conservative treatment.

If the patient has not responded to methylnatrexone and a mechanical obstruction has been excluded, then neostigmine, a cholinesterase inhibitor, should be used in consultation with a gastroenterologist. Bradycardia is the most significant side effect of neostigmine, and thus the patient must be in a monitored setting and all electrolyte abnormalities should be corrected. More than 90 % of patients respond within 4 min. If the patient fails to respond to an initial dose of neostigmine, a second dose may be given. Serial abdominal exams and follow-up abdominal X-rays should be obtained since the ileus may reoccur. Alternatively colonoscopic decompression may be attempted but is a second choice. It is prudent to involve the general surgeons as surgical decompression may be required.

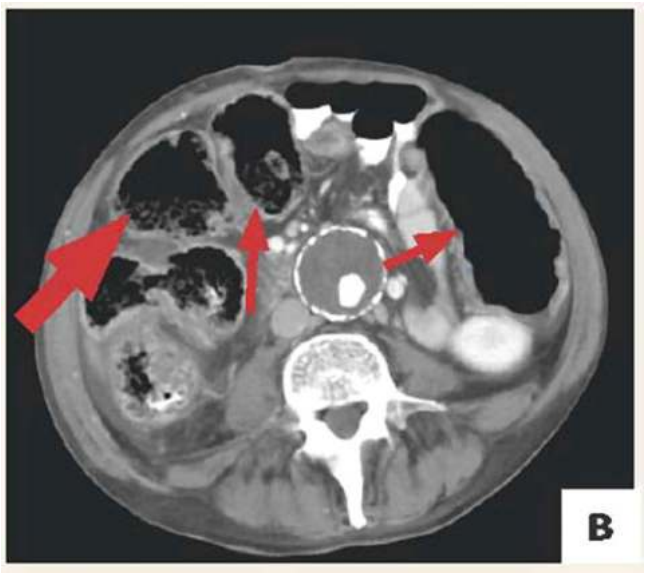


**Fig. 15.2** Pneumatosis

## *Clostridium difficile* Colitis and Postoperative Diarrhea

As noted previously, infection with *Clostridium difficile* should be in the differential diagnosis in the postoperative patient with abdominal distention. In mild cases, *C. difficile* may present with diarrhea and an elevated white blood cell count; more severe cases, which tend to occur in elderly debilitated individuals, can progress to toxic megacolon requiring colectomy. In this setting, thickening of the colonic wall may be seen along with air in the wall of the colon (pneumatosis) on CT scanning (Fig. 15.2). If a colonoscopy or a flexible sigmoidoscopy is performed, the endoscopist may see pseudomembranes (Fig. 15.3).

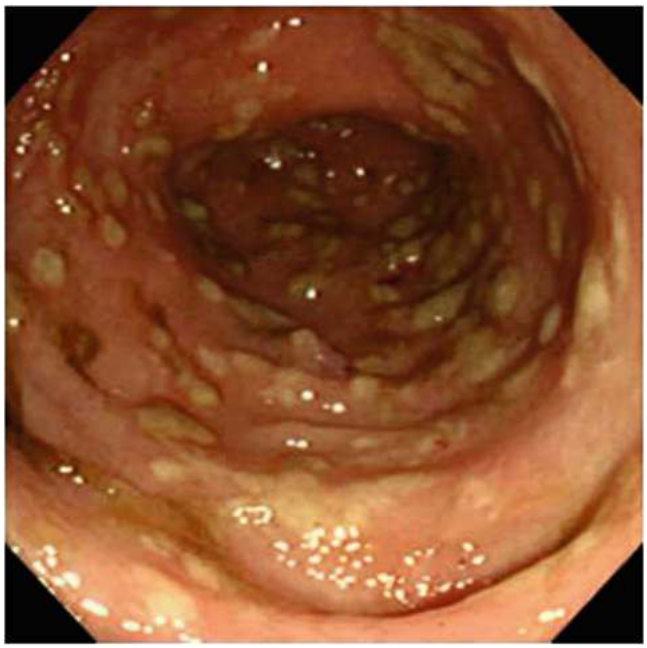

**Fig. 15.3** Pseudomembranes

Cases of *C. difficile* are most often seen in patients who had received antibiotics in the perioperative period or those who have had recent stays in a hospital or a rehabilitation facility. Although unusual, such infections can arise in patients who have received no antibiotics at all. Diagnosis is made via stool sampling for PCR detection of toxins. A single negative stool for *C. difficile* by PCR suffices to rule out *C. difficile* infection. Any postoperative patient with significant diarrhea should undergo an infectious work-up. The most important test is that for "*C. diff*." With rare exception, there is no role for sending stool for ova and parasites since these are not acquired in hospital. Leukocytosis is often associated with a *C. difficile* infection. If the work-up is negative for *C. difficile*, one should consider an antibiotic-associated diarrhea non-*C. difficile* related. Mild cases may simply reflect carbohydrate malabsorption due to changed gut flora, but other pathogens such as *Staphylococcus aureus* [15] or *Klebsiella oxytoca* [16] have been implicated as causative agents in antibiotic-associated diarrhea.

Once a positive *C. difficile* toxin has been confirmed, or if it appears that the diarrhea is secondary to an antibiotic-associated diarrhea, the first step is to discontinue the offending antibiotic. Antibiotics that are more likely to result in *C. difficile* infection are clindamycin, ampicillin, and quinolones. If an antibiotic is needed, guided by sensitivities, then sulfamethoxazole–trimethoprim is a good alternative. Mild cases of *C. difficile* can be treated with oral metronidazole. More severe cases, particularly in the setting of toxic

megacolon from *C. difficile*, should be treated with the combination of oral vancomycin and intravenous metronidazole. A new antibiotic, fidaxomicin, that appears to be equivalent to vancomycin but with lower recurrence rates has recently been approved. Fecal transplant has the highest rate of success, but the logistics make this difficult [17]. Anti-motility agents should be avoided. A general surgery consult is prudent if there is concern for toxicity or poor response to medical therapy. Surgery may be necessary if there is associated hypotension, an elevated lactate level, and worsening dilation of the colon on abdominal imaging. Of note, the toxin may remain positive for months so that follow-up stool studies are not indicated if the diarrhea has resolved. In the setting of an antibiotic-associated diarrhea with a negative *C. difficile* toxin, the diarrhea will often resolve without treatment. In an effort to prevent *C. difficile* infections, probiotics are commonly given along with antibiotics. The most frequently prescribed is the fungus *Saccharomyces boulardii*. Data for its efficacy are equivocal.

## Postoperative Gastrointestinal Bleeding

Orthopedic patients, particularly those undergoing total joint arthroplasty, are almost universally placed on anticoagulation or antiplatelet agents for prophylaxis of deep vein thrombosis. Additionally, NSAIDs are often given for pain management postoperatively, and patients may also have been taking them regularly in the preoperative setting for joint discomfort. Thus, given the iatrogenic coagulopathic state of these patients, one must be attuned to the potential outcome of gastrointestinal bleeding in the postoperative state of an orthopedic patient.

The initial assessment of a GI bleed is focused on the location and determination of the characteristics of the bleeding. The history involves an assessment of a coagulopathic state, usually an active exposure to such medications as aspirin, coumadin, NSAIDS, clopidogrel, and dabigatran. Additionally, if the patient has a history of cirrhosis, then portal hypertension with esophageal or gastric varices should be considered as a potential bleeding source. The type of bleeding, whether it is hematemesis, melena, or hematochezia, should be explored. A rectal exam with fecal occult blood testing is often necessary. As part of the physical examination, vital signs, noting specifically blood pressure and heart rate, should be measured to determine hemodynamic stability. Care should be taken to ensure that the patient has proper intravenous access. At this point, if the patient shows evidence of GI bleeding, it is prudent to prevent the patient from taking any food or water by mouth. Blood should be drawn in order to measure a complete blood count and coagulation profile as well as type and cross for possible transfusion. A GI consult should be called.

The nature of the bleeding helps to determine the source of the bleeding. If the patient presents with either hematemesis or melena, an upper gastrointestinal source of the bleeding is likely. The differential includes peptic ulcer disease, which can occur in the setting of aspirin, clopidogrel, and/or NSAID use, esophageal variceal bleeding with cirrhosis as mentioned previously, and also arteriovenous malformations, gastritis, esophagitis, or even underlying malignancy. A common scenario is the postoperative patient experiencing nausea and coffee ground emesis. In the setting of a suspected upper GI bleed, one should give bolus proton pump inhibition followed by intravenous drip, a treatment shown to accelerate the resolution of ulcer bleeding and reduce the need for endoscopic therapy [18, 19]. These patients often require upper endoscopy for further evaluation and possible treatment. Patients placed on aspirin, coumadin, or NSAIDs after surgery may benefit from simultaneous proton pump inhibitor therapy by mouth daily, added for its gastro-protective effect against bleeding.

If a patient presents with hematochezia or frank bright red blood per rectum, a more distal bleeding source, such as the colon, is probable. The differential includes diverticulosis, ischemic colitis, or hemorrhoidal bleeding. Any of these conditions can be exacerbated by the medications listed previously. Depending on the clinical picture and the timing of the patient's bleeding, a colonoscopy may be indicated. A gastrointestinal consultant will dictate the remainder of the management.

## Summary

There are several relatively frequent GI/liver issues that may arise in the perioperative management of orthopedic patients. Some, such as abnormal preoperative liver function studies, are often benign; however, other conditions, specifically cirrhosis, are important to define before surgery is performed. In addition, a number of gastrointestinal problems may arise postoperatively ranging from nausea and vomiting through to more severe conditions such as abdominal ileus and *C. difficile* colitis. Physicians involved in postoperative care need to be attuned to these conditions, many of which may be subtle at first but quickly evolve and produce severe morbidity. This chapter reviews the most common and potentially severe of the postoperative gastrointestinal problems. The best strategy for avoiding and

dealing successfully with these perioperative complications is prevention, anticipation, and early therapy.

**Summary Bullet Points**

- Abnormal liver tests noted preoperatively should be evaluated so that the presence or the absence of cirrhosis can be determined as well as the acuity, etiology, and severity of any hepatic inflammation.
- Postoperative distention may reflect simple constipation, pseudo-obstruction (*Ogilvie's* syndrome), or megacolon from *C. difficile* colitis. The treatment differs depending on the cause, so a correct diagnosis is crucial to a good outcome.
- Postoperative bleeding is usually minor and will respond to acid reduction therapy. More significant bleeding will require a gastroenterologist for endoscopic evaluation.
- Postoperative nausea and vomiting are usually medication related and respond to appropriate change in medication and antiemetic treatment.

## Case Studies

Case studies for this chapter are included in Appendix J at the end of this book.

## References

1. Inannou GN, Boyko EJ, Lee SP. The prevalence and predictors of elevated serum aminotransferase activity in the United States in 1999–2002. Am J Gastroenterol. 2006;101(1):76–82.
2. O'Shea RS, Dasarathy S, McCullough AJ. Alcoholic liver disease. Hepatology. 2010;51(1):307–28.
3. Frye JW, Perri RE. Perioperative risk assessment for patients with cirrhosis and liver disease. Expert Rev Gastroenterol Hepatol. 2009;3(1):65–75.
4. Teh SH, Nagorney DM, Stevens SR, et al. Risk factors for mortality after surgery in patients with cirrhosis. Gastroenterology. 2007;132:1261–9.
5. Costa BP, Sousa FC, Serodio M, Carvalho C. Value of MELD and MELD-based indices in surgical risk evaluation of cirrhotic patients: retrospective analysis of 190 cases. World J Surg. 2009;23:1594–8.
6. Farnsworth N, Fagan SP, Berger DH, Awad SS. Child-Turcotte-Pugh versus MELD score as a predictor of outcome after elective and emergent surgery in cirrhotic patients. Am J Surg. 2004;188:580–3.
7. Cohen SM, Te HS, Levitsky J. Operative risk of total hip and knee arthroplasty in cirrhotic patients. J Arthroplasty. 2005;20:460–6.
8. Moon YW, Kim YS, Kwon SY, Kim SY, Lim SJ, Park YS. Perioperative risk of hip arthroplasty in patients with cirrhotic liver disease. J Korean Med Sci. 2007;22:223–6.
9. Cohen MM, Duncan PG, DeBoer DP, Tweed WA. The postoperative interview: assessing risk factors for nausea and vomiting. Anesth Analg. 1994;78:7–16.
10. Gan T, Sloan F, Dear Gde L, El-Moalem HE, Lubarsky DA. How much are patients willing to pay to avoid postoperative nausea and vomiting. Anesth Analg. 2001;92:393–400.
11. Fund D, Gan TJ. Gastrointestinal system: prevention and treatment of gastrointestinal morbidity. In: Newman MF, Fleisher LA, Fink MP, editors. Perioperative medicine: managing for outcome. Philadelphia: Saunders Elsevier; 2008. p. 383–96.
12. Apfer CC, Laara E, Koivuranta M, et al. A simplified risk score for predicting postoperative nausea and vomiting: conclusions from cross-validations between two centers. Anesthesiology. 1999;91:693–700.
13. Parvizi J, Han SB, Tarity TD, Pulido L, Weinstein M, Rothman RH. Postoperative ileus after total joint arthroplasty. J Arthroplasty. 2008;23(3):360–5.
14. Sunders MD, Kimmey MB. Systematic review: acute colonic pseudo-obstruction. Aliment Pharmacol Ther. 2005;22(10):917–25.
15. Rhee KY, Soave R, Maltz C. Methicillin-resistant Staphylococcus aureus as a cause of antibiotic-associated diarrhea. J Clin Gastroenterol. 2004;38(3):299–300.
16. Kulkarni K, Weine D, Maltz C. Klebsiella oxytoca and antibiotic-associated hemorrhagic colitis. Am J Gastroenterol. 2008;103:S226.
17. van Nood E, Vrieze A, Nieuwdorp M, et al. Duodenal infusion of donor feces for recurrent Clostridium difficile. NEJM. 2013;368(5):407–15.
18. Cappell MS, Friedel D. Initial management of acute upper gastrointestinal bleeding: from initial evaluation up to gastrointestinal endoscopy. Med Clin North Am. 2008;92(3):491.
19. Lau JY, Leung WK, Yu JCY, et al. Omeprazole before endoscopy in patients with gastrointestinal bleeding. NEJM. 2007;356:1631–40.

# Perioperative Care of the Orthopedic Patient with Neurological Disease

16

Dale J. Lange, Alexander Shtilbans, Brion Reichler, and Dora Leung

**Objectives**

- To appreciate the disparate array of neurological conditions that may be seen in the perioperative period.
- To recognize the significant postoperative morbidity associated with these conditions.
- To appreciate the impact of these conditions and complications on postoperative functional recovery.
- To appreciate the antecedents and predictors of postoperative cognitive dysfunction, a common complication of surgery in the elderly.
- To learn about the management of such important perioperative problems such as stroke, Parkinson's disease, and postoperative neuropathy, a relatively common occurrence after lower extremity arthroplasty.

**Key Points**

- Neurologic conditions of a chronic nature as well as those arising in the postoperative period present important challenges to the orthopedic surgeon and perioperative physician alike.
- When these arise de novo in the postoperative period, they challenge all involved in the care of these patients and, indeed, threaten the benefit of the surgery.
- An effective approach to the preoperative assessment and postoperative management of neurological conditions is essential.
- Conditions such as cerebrovascular disease, Parkinson's disease, multiple sclerosis, myasthenia gravis, the muscular dystrophies, epileptogenic disorders, cerebral aneurysms, and arteriovenous malformations are important and challenging, as are the postoperative complications of stroke, postoperative cognitive dysfunction, delirium, and, in lower extremity surgery, the development of acute neuropathy.

## Introduction

Patients with chronic neurological conditions and those at risk for postoperative neurological complications tend to be older, sicker, and more functionally compromised than the general surgical population. With the aging of the population, more patients of advanced age are undergoing surgery; further the number of patients with comorbid neurological diseases is also on the rise. Owing to these considerations, chronic neurological disease and an array of postoperative neurological complications are frequently encountered in the perioperative setting. Such problems involve a wide range of neurologic conditions including those of a neurovascular, neurodegenerative, and neuromuscular nature. This chapter reviews the implications of these conditions in the orthopedic setting.

D.J. Lange (✉) • A. Shtilbans • D. Leung
Department of Neurology, Hospital for Special Surgery/Weill Cornell Medical College, 535 E70th Street, New York, NY 10021, USA
e-mail: langed@hss.edu

B. Reichler
Department of Neurology, Hospital for Special Surgery, 525 E 71st Street, 5th Floor, New York, NY 10021, USA

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_16, © Springer New York 2014

## The Preoperative Evaluation

The preoperative evaluation of the patient with preexisting neurological disease begins with a thorough clinical assessment the intent of which is to clarify the etiology and severity of the underlying neurologic condition and to ensure it is optimally controlled. This requires a thorough understanding of the pathophysiology of each patient's neurological condition, its treatment, and the patient's capacity to functionally recover from the surgical procedure. Due to the heterogeneity of the neurological comorbidities, the impact of the preoperative decisions may be wide-ranging influencing such considerations as perioperative medication management, the anesthetic agents and techniques employed and, particularly in the orthopedic setting, the patient's capacity to rehabilitate from surgery.

Owing to the frequency of postoperative cognitive dysfunction (PCD) in elderly patients undergoing surgery, the patient and their family members should be asked about a history of ongoing medical conditions (e.g., diabetes or lumbar stenosis which may predispose to developing complications after joint replacement as noted later in this chapter), prior cognitive problems in the postoperative or illness setting, prior medication reactions, subtle evidence of cognitive impairment, and remote neurologic issues, such as stroke, seizure, or head trauma. It is imperative to take an accurate history of alcohol and standing sedative use, and the latter should generally be continued through the initial postoperative period. A full neurologic examination, including mental status, is indicated, especially in patients at risk. Useful screening tools for cognitive dysfunction include the mini-mental status examination and assessment of verbal fluency. Evidence of a subtle upper motor neuron lesion should be sought (facial asymmetry, pronator drift, tendon reflex asymmetry, Babinski sign). Abnormalities in gait, previous unprovoked falls, and problems with tremor are also important to identify preoperatively. Preoperative counseling about the possibility and natural history of POD can spare much anguish later on.

Although the preoperative laboratory and general medical assessment also impart important information to the neurologist, these considerations are discussed in detail in other sections of this book. Usually the neurologist is consulted to advice regarding the presence of a specific neurological condition or a perceived heightened risk for problems of a neurological nature, most often the risk for postoperative stroke. Although falling within the general designation of neurological disease, the underlying pathophysiology, clinical manifestations, and treatment of these conditions are disparate. Hence they are examined herein separately.

## Assessment of Perioperative Risk

### Cerebrovascular Diseases

Atherosclerotic cerebrovascular disease is amongst the most common phenomenon of aging, the major consequence of which is stroke. Although the prevalence of stroke in the postoperative orthopedic setting is low, its consequences can be so serious such that stroke is still amongst the most feared potential complications of surgery.

The risk factors for postoperative stroke can be divided into three groups (Table 16.1): patient-related, intraoperative, and postoperative factors. Patient-related risk factors include age ($\geq$62 years), chronic hypertension, myocardial infarction (<6 months of surgery), renal failure (acute or on dialysis), history of stroke or transient ischemic attack (TIA), history of peripheral vascular disease or carotid stenosis, COPD or current smoker, and abrupt discontinuation of antithrombotic therapy prior to surgery. The risk for perioperative stroke can be stratified based on these risk factors; patients $\leq$2 risk factors are at low risk, those with 3–4 risk factors are at moderate risk, and those with $\geq$5 risk factors are considered high risk (OR = 21 of having a stroke compared with those with no risk factors). Not included in this list is untreated atrial fibrillation, a condition with a 15 % annual risk of stroke.

### Neurodegenerative and Neuromuscular Diseases

Amongst the significant diseases falling within these diagnostic categories include Parkinson's disease, multiple sclerosis, myasthenia gravis, and the muscular dystrophies. Table 16.2 summarizes various relevant considerations having to do with perioperative risk. Given the distinct underlying pathophysiologies involved across these disorders, surgical risk modification is distinct for each condition. If there is a common thread, it is the pulmonary risk conferred by these conditions, the mechanisms of which also vary according to the specific pathophysiology involved. Therefore, in addition to the involvement of the neurologist, pulmonary and preoperative anesthesiology consultation may be prudent in such patients.

### Epileptogenic Disorders

Epilepsy, a disorder of recurring seizures, has a prevalence of 0.5–2.0 % of the general population and thus is not rare in the perioperative setting. Challenging to the anesthesiologist, the

**Table 16.1** Risk factors for postoperative stroke

| |
|---|
| *Preoperative (patient-related) risk factors* |
| Advanced age (>70 years) |
| Female sex |
| History of hypertension, diabetes mellitus, renal insufficiency (creatine, >2 mg/dl [177 μmol/l]), smoking, chronic obstructive pulmonary disease, peripheral vascular disease, cardiac disease (coronary artery disease, arrhythmias, heart failure), and systolic dysfunction (ejection fraction, <40 %) |
| History of stroke or transient ischemic attack |
| Carotid stenosis (especially if symptomatic) |
| Atherosclerosis of the ascending aorta (in patients undergoing cardiac surgery) |
| Abrupt discontinuation of antithrombotic therapy before surgery |
| *Intraoperative (procedure-related) risk factors* |
| Type and nature of the surgical procedure |
| Type of anesthesia (general or local) |
| Duration of surgery and, in cardiac procedures, duration of cardiopulmonary bypass and aortic cross-clamp time |
| Manipulations of proximal aortic atherosclerotic lesions |
| Arrhythmias, hyperglycemia, hypotension, or hypertension |
| *Postoperative risk factors* |
| Heart failure, low ejection fraction, myocardial infarction, or arrhythmias (atrial fibrillation) |
| Dehydration and blood loss |
| Hyperglycemia |

Used with permission from Selim M. Perioperative Stroke. NEJM 2007;356(7):706–13

**Table 16.2** Neurodegenerative, neuromuscular, and muscular dystrophy disorders

| | Parkinson's disease | Myasthenia gravis | Multiple sclerosis | Muscular dystrophy |
|---|---|---|---|---|
| Classification | Movement disorder | Neuromuscular disease | Demyelinating disease | Myopathic disease |
| Pathophysiology | Cell death in midbrain (substantia nigra) | Autoimmune modulated disease by antibodies that block the acetylcholine receptor | Autoimmune-mediated damage to CNS and spinal cord | Inherited x-linked affecting skeletal muscle |
| Perioperative considerations | • ↓ Respiratory capacity<br>• ↑ Atelectasis<br>• ↑ Respiratory failure<br>• ↑ Aspiration<br>• ↑ Delirium<br>• ↓ Rehab capacity | • ↑ Respiratory failure<br>• Resistance to depolarizing muscle relaxants<br>• Sensitive to nondepolarizing muscle relaxant | • Surgery may exacerbate<br>• Sensitivity to pyrexia (avoid)<br>• Diaphragmatic paralysis<br>• ↑ Aspiration<br>• Autonomic dysfunction (BP)<br>• Bowel, bladder dysfunction | • ↓ Respiratory capacity<br>• ↑ Respiratory failure<br>• Associated cardiomyopathy<br>• ↑ Malignant hyperthermia<br>• Muscle damage, hypercalcemia with volatile anesthesia and succinylcholine |
| Management considerations | • Pulmonary function studies<br>• Initiate longer acting anti-Parkinson's therapy pre-op | • PFTs/ABG in high-risk patients<br>• Steroids, IVIg, plasmapheresis<br>• Titrate anticholinesterase Rx<br>• Avoid drugs acting on neuromuscular junction<br>• Avoid respiratory depressants (barbiturates, benzodiazepines, opioids, propofol) | • Treat pyrexia (ASA, Tylenol)<br>• Avoid warming devices<br>• PFTs/ABG if cervical/thoracic disease<br>• Avoid abrupt withdrawal of Baclofen | • PFTs, ABG<br>• EKG, Echocardiogram<br>• Avoid volatile anesthetics, avoid succinylcholine |

[a]Aminoglycosides, Polymyxins, β-blockers, $Ca^{2+}$ Channel blockers, Procainamide, Phenytoin
Adapted with permission from Kallas PG. Assessing and managing neurovascular, neurodegenerative and neuromuscular disorders. In: Jaffer AK, Grant PJ, editors. Perioperative medicine. New York: Wiley-Blackwell; 2012

primary concern is the risk of aspiration, delayed awakening from anesthesia, and disruption of the wound, all potential postoperative complications of a seizure.

Interactions between the anesthetic agents and antiepileptic drugs, specifically the capacity of various anesthetics to modulate or potentiate seizure activity, are important management considerations [1]. Given the polypharmacy of the perioperative period, medication interactions can alter the concentration of antiepileptic drugs in unpredictable ways. Some may decrease seizure

thresholds, while others alter the amount of circulating anticonvulsant available resulting in either insufficient or excessive anticonvulsant effects. Further suboptimal patient compliance preoperatively is common in epileptic patients augmenting their vulnerability.

### Cerebral Aneurysms and Arteriovenous Malformations

Intracranial vascular anomalies such as aneurysms and arteriovenous malformations (AVMs) are relatively prevalent phenomena occurring in up to 6 and 0.01 % of the population respectively [2]. Although usually stable conditions, their risk of spontaneous bleeding varies according to a number of characteristics, namely the arterial systems in which the lesion arises as well as their size [3]. For instance, aneurysms $<7$ mm arising in the carotid artery are at low risk for bleeding [4]. Aneurysms in the anterior, middle, and posterior (noncavernous) internal carotid arterial systems, with no history of bleeding, exhibit similar risk for hemorrhage. However, the low risk status of these patients is based on their history of an absence of a prior hemorrhage. There is increased risk or rebleeding regardless of the size and location of the aneurysm.

Arterial vascular malformations similarly challenge decision-making though owing to their low prevalence they are encountered much less frequently. The risk they impose remains significant and influenced by such characteristics as prior hemorrhage, age of the patient, and their location, because lesions deep within the brain are of the greatest concern [5].

## Optimization of the Patient with Neurological Disease

### Cerebrovascular Disease

Amongst the modifiable patient-related risk factors are diabetes, hypertension, peripheral vascular disease, smoking, and carotid stenosis, the latter constituting a common neurological dilemma in the perioperative context. As patients with symptomatic carotid stenosis have ipsilateral stroke risk of 26 % over 2 years with medical therapy alone, carotid endarterectomy is recommended for those patients with high-grade (70–90 %) symptomatic carotid stenosis prior to certain surgical procedures such as coronary artery bypass (CABG). Current data do not support benefit of carotid stenting over carotid endarterectomy. For patients with asymptomatic carotid stenosis, the stroke rate from both carotid endarterectomy and general surgery is about 3 %. As such carotid endarterectomy is not recommended prior to the surgical procedure. There are no data regarding relationship between asymptomatic carotid stenosis of any grade with respect to the incidence of perioperative stroke in elective general surgery. However, in patients with known vascular disease such as coronary artery or peripheral arterial disease, it may be prudent to include imaging of the carotid arteries, either with carotid Doppler studies or magnetic resonance arteriography (MRA), as part of preoperative evaluation. If there is hemodynamically significant bilateral carotid stenosis (defined as 70–90 %) using either modality, vascular consultation is advised as endarterectomy may be indicated.

### Epileptogenic Disorders

In patients with a chronic seizure disorder, a careful history emphasizing the frequency and occurrence of breakthrough seizure should be obtained, medication compliance should be discussed and emphasized, and when possible drug levels should be obtained. Preoperatively all anticonvulsants should be continued at their usual dosage, taken on the morning of the surgical procedure, and restarted immediately after surgery.

### Cerebral Aneurysms and Arteriovenous Malformations

The decision to treat high-risk aneurysms or AVMs prior to surgery depends on the nature of the proposed surgery (coronary bypass, carotid surgery) and the attendant need for anticoagulant and antiplatelet therapy postoperatively. From the standpoint of risk associated with the procedures, orthopedic surgery is not especially hazardous in the setting of intracranial vascular pathology. Prophylactic anticoagu lation is, however, standard practice after total joint arthroplasty. The use of low molecular weight heparins (LMWH), rather than Coumadin, may be preferable.

### Postoperative Complications

For the purposes of this review, selected postoperative complications are reviewed. These include stroke, Parkinson's disease, and the peripheral nerve injuries not infrequently seen after total joint arthroplasty. Although included elsewhere in this textbook, the problem of postoperative delirium is also reviewed here from the perspective of the consultant neurologist.

## Postoperative Stroke

Although the incidence of postoperative stroke is low, particularly in the orthopedic setting, it is amongst the most devastating of surgical complications. In addition to its disabling consequences, postoperative stroke is associated with an eightfold risk of (30 day) mortality. Indeed after total hip replacement, a 12 % stroke-related mortality has been reported [6].

The etiology of stroke perioperatively is predominantly ischemia and embolic, accounting for 90 % of strokes. A large study of patients with stroke after coronary artery bypass reported an embolic (from manipulation of the heart or aorta, atrial fibrillation) mechanism as the most common etiology (62 %). Cerebral hypoperfusion, due to combination of arterial stenosis and hypotension, has been reported to be associated with about 9 % of postoperative strokes in cardiac surgery patients [7]. While hemorrhagic stroke is seen in 10–15 % of strokes in the general population, it is reported in only 1 % of patients with stroke after (CABG) surgery. However, other mechanisms may also be at play. These include a hypercoagulable state which can develop immediately postsurgery, either as result of bed rest/arterial stasis or from withholding of antiplatelet/anticoagulants for surgery; air or fat embolism (not uncommon after total knee and hip replacement); paradoxical embolism in patients with patent foramen ovale; and extracranial carotid or vertebral artery dissection.

Perioperative stroke occurs in a bimodal distribution: half are identified within first day postsurgery; the remaining half occurs after the second postoperative day, even if there appears to be an uneventful recovery from surgery. Postoperatively patients are at greatest risk for stroke within the first week.

Many older patients who undergo elective surgeries are on oral anticoagulants, and for those patients the risk of thromboembolic events when taken off anticoagulation must be balanced with the risk of bleeding perioperatively. Atherothrombotic events and stroke rates are lower in patients with atrial fibrillation who are on Coumadin but stopped prior to surgery, compared with controls without prior anticoagulation; however, they also suffer more major bleeding events. The risk of severe bleeding with the new oral anticoagulants dabigatran (Pradaxa) and rivaroxaban (Xarelto) is reportedly similar to patients who used LMWH and similar or lower than those patients with atrial fibrillation on Coumadin.

The incidence of antiplatelet use in the perioperative setting is high because of the high prevalence of cardiac disease in the elderly population. Aspirin is effective for primary as well as secondary prevention of cardiac and cerebrovascular disease, but also carries with it an increased bleeding risk during surgery. Studies have shown that patients taking aspirin have an increased risk of bleeding but no increase in morbidity or mortality. Patients on clopidogrel (Plavix) who stopped the medication 5 days before surgery experienced more perioperative bleeding complications and strokes when compared with controls. Therefore the discontinuation of antiplatelet therapy is not recommended because of associated rebound phenomena that promote thrombosis. Guidelines provided by the American College of Chest Physicians (ACCP) recommend that oral anticoagulants such as warfarin be stopped 5 days prior to major surgery, followed by the institution of shorter acting heparin preparations. This so-called bridging anticoagulation employs either subcutaneous LMWH or IV unfractionated heparin. In the case of the former (LMWH), the last dose is given the morning of the day before surgery (that is it should be stopped 24 h before the procedure); IV heparin is stopped 4–6 h before surgery. Pradaxa does not need to be stopped before minor surgery but should be held 1–5 days before major surgery, depending on the bleeding risks and patient's renal function; it can be resumed 1–4 h after surgery if the wound is stable and an epidural catheter is not in place. Xarelto should be stopped 48–72 h before surgery. Perioperative discontinuation of aspirin therapy is discouraged, especially if it is used for secondary prevention. If ASA must be stopped for surgery, it is recommended to restart it 24 h after surgery. The Antiplatelet Agents in Perioperative Management of Patients Trial is ongoing. This study is a randomized controlled trial of patients undergoing general or abdominal surgery in which ASA is held from 5 days before to 5 days postsurgery, their outcome compared with the control group that did not discontinue aspirin. This study should help define the optimal approach to this common clinical dilemma.

Intraoperative risk factors for stroke have also been identified which include the type of surgery, with cardiovascular surgeries having higher risk, as well as duration of surgery, hypotension, hypertension, and cardiac arrhythmias. General anesthesia has been associated with more stroke complications then regional anesthesia. Patients undergoing CABG with higher mean arterial pressure (MAP) (80–100 mg) have fewer strokes compared to those with lower MAP (50–60 mg). Hypotension has been associated with increased stroke risk. In the POISE trial, extended-release metoprolol was given to patients with known atherosclerotic disease undergoing noncardiac surgery. The treatment group had fewer cardiac events but had more deaths overall. Further the stroke rate was doubled in the treatment group (1 %) vs. placebo group (0.5 %). In a study of patients undergoing noncardiac, non-neurosurgical procedures, a decrease in MAP >30 % below baseline was associated with increased risk of postoperative stroke [8].

Intra- and postoperative hyperglycemia is associated with increased incidence of atrial fibrillation, stroke, and death

making tight control of glucose in the perioperative period essential. Postoperative atrial fibrillation peaks about 2–3 days postsurgery, and can occur in up to 25–40 % of patients with CABG as well as valvular surgeries. About half revert spontaneously to sinus rhythm within 24 h; 90 % are in sinus rhythm by day 8. If atrial fibrillation continues after 48 h, heparin should be given to high-risk patients if the wound allows, followed by warfarin stopping the latter 30 days after converting to sinus rhythm.

In patients who develop stroke perioperatively, emergent imaging of the brain to determine etiology (hemorrhagic or ischemic) is important. Patients who had major surgery within the preceding 14 days are not eligible for IV tissue Plasminogen Activator (t-PA); intra-arterial thrombolysis is a potential option, and can be administered up to 6 h post-stroke onset. Mechanical thrombolysis using devices such as the Merci device can also be used when IV t-PA is contraindicated and can be used for up to 8 h after stroke symptom onset, later in basilar artery occlusion, as prognosis is so grim for that diagnosis.

## Managing Patients with Parkinson Disease in the Hospital Setting

Parkinson's disease (PD) is a second most common neurodegenerative disease with disability ranging from mild to severe. Approximately 1 % of the population over the age of 60 has PD with a male predominance of 3:2 [9]. While management issues related to PD itself do not typically necessitate hospital admission, patients with PD are hospitalized for a variety of other reasons including surgery. Managing PD in the in-patient medical and surgical setting can be challenging; the disruption of medication schedules, NPO status, reduced mobility, and use of certain medications can exacerbate the symptoms of this condition and lead to various complications.

An important concern for PD patients in the perioperative setting is to maintain their previously prescribed medication schedule. Most patients are taking carbidopa/levodopa, or other dopaminergic therapy such as dopamine agonists (ropinirole and pramipexole) or MAO-B inhibitors (selegiline or rasagiline) [10, 11]. Delays and alterations in the PD medication regimen may increase morbidity, prolong recovery, and lengthen hospital stay. An abrupt cessation of dopaminergic drugs (especially levodopa) can be life threatening, leading to Parkinsonism Hyperpyrexia syndrome. This presents in a fashion similar to neuroleptic malignant syndrome with altered mental status, rigidity, tremors, fevers, and autonomic dysfunction. The incidence of this condition is 4 %; mortality is reported at 4 % in treated patients and 20 % for those who do not receive treatment [12].

The exact timing of drug administration is important and varies from one patient to another. If a patient cannot receive anti-Parkinsonian medications by mouth or via a feeding tube, one may consider using apomorphine subcutaneously or rotigotine transdermally [13]. However, these should be used as a temporary bridge until the patient can return to their home regimen. MAO-B inhibitors, in contrast, should be stopped 1–2 weeks prior to elective surgery. This will decrease the risk of perioperative hypertension and analgesia overdose [14].

Caution should be taken when using anti-emetics and neuroleptics. Metoclopramide and prochlorperazine should be avoided, while domperidone, trimethobenzamide, and ondansetron may be used [13, 15]. Typical and some atypical antipsychotics may also worsen Parkinsonism, including haloperidol, risperidone, olanzapine, aripiprazole, and ziprasidone. If needed, quetiapine and clozapine can be used in PD patients [10].

PD patients are more prone to infections, particularly pneumonias and urinary tract infections, and should be closely monitored for such problems [8, 16]. They are also more likely to have autonomic disturbance as part of their underlying pathology or as a side effect of PD medications (orthostatic dysregulation), which can be exacerbated by dehydration [17]. Thus adequate hydration is essential and should be provided before adjusting PD medications.

Psychiatric disturbances are also common in advanced PD, as well as other Parkinsonian syndromes such as Parkinson's and Lewy body dementia. Symptoms may include agitation, hallucinations, paranoia, delusions, and sundowning. A rapid worsening of PD symptoms with alterations in mental status is most commonly due to a toxic-metabolic cause including infectious and metabolic derangements which should be investigated [18]. If found the underlying cause should be treated before making any adjustments to PD medications. Finally, physical therapy is essential in all PD patients and will help to increase mobility and decrease recovery time.

## Postoperative Neuropathy

Leg weakness after hip or knee surgery is a common cause for neurological consultation in the postoperative setting. Weakness of the ankle (foot drop) is an area frequently affected. Foot drop is associated with a variety of surgical procedures, including cervical and lumbar spine surgery [19] as well as knee [20] and hip [21] replacement. Simply having surgery is thought to be a rare cause of an autoimmune inflammatory neuropathy than can cause foot drop [22].

Foot drop occurs most often after hip surgery with a prevalence of 0.17–1.9 % of patients undergoing total hip

arthroplasty [23, 24]. The nerves affected include the sciatic (71–100 %), femoral (0–20 %), and obturator (rare but one series reported 7 % involvement). When the sciatic nerve is involved, the peroneal division is most often affected [25]. Risk factors include revision surgery [23], co-existing lumbar spinal stenosis [26], preexisting peripheral neuropathy, younger age, and smoking.

Femoral neuropathy also occurs after THA. The incidence after primary THA is 0.1–2.4 % and it is higher after revision procedures (0.3–3 %) [27]. It may also occur after hip arthroscopy and lumbar spine surgery. Causes include iatrogenic/mechanical factors (trauma, cement, heat) [28], hip dysplasia [26], difficulty of the surgery and positioning, leg lengthening, surgical approach (anterior) [29], and compression from hematoma [30–32]. Women may experience this complication more than men, but the reason is uncertain. The reason why neuropathy occurs more often after revisions is uncertain but it may be related to the more extensive dissection through scar tissue required in these procedures as well as possible tethering of the nerve by scar tissue.

Obturator and superior gluteal nerve injuries rarely occur in association with THA but have been reported. Gluteal injuries may occur in association with the direct lateral approach. Obturator nerve injuries are often undiagnosed and cause inguinal or groin pain.

Neuropathy after total knee arthroplasty (TKA) is also unusual (0.3–1.3 %) but some studies suggest risk factors to include preoperative valgus deformity, postoperative epidural anesthesia, rheumatoid arthritis, preexisting neuropathy, use of tourniquet, and hematoma formation at the wound site [33, 34]. Patients usually have weakness immediately after surgery, manifested as difficulty moving their toes if the sciatic nerve is involved. Weak muscles and sensory loss in the distribution of the peroneal division of the sciatic nerve are typical. The reason that the peroneal division is more affected than the tibial division is not known, though it is thought the density with which the axons are packed in the peroneal division is significantly greater than that of the tibial nerve providing a potential explanation for the differences that mechanical forces might exert. Nevertheless, muscles innervated by the tibial nerve are often affected, just to a lesser extent.

Femoral and obturator nerve dysfunction occur in 0.1–2.4 % of cases and are often detected slightly later in the postoperative period as the subjective awareness of problems with knee movement may not be realized until the patient resumes mobility [24, 35]. Once weakness is detected, a diagnostic search for cause is necessary. Review of blood results looking for markers of diabetes, inflammatory disease, connective tissue disease, or vasculitis is appropriate. An MRI through the site of surgery is necessary to determine if a hematoma might be responsible for the nerve dysfunction. If blood is detected, there is uncertainty as to how to treat, though one study suggests evacuation was associated with better prognosis. MRI of the lumbar spine is also important as identification of lumbar stenosis may herald the presence of a known risk factor for postoperative neuropathy. Nerve conduction studies and needle EMG are useful in confirming the clinical examination, excluding an underlying neuropathy, estimating severity of the nerve damage, and estimating prognosis. For example, sensory nerve potentials in the distribution of sensory loss are usually lost within 7 days after the axons are severed. Denervation potentials (positive sharp waves and fibrillation potentials) occur within 2–3 weeks. Retained sensory potentials and paucity of denervation after these time periods may be harbingers of good prognosis, especially if these findings are replicated on serial studies.

Recovery from weakness associated with THA is poor. However, recover after TKA is good as it is with femoral neuropathy. Intensive rehabilitation for strengthening combined with gait and balance is essential.

## Postoperative Delirium

Alteration of mental status is a common complication of surgery. The question of etiology is problematic, as most cases are probably multifactorial. However, some of these factors may be subject to treatment or modification, and to this extent it is crucial to properly examine and evaluate every patient who develops confusion. At the very least, education of patient and family about the possibility of this complication can greatly ease the stress associated with it.

Best defined as a "global impairment of upper brain functions that involves consciousness, attention, cognition and perception," [36] delirium is by definition transient and fluctuating. It is generally considered to be multifactorial, resulting from the "interaction of vulnerability on the part of the patient... and hospital-related insults" [37]. Typical incidence in noncardiac surgery is in the range of 15–25 % [38].

### Causes

It is helpful to divide this into three separate categories, which correlate roughly to the time course with respect to the surgery: (1) Risk factors, i.e., demographic and other variables predating the surgery (age, gender, medication use, preexisting medical conditions); (2) Perioperative factors, i.e., factors related to the surgery itself or immediate perioperative care – rarely can we speak of a clear-cut "etiology"; and (3) Aggravating factors, those often modifiable medical or environmental conditions present following surgery, in the day(s) leading up to the onset of delirium. In addition to older age, the occurrence of multiple

systemic medical condition places individuals at increased risk. Chief among these are preexisting brain disorders, including dementia, Parkinson's disease, and prior stroke. Also important are impaired sensorium (vision, hearing), multiple medications, specific psychoactive medications, and chronic alcohol or sedative use. Aggravating factors include sleep deprivation and sleep cycle disturbance, unfamiliar environment, immobility, hypovolemia, metabolic derangements, and possibly inadequate analgesia. Of these, the second is perhaps the most disputed.

Intraoperative factors that have been considered include type of surgery, type and duration of anesthesia, and degree of blood loss and/or hypotension. Outside of cardiothoracic surgery, the highest rates of delirium are seen in vascular and orthopedic procedures (particularly after hip fracture) [39]. Duration of anesthesia seems to have at most a mild effect [40, 41]. General anesthesia confers no increase in risk over regional anesthesia [42]. Data on specific agents are difficult to come by. While avoidance of N2O led to fewer major complications in one study [43], there is no clear effect on the incidence of postoperative delirium [40]. Controlled hypotension is a commonly used technique to limit intraoperative blood loss. Two studies [41, 44] found no significant effect on POD, whereas a 2004 literature review did find it to be a risk factor after hip fracture [45]. A large study, randomizing primary hip replacement patients to high and low MAP groups, found a difference in incidence (9 vs. 4 %) that was not statistically significant [46].

Although less common as causes of acute confusional episodes, one must also consider primary neurologic conditions. Stroke usually does not present as a pure confusional syndrome without focal deficits. However, acute stroke is frequently complicated by delirium, and it may be difficult for the nonspecialist to distinguish severe aphasia clinically from a global confusional state [47]. Moreover, certain stroke locations may rarely produce an isolated confusional syndrome. These usually lack the attentional disturbance and fluctuating pattern. Nonconvulsive status epilepticus should be considered whenever there are abrupt changes in consciousness or attentiveness, or in the presence of strange behavior or automatisms. Subtle twitching of the face or extremities may be seen.

Postoperative analgesic use is frequently blamed for POD, but this turns out to be a controversial subject. The use of patient controlled analgesia (PCA) has been correlated with an increased rate of delirium, and a pilot study of gabapentin preoperatively reduced both postoperative opiate use and POD [40, 48]. Higher pain scores are associated with increased POD rate [49]. However, a large prospective study found that the pain effect was primary and that in cognitively intact patients higher rates of POD correlated with lower rates of opiate use [50]. Thus, it remains controversial as to whether excessive analgesic use vs. inadequate analgesia is more likely to be responsible. Medications implicated in a higher rate of POD include those with anticholinergic (e.g., tricyclic antidepressants, amantadine, diphenhydramine) and dopaminergic properties. Corticosteroid and opiate use is also of concern. Benzodiazepines are well known to cause paradoxical agitation, especially in the elderly, and therefore to increase the risk of POD. However, in some series a potential preventive effect has been suggested [41, 51].

## Presentation

Onset is usually between the first and fifth postoperative days, but may occasionally develop preoperatively [36]. Prodromal symptoms of incoherence and mild disorientation may precede frank delirium by 1–4 days. Level of consciousness ranges from normal to moderately impaired, and patients often have reduced awareness of their environment. Attention is impaired. There is often disruption of the sleep–wake cycle. Disorientation to time and place is common. Language is typically normal in form, which helps to distinguish this from aphasia. Perceptual disorders include delusions and paranoia, and in more severe cases, hallucinations. These symptoms usually fluctuate over the course of the day, often being worse at night. Prognosis is excellent for garden-variety "metabolic" and withdrawal cases. Typical recovery is within 10–12 days [36]. However, it may be more prolonged in the elderly and in those with superimposed medical problems or neurodegenerative disease. Moreover, it is not uncommon for POD to "unmask" previously unsuspected dementia, which may have been subclinical. Compared to patients without POD, there is an increase in average recovery time, morbidity and mortality. However, the latter may be an epiphenomenon of the underlying medical factors, and it is not clear that treatment of the delirium alters these complications.

## Evaluation

Patients and their family members should be asked about a history of prior POD, prior medication reactions, subtle evidence of cognitive impairment, and even remote neurologic issues, such as stroke, seizure, or head trauma. At the time of presentation, it is imperative to take an accurate history of alcohol and standing sedative use, and the latter should generally be continued through the initial postoperative period. A full neurologic examination, including mental status, is indicated, especially in patients at risk. Useful screening tools for dementia include the mini-mental status examination and clock face drawing. Evidence of a subtle upper motor neuron lesion should be sought (facial

asymmetry, pronator drift, tendon reflex asymmetry, Babinski sign). Frontal release signs, such as the glabellar reflex, offer a clue to CNS degenerative disease. Preoperative counseling about the possibility and natural history of POD can spare much anguish later on.

It is important to identify treatable factors. The neurologic examination is directed at ruling out a focal lesion suggestive of stroke, post-ictal state, or another structural disorder. Mental status testing may be limited by the attentional deficit, but a prominent disturbance of language despite normal attention is suspicious for a focal syndrome. Asterixis may be present, but is nonspecific for cause. Level of pain control and extent and type of opiate use are assessed. Clarification of baseline mental status can derive from preoperative evaluation or from family members. Among the most common complicating metabolic disturbances are hypovolemia, hyponatremia, and hyperglycemia. The laboratory examination should include an electrolyte and metabolic panel, TSH, B12 and folate level, CBC, and ammonia. In appropriate cases, blood alcohol level, toxicology screen, Lyme serology, and RPR may be ordered. Routine search for infection includes chest X-ray, urinalysis, blood cultures, and assessment of wound infection. Lumbar puncture is rarely indicated on the first pass. Arterial blood gas and VQ scanning may be indicated when clinical suspicion warrants. EEG should be considered when there is a fluctuating level of consciousness or attention, staring spells, or abnormal eye movements [52]. Brain imaging is not always critical on initial evaluation when stroke is not suspected, when the delirium is mild, and when there is a likely alternative explanation.

### Treatment

Although most cases of POD run their course naturally, with supportive measures, more proactive intervention is recommended in order to lessen patient discomfort and anxiety, reduce length of stay (with associated cost and morbidity), and improve management, including hastening the start of physical therapy. Treatment can be divided into prevention, symptomatic treatment, and treatment of underlying disorders. The latter is the most direct, and includes correction of metabolic abnormalities, such as hyponatremia and hyperglycemia. Blood pressure and oxygenation should be maintained, and treatment of other conditions such as suspected infection is self-explanatory. Evaluation and treatment of seizures and stroke are beyond the scope of this chapter. As measurement of thiamine level (function) is impractical, and frank or borderline thiamine deficiency may be more common than realized, we recommend that all POD patients presumptively receive thiamine 100 mg for 3 days [53]. Symptomatic treatment of agitation is generally accomplished with antipsychotic medication, either traditional (e.g., haloperidol) or second-generation (e.g., quetiapine, olanzapine). Benzodiazepines are generally discouraged, particularly in the elderly, as they can cause over-sedation that may confound the lack of responsiveness due to the delirium itself, as well as potentially causing paradoxical agitation. The exception is in the patient with standing sedative use, in whom sudden discontinuation could cause a withdrawal syndrome.

Prevention is complex and multifaceted. Excessive opiate use is generally considered to contribute to many cases of POD, although, as mentioned, inadequate analgesia may also play a role. It is generally best to convert from patient-controlled parenteral analgesia to oral opiates as early in the course as possible. There is preliminary evidence that preoperative treatment with either alternative analgesics (e.g., gabapentin) [54] or antipsychotic medication [55, 56] may reduce the incidence of POD. Prophylaxis should be initiated for potential alcohol withdrawal, and standing sedatives should be continued. Anticholinergic medications should be avoided. Bowel and urinary retention should be minimized. Modification of the environment includes normalization of sleep pattern, increasing mobility, correction of visual and hearing impairment, regular orientation of the patient to time and place, cognitive engagement, and optimization of environmental stimulation [37].

## Summary

Neurologic conditions, both those of a chronic nature as well as those arising in the postoperative period, present important challenges to the orthopedic surgeon and perioperative physician alike. Disparate in their nature, these conditions impose their own restrictions on the functional capacity of those afflicted, and when they arise *de novo* in the postoperative period challenge all involved in the care of these patients and, indeed, threaten the benefit of the surgery. This chapter reviews those neurological conditions that are seen with some frequency in the perioperative orthopedic setting and presents an approach to their preoperative assessment and postoperative management. Certain conditions, specifically cerebrovascular and Parkinson's disease, are especially important and challenging as are the postoperative complications of stroke, postoperative cognitive dysfunction and in lower extremity surgery, the development of acute neuropathy. Due to their importance in the orthopedic surgical setting each of these is discussed with particular attention.

**Summary Bullet Points**

- The preoperative evaluation of chronic neurological disease requires a thorough understanding of the pathophysiology of the condition.
- Chronic neurological disease encompasses a disparate array of conditions with distinct therapies, employing medications that have relevant implications in the perioperative context.
- Parkinson's disease presents distinct challenges in the perioperative period.
- Postoperative cognitive dysfunction frequently arising in the elderly after surgery, challenging management, compromising physical therapy initiatives, and prolonging length of stay.
- Postoperative neuropathy is an important complication after lower extremity surgery.

## References


1. Kofke WA. Anesthetic management of the patient with epilepsy or prior seizure. Curr Opin Anaesthesiol. 2010;23(3):391–9.
2. Sapf C, Mast H, Sciacca RR, et al. The New York Islands AVM Study. Stroke. 2003;l34:e29–33.
3. International Study of Unruptured Intracranial Aneurysms Investigators. Unruptured intracranial aneurysms: natural history, clinical outcome, and risks of surgical and endovascular treatment. Lancet. 2003;362:103–10.
4. Juvela S, Poussa K, Lehto H, et al. Natural history of unruptured intracranial aneurysms: a long-term follow-up study. Stroke. 2013;44(9):2414–21.
5. Stapf C, Mast H, Sciacca RR, et al. Predictors of hemorrhage in patients with untreated brain arteriovenous malformation. Neurology. 2006;66:1350–5.
6. Bateman BT, Schumacher C, Wang S, et al. Perioperative acute ischemic stroke in noncardiac and nonvascular surgery. Anesthesiology. 2009;110:231–8.
7. Likosky DS, Marrin CA, Caplan LR, Northern New England Cardiovascular Disease Study Group, et al. Determination of etiologic mechanisms of strokes secondary to coronary artery bypass graft surgery. Stroke. 2003;34:2830–4.
8. Bijker JB, Persoon S, Peelen LM, et al. Intraoperative hypotension and perioperative ischemic stroke after general surgery: a nested case- control study. Anesthesiology. 2012;116(3):658–64.
9. Fahn S. Description of Parkinson's disease as a clinical syndrome. Ann N Y Acad Sci. 2003;991:1–14.
10. Horstink M, Tolosa E, Bonuccelli U, Deuschl G, Friedman A, Kanovsky P, et al. Review of the therapeutic management of Parkinson's disease. Report of a joint task force of the European Federation of Neurological Societies and the Movement Disorder Society-European Section. Part I: early (uncomplicated) Parkinson's disease. Eur J Neurol. 2006;13(11):1170–85.
11. Fox SH, Katzenschlager R, Lim SY, Ravina B, Seppi K, Coelho M, et al. The Movement Disorder Society Evidence-Based Medicine Review Update: Treatments for the motor symptoms of Parkinson's disease. Mov Disord. 2011;26 Suppl 3:S2–41.
12. Newman EJ, Grosset DG, Kennedy PG. The Parkinsonism-hyperpyrexia syndrome. Neurocrit Care. 2009;10(1):136–40.
13. Brennan KA, Genever RW. Managing Parkinson's disease during surgery. BMJ. 2010;341:c5718.
14. Shaikh SI, Verma H. Parkinson's disease and anaesthesia. Indian J Anaesth. 2011;55(3):228–34.
15. Burton DA, Nicholson G, Hall GM. Anaesthesia in elderly patients with neurodegenerative disorders: special considerations. Drugs Aging. 2004;21(4):229–42.
16. Mu L, Sobotka S, Chen J, Su H, Sanders I, Adler CH, et al. Altered pharyngeal muscles in Parkinson disease. J Neuropathol Exp Neurol. 2012;71(6):520–30.
17. Seppi K, Weintraub D, Coelho M, Perez-Lloret S, Fox SH, Katzenschlager R, et al. The Movement Disorder Society Evidence-Based Medicine Review Update: Treatments for the non-motor symptoms of Parkinson's disease. Mov Disord. 2011; 26 Suppl 3:S42–80.
18. Zheng KS, Dorfman BJ, Christos PJ, Khadem NR, Henchcliffe C, Piboolnurak P, et al. Clinical characteristics of exacerbations in Parkinson disease. Neurologist. 2012;18(3):120–4.
19. Kumar R, Kalra SK, Vaid VK, Mahapatra AK. Bilateral acute foot drop following lumbar disc herniation – a case report. J Indian Med Assoc. 2011;109(11):834–5.
20. Johnson DS, Sharma DP, Bangash IH. Common peroneal nerve palsy following knee arthroscopy. Arthroscopy. 1999;15(7):773–4.
21. Farrell CM, Springer BD, Haidukewych GJ, Morrey BF. Motor nerve palsy following primary total hip arthroplasty. J Bone Joint Surg Am. 2005;87(12):2619–25.
22. Staff NP, Engelstad J, Klein CJ, Amrami KK, Spinner RJ, Dyck PJ, et al. Post-surgical inflammatory neuropathy. Brain. 2010;133(10): 2866–80.
23. Fowble VA, Schmalzried TP. Nerve palsy associated with total hip arthroplast. Semin Arthroplasty. 2005;16:114–8.
24. Fox AJS, Bedi A, Wanivenhaus F, et al. Femoral neuropathy following total hip arthroplasty: review and management guidelines. Acta Orthop Belg. 2012;78(2):145–51.
25. Della Valle CJ, Di Cesare PE. Complications of total hip arthroplasty: neurovascular injury, leg-length discrepancy, and instability. Bulletin. 2001;60(3–4):134–42.
26. Pritchett JW. Lumbar decompression to treat foot drop after hip arthroplasty. Clin Orthop Relat Res. 1994;303:173–7.
27. Nercessioan OA, Ugwonali OFC, Park S. Peroneal nerve palsy after total knee arthroplasty. J Arthroplasty. 2005;20:1068–73.
28. Zwolak P, Eysel P, William-Patrick Michael J. Femoral and obturator nerves palsy caused by pelvic cement extrusion after hip arthroplasty. Orthop Rev (Pavia). 2011;3(1):e6.
29. Lohana P, Woodnutt DJ, Boyce DE. Sciatic nerve palsy – a complication of posterior approach using enhanced soft tissue repair for total hip arthroplasty. J Plast Reconstr Aesthet Surg. 2010;63(4): e400–1.
30. Weil Y, Mattan Y, Goldman V, Liebergall M. Sciatic nerve palsy due to hematoma after thrombolysis therapy for acute pulmonary embolism after total hip arthroplasty. J Arthroplasty. 2006;21 (3):456–9.
31. Austin MS, Klein GR, Sharkey PF, Hozack WJ, Rothman RH. Late sciatic nerve palsy caused by hematoma after primary total hip arthroplasty. J Arthroplasty. 2004;19(6):790–2.
32. Butt AJ, McCarthy T, Kelly IP, Glynn T, McCoy G. Sciatic nerve palsy secondary to postoperative haematoma in primary total hip replacement. J Bone Joint Surg Br. 2005;87(11):1465–7.
33. Yacub JN, Rice JB, Dillingham TR. Nerve injury in patients after hip and knee arthroplasties and knee arthroscopy. Am J Phys Med Rehabil. 2009;88(8):635–41. quiz 42–4, 91.
34. Schinsky MF, Macaulay W, Parks ML, Kiernan H, Nercessian OA. Nerve injury after primary total knee arthroplasty. J Arthroplasty. 2001;16(8):1048–54.
35. Brown GD, Swanson EA, Nercessian OA. Neurologic injuries after total hip arthroplasty. Am J Orthop. 2008;37(4):191–7.

36. Cavaliere F, D'Ambrosio F, Volpe C, Masieri S. Postoperative delirium. Curr Drug Targets. 2005;6:807–14.
37. Inouye SK, Bogardus ST, Charpentier PA, Leo-Summers L, Acampora D, Holford TR, Cooney LM. A multicomponent intervention to prevent delirium in hospitalized older patients. NEJM. 1999;340:669–76.
38. Dyer CB, Ashton CM, Teasdale TA. Postoperative delirium. A review of 80 primary data-collection studies. Arch Intern Med. 1995;155:461–5.
39. Bruce AJ, Ritchie CW, Blizard R, Lai R, Raven P. The incidence of delirium associated with orthopedic surgery: a meta-analytic review. Int Psychogeriatr. 2007;19(2):197–214.
40. Leung JM, Sands LP, Vaurio LE, Wang Y. Nitrous oxide does not change the incidence of postoperative delirium or cognitive decline in elderly surgical patients. Br J Anaesth. 2006;96:754–60.
41. Moller JT, Cluitmans P, Rasmussen LS, Houx P, Rasmussen H, Canet J, Rabbitt P, Jolles J, Larsen K, Hanning CD, Langeron O, Johnson T, Lauven PM, Kristensen PA, Biedler A, van Beem H, Fraidakis O, Silverstein JH, Beneken JE, Gravenstein JS. Long-term postoperative cognitive dysfunction in the elderly ISPOCD1 study. ISPOCD investigators. International study of post-operative cognitive dysfunction. Lancet. 1998;351:857–61.
42. Bryson GL, Wyand A. Evidence-based clinical update: general anesthesia and the risk of delirium and postoperative cognitive dysfunction. Can J Anesth. 2006;53:669–77.
43. Myles PS, Leslie K, Chan MT, Forbes A, Paech MJ, Peyton P, Silbert BS, Pascoe E, ENIGMA Trial Group. Avoidance of nitrous oxide for patients undergoing major surgery: a randomized controlled trial. Anesthesiology. 2007;107:221–31.
44. Marcantonio ER, Goldman L, Mangione CM, Ludwig LE, Muraca B, Haslauer CM, Donaldson MC, Whittemore AD, Sugarbaker DJ, Poss R, et al. A clinical prediction rule for delirium after elective noncardiac surgery. JAMA. 1994;271:134–9.
45. Bitsch MS, Foss NB, Kristensen BB, Kehlet H. Pathogenesis of and management strategies for postoperative delirium after hip fracture. Acta Orthop Scand. 2004;75:378–89.
46. Williams-Russo P, Sharrock NE, Mattis S, Liguori GA, Mancuso C, Peterson MG, Hollenberg J, Ranawat C, Salvati E, Sculco T. Anesthesiology. 1999;91(91):926–35.
47. Ferro JM, Caeiro L, Vedelho A. Delirium in acute stroke. Curr Opin Neurol. 2002;15:51–5.
48. Wang Y, Sands LP, Vaurio L, Mullen EA, Leung JM. The effects of postoperative pain and its management on postoperative cognitive dysfunction. Am J Geriatr Psychiatry. 2007;15:50–9.
49. Lynch EP, Lazor MA, Gellis JE, Orav J, Goldman L, Marcantonio ER. The impact of postoperative pain on the development of postoperative delirium. Anesth Analg. 1998;86:781–5.
50. Morrison RS, Magaziner J, Gilbert M, Koval KJ, McLaughlin MA, Orosz G, Strauss E, SIu AL. Relationship between pain and opioid analgesics on the development of delirium following hip fracture. J Gerontol A Biol Sci Med Sci. 2003;58:76–81.
51. Aizawa K, Kanai T, Saikawa Y, Takabayshi T, Kawano Y, Miyazawa N, Yamamoto T. A novel approach to the prevention of postoperative delirium in elderly after gastrointestinal surgery. Surg Today. 2002;32:310–4.
52. Kolls BJ, Husain AM. Assessment of hairline EEG as a screening tool for nonconvulsive status epilepticus. Epilepsia. 2007;48 (5):959–65.
53. Pepersack T, Garbusinski J, Robberecht J, Beyer I, Willems D, Fuss M. Clinical relevance of thiamine status amongst hospitalized elderly patients. Gerontology. 1999;45:96–101.
54. Leung JM, Sands LP, Rico M, Petersen KL, Rowbotham MC, Dahl JB, Ames C, Chou D, Weinstein P. Pilot clinical trial of gabapentin to decrease postoperative delirium in older patients. Neurology. 2006;67:1251–3.
55. Kalisvaart KJ, de Jonghe JF, Bogaards MJ, Vreeswijk R, Egberts TC, Burger BJ, Eikelenboom P, van Gool WA. Haloperidol prophylaxis for elderly hip-surgery patients at risk for delirium: a randomized placebo-controlled study. J Am Geriatr Soc. 2005; 53:1658–66.
56. Larsen KA, Kelly SE, Stern TA, Bode RH, Price LL, Hunter DJ, Gulczynski D, Bierbaum BE, Sweeney GA, Hoikala KA, Cotter JJ, Potter AW. Administration of olanzapine to prevent postoperative delirium in elderly joint-replacement patients: a randomized, controlled study. Pschosomatics. 2010;51:409–18.

# Perioperative Care of the Patient with Psychiatric Disease

17

John W. Barnhill

**Objectives**

- To better understand the preoperative assessments that can reduce surgical complications, morbidity, and delays
- To better understand the diagnosis and treatment of postoperative psychiatric complications, including delirium, depression, anxiety, and alcohol withdrawal
- To better understand how to make use of a psychosocial team and the psychiatric consultant

**Key Points**

- Psychiatric conditions such as delirium, alcohol withdrawal, and the "difficult patient" are more robust predictors of hospital complications and delayed discharge than virtually any medical or surgical complication.
- Brief psychiatric assessments can reduce the likelihood of these complications.
- By anticipating and then managing complications, the consulting psychiatrist and/or psychosocial team can help the primary surgical team retain its focus on the patient.

## Introduction

Psychiatric and behavioral problems can sabotage the surgeon's best efforts. They delay surgery and discharge, complicate the hospitalization, and undermine rehabilitation. Further, the evaluation and treatment of psychiatric issues require a perspective and fund of knowledge that is different from that which goes into orthopedic surgery.

Fortunately, the majority of psychiatric issues encountered in the perioperative period fall into one of the three basic categories: drugs and alcohol, delirium, and the psychiatrically "difficult" patient. These three categories can overlap but are useful to distinguish. Two additional topics that are of particular concern are capacity to provide informed consent and how to best work with a psychosocial team during the perioperative period.

*Withdrawal and intoxication* can occur from illicit substances and alcohol as well as from medications prescribed by physicians. Withdrawal leads to the most difficulty in the perioperative period, while intoxication is most likely to be involved in orthopedic trauma. Withdrawal can be subtle and cause mild physical and psychological symptoms, but it can also be potentially life threatening. In most populations, alcohol is the most common type of abused substance, though opiates are also commonly used and abused in the chronic pain population.

*Delirium* may be the single most robust predictor of perioperative delays and complications. Also known as encephalopathy and ICU psychosis, delirium is commonly encountered after all types of surgery. Delirium is especially typical in patients who combine multiple risk factors such as advanced age and cognitive decline (e.g., hip fracture repair). The diagnosis of delirium is usually missed, and, when identified, it is often mistreated. Evidence indicates that early and effective recognition and intervention can reduce the incidence and severity of delirium and can reduce the resulting complications and extended lengths of stay [1].

J.W. Barnhill (✉)
Division of Psychiatry, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA
e-mail: Jwb2001@med.cornell.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_17, 

*Psychiatrically difficult patients* have a range of psychiatric diagnoses, including personality disorders, depression, anxiety, and chronic psychosis that may be lifelong or be precipitated by the stress of hospitalization and/or surgery. From a psychiatrist's perspective, this category is overly broad, but, from the perspective of an orthopedist, these patients are presenting with behavioral and psychological difficulties that impede treatment. Regardless of the specific diagnosis and degree of severity or chronicity, the vast majority of these "difficult" patients can be efficiently identified and managed so that the necessary surgery can be successfully performed.

*Capacity to provide informed consent* is evaluated routinely by surgeons prior to doing a procedure. In most circumstances, patients provide informed consent without difficulty. When concerns do arise, surgeons are expected to follow the hospital's guidelines for an independent capacity evaluation. Generally done by either the psychiatric consultation-liaison service or a member of the hospital's ethics committee, the "capacity consult" can pave the way for an efficient hospital course or can contribute to ongoing delays and miscommunications.

*The psychiatric consultant and psychosocial team* may include psychiatrists, psychologists, social workers, nurse practitioners, and a variety of allied health personnel. These colleagues can be helpful for two basic reasons. First, they are focused on a different aspect of patient care than is the surgical team, and, just as surgeries are often complicated, many patients do not spontaneously disclose psychiatric or addiction problems, reveal a history of post-op delirium, or mention that they are likely to be a difficult patient. Secondly, the psychosocial team has both a fund of knowledge and an interest in topics that range from psychopharmacology to adherence strategies that are unlikely to be of primary interest to a surgical team. This chapter discusses ways that the team can develop and make use of a psychiatric or a psychosocial team during the perioperative period.

This chapter focuses on common psychiatric complications of the perioperative period by dividing them into the pre- and postoperative periods.

## Preoperative Assessment

The preoperative assessment already includes a psychiatric assessment. Not always explicit and not requiring the patient to even be conscious, the evaluation includes the team's own reaction to the patient as well as some consideration of whether the patient is liable to cause some sort of trouble. "Trouble" can be almost anything but is most often related to a psychiatric diagnosis such as substance abuse or dementia or it can relate to issues related to informed consent or excessive worries about the surgery. Such patients are disproportionally represented among patients whose perioperative course is marked by delays, cancellations, and complications.

Psychiatric involvement can be useful preoperatively by helping to provide an assessment structure that clarifies risks, provides useful interventions, and reduces later morbidity. Most initial "screens" take just a few minutes and are done by the surgeon or a member of the surgical team. One important principle that underlies such screens is that their primary task is to streamline the surgical intervention and *not* to diagnose and treat every psychiatric diagnosis.

No simple algorithm or roster of questions can replace a tactful and sensitive psychiatric interview, but a handful of straightforward questions will identify most people at risk. While some of these questions can often be elicited by a form or elsewhere in the evaluation process, Fig. 17.1 lists a typical preoperative psychiatric screen.

A psychiatric screen is not without complications. For example, some people will get offended by personal inquiries when they have presented to their surgeon for a different purpose. Other people will take these questions as an opportunity to discuss their problems at great length. Most problematic, however, is that some patients will reveal information about their substance abuse, memory deficits, and suicidal thoughts that will require a response from the surgical team [2]. Without an intact psychosocial team or psychiatric consultant, this will require additional work from the orthopedic team. For that reason, many orthopedic services have employed people whose specific role is to handle psychosocial problems and develop a referral network for patients whose needs extend beyond what can be comfortably handled by the surgical team.

## Preoperative Assessment of Alcohol, Opiate, and Other Substance Abuse

The best way to prevent withdrawal is to do a good drug history. Many patients do not spontaneously report the use of drugs and medications, and so a tactful but skeptical history is essential [3–5]. All substances of abuse should be considered, especially the sedating ones that can cause severe withdrawal symptoms: alcohol, benzodiazepines, and barbiturates. Some commonly used prescribed medications can also cause very unpleasant withdrawals. These include two antidepressant medications, paroxetine (Paxil®, GlaxoSmithKline, Inc.) and venlafaxine (Effexor®, Pfizer), but many drugs from many classes can induce unpleasant withdrawal effects during a several-day restriction of intake by mouth. History should include a focus on withdrawal complications that accompanied prior hospitalizations, since they are likely to recur. Because so many prescribed medications can cause withdrawal symptoms, it is generally

- How are you feeling about the upcoming surgery?
  - Any particular concerns?
- Do you have any particular psychiatric conditions we should know about?
- How has your mood been?
  - Have you been depressed? Have you been suicidal?
- Are you on any psychiatric medications?
- What other medications are you on?
- Do you use health food supplements?
- How much alcohol do you drink?
  - It's useful for us to get a clear view of your drinking since people often have symptoms when they stop drinking for surgery. Have you had difficulties before? Any withdrawal problems?
- How has your memory been?
  - What's today's date?
  - Where are we?
  - If any concerns: Would you draw a clock with all the numbers that indicates 10 after 10?

**Fig. 17.1** Sample of preoperative psychiatric screen

wise to try to continue the outpatient regimen whenever possible.

Patients tend to hide their abuse of alcohol and other substances. Many patients will be relatively frank about their substance use, however, if the clinical approach is a matter of fact and motivated by a desire to prevent complications. A central credo of substance abuse treatments is that many people are "pre-contemplative" and may not consciously realize that they have a problem and, even if they do, that they do not feel ready to quit. The goal of a perioperative evaluation is not, however, the same as that of a substance abuse counselor. The first goal is to prevent surgical and medical complications; a secondary goal is long-term remission. Once that is clarified in the interviewer's mind, exploration of possible substance abuse needs to be no more tense than a discussion of other elements of the patient's history.

The preoperative screen should also include a review of pertinent labs and vital signs. The tests that are the most reliable indicators of chronic substance use happen to assess the most common substance of abuse, alcohol. An elevated or high–normal mean corpuscular volume (MCV) is suggestive, as is an elevated aspartate transaminase (AST), especially if the AST/ALT ratio is approximately 2:1. There are other causes besides alcohol for an elevated MCV and a transaminitis, but in at-risk populations, they are definitely suggestive of alcohol dependence and likelihood for withdrawal symptoms.

The screen should be part of all preoperative evaluations, but it is especially crucial for trauma patients since substance abuse often accompanies accidents of all sorts. A toxicology screen and a blood alcohol level can help identify the particular substance of abuse; these tests will only reveal recent use, however, and neither will reveal whether someone is

likely to go into withdrawal. These lab screens can, however, point the clinician in useful directions. If a known alcohol-dependent patient is admitted with an alcohol level of 0, for example, the clinician should anticipate that alcohol withdrawal symptoms might develop on the first hospital day. If a patient is admitted with an alcohol level of 0.220 and does not appear impaired, then the clinician should anticipate withdrawal regardless of the patient's claims of only "social drinking." On the other hand, if a trauma patient is stumbling and slurred with a relatively low alcohol level, the clinician might be inclined to believe that the patient is not a regular heavy drinker, though it could also indicate head trauma or cirrhosis. Because substances are so often implicated in trauma, surgery services are increasingly mandating a psychiatric evaluation for all trauma patients who have any recent history of substance abuse.

## Preoperative Assessment of Capacity

Patients have the right to provide informed consent for all surgical procedures unless they are deemed to lack capacity by a physician. The capacity to provide informed consent can be determined by any physician, and 99 % of pre-op capacity assessments are done by the primary surgeon in the course of discussing the proposed intervention. Occasionally, however, patients recurrently change their minds, appear to be making unwise or idiosyncratic decisions, demonstrate cognitive impairment, or appear to be psychotic or severely depressed. In these situations, the surgeon tends to look elsewhere for help in deciding the patient's capacity to provide informed consent.

The laws that underlie capacity vary between countries and also between states within the United States. The laws tend to be patchwork and incomplete even within a particular state so that the de facto rules and procedures tend to vary between adjacent hospitals and sometimes between services within the same hospital. In addition, there is no single definition of capacity and no agreed-upon tool for measuring capacity. These multiple layers of uncertainty can lead to the involvement of psychiatrists, ethicists, lawyers, and administrators, and the path to surgical efficiency can get frustrated.

It is important, therefore, for the orthopedic team to understand the definition of capacity and to have a working knowledge of the principles of specificity, the sliding scale, and the use of proxies. Capacity refers to the ability to understand the pertinent medical information and to make a reasonable, consistent decision. For example, an elderly patient may lack the ability to process information related to his hip fracture because of a dementia, while other patients might have questionable capacity because of the confusion related to an alcohol withdrawal delirium, the paranoid mistrust of schizophrenia, or the waffling uncertainty brought about by depression, anxiety, and panic.

All capacity decisions are *situation specific* in that a particular capacity decision relates to a specific question. The *sliding scale of capacity* refers to the concept that it requires a higher degree of cognitive and emotional capacity to consent to an intervention that is deemed to be high risk/low benefit or to refuse an intervention that is low risk/high benefit. This concept explains why a patient may have the capacity to consent to the repair of a hip fracture but lack the capacity to refuse the same procedure. Some ethicists have argued that the sliding scale creates a Catch-22 for patients: if they accept the physician's recommendations, they are deemed to have capacity, but if they disagree, they lack capacity. In general, however, hospital-based ethics committees tend to abide by the sliding scale at least partly because it seems both fair and pragmatic.

Patients who are deemed to lack capacity do not immediately lose their rights or their ability to obtain necessary treatment. Specific laws vary from state to state, but, in general, the aim is to abide by what the patients would have wanted if they did have capacity. Some patients will have spelled out their intentions in an *advance directive*. Since medical and surgical circumstances are often complex and specific, even a well-designed advance directive may be inadequate to spell out an exact course of action. When the advance directive is not adequate or available, the goal is to identify the person, or the *proxy*, who is best able to stand in for what that particular patient would have chosen if he or she did have capacity. The proxy may have been previously identified by the patient, may be chosen as next of kin, or may be a member of the hospital administration who functions as an independent advocate for the patient's wishes. Virtually the only adults excluded from serving as health care proxies are members of the treatment team, since they may be viewed as having a conflict of interest in regard to the medical and surgical care.

To speed the process of assessing capacity, the orthopedic team can help clarify the medical and surgical issues: the specific procedure being proposed; its likely risks and benefits; reasons that the procedure might be specifically useful or problematic to this particular patient; reasonable alternative treatments that might be more acceptable to the patient; and anything that is known about the patient that might be affecting his or her judgment (e.g., pain, fear, dementia, or withdrawal), particularly if he or she can be treated.

## Preoperative Prevention of Delirium

Perioperative confusion is one of the most robust predictors of morbidity, mortality, and delayed discharge in orthopedic

patients [6–10]. While often unrecognized, delirium develops in about 30–40 % of at-risk patients following orthopedic surgery. Often viewed as a postoperative condition, delirium has also been found in as many as 21 % of hip fracture patients *prior* to surgery [11].

Efforts to reduce the impact of delirium have focused on three strategies within the at-risk population. While the studies are limited, they have generally shown a reduction in the incidence and severity of delirium and a reduction in overall length of stay. One important study reduced the incidence of delirium in at-risk hospitalized patients by reducing sleep deprivation, immobility, hearing and visual impairment, and dehydration [12, 13]. Other studies have demonstrated the usefulness of prophylaxing with low doses of antipsychotic medication to reduce the incidence of delirium in at-risk patients prior to surgery [14]. Other interventions have focused on an active search and treatment of such delirium contributors as infection, anemia, pulmonary edema, and pulmonary embolus.

A more extensive discussion of delirium can be found later in this chapter.

## Preoperative Assessment of Psychiatric Medications

Psychiatric medications are widely used, and almost all can be safely given on the day of surgery or held briefly while the patient is NPO. While some surgeons routinely take patients off as many medications as possible during the perioperative period, it is likely that far more morbidity has ensued from unnecessary medication discontinuation than from actual drug interactions.

At the same time, it is useful to have tactfully elicited a psychiatric medication history for all patients. Some medications are particularly important. For example, two of the older classes of antidepressant medication, the monoamine oxidase inhibitors (MAOIs) and the tricyclic antidepressants (TCAs), have potential anesthetic interactions. While neither class of medication is currently used extensively by psychiatrists, the TCAs are often used to help manage pain. More dramatically, one of the MAOIs, phenelzine (Nardil®, Pfizer), has been famously implicated in sudden death when combined with opiates, particularly meperidine [15]. By and large, however, psychiatric medications do *not* interact with pain medications or with anesthesia, and they need not be discontinued prior to surgery [16].

Discontinuation of several psychiatric medications can lead to withdrawal symptoms. For example, virtually all of the sedating medications can have withdrawal effects, with benzodiazepine withdrawal being the most medically serious. Acute withdrawal from antidepressants—especially paroxetine (Paxil) and venlafaxine (Effexor)—can be highly unpleasant. Opiate withdrawal symptoms are also difficult, but a more common situation in the orthopedic population is an altered pain threshold and opiate requirement in the postoperative period.

Withdrawal of psychiatric medications can also lead to a recurrence of the primary psychiatric condition. A brief period of insomnia can, for example, induce a manic episode in a bipolar patient, while some patients with schizophrenia and anxiety are very sensitive to even a few days away from their psychiatric medication. On the other hand, a brief break from antidepressants is unlikely to induce a depression, which is fortunate since all of the currently available antidepressant medications must be given by mouth.

## Postoperative Psychiatric Issues

The psychiatric issues that most commonly complicate the postoperative course include delirium, withdrawal, mood disorders, behavioral disturbances, and a reluctance to progress with physical therapy and/or transfer to a rehabilitation center.

## Postoperative Delirium

Delirium can sometimes be predicted, but it generally develops quietly during the day or two following surgery. It is not usually diagnosed by the treatment team. Also called metabolic encephalopathy and ICU psychosis, delirium is marked by acute and fluctuating disturbances in cognition, behavior, and mood. While alcohol withdrawal delirium is generally hyperactive and accompanied by agitation and obvious confusion, most postoperative patients with delirium appear subdued and depressed. When interviewed, even quietly delirious patients will reveal some combination of confusion, inattention, diminished memory, anxiety, paranoia, and depression [17, 18].

While common, delirium is generally ignored. When delirium is noticed, a common response is to normalize (e.g., "Who wouldn't be a little confused?" or "they are better off not knowing what is going on").

There are several problems with not aggressively diagnosing delirium. The first is that delirium often reflects an underlying medical problem that warrants attention. The second is that patients and loved ones are often frightened by the change in mental status, often worrying that the patient has acutely developed a dementia. Treatment can reduce patient suffering, and an encouraging explanation can reduce their family members' worry. A third reason is more pragmatic. Delirium may be the most robust predictor of a prolonged hospital stay, and so hospitals, administrators,

and medical teams are increasingly motivated to prevent and treat delirium.

Risk factors for delirium include age, cognitive impairment, low body mass index, and anything that increases metabolism (e.g., infection) or decreases physiologic efficiency (e.g., anemia or electrolyte abnormality). Hundreds of medications have also been implicated in delirium, but the classes that appear most risky include opioids, benzodiazepines, and calcium channel blockers [19].

Treatment of delirium once it has been identified is problematic [20]. The single best medication appears to be a low-dose antipsychotic, generally given in the evening [21], but all of the antipsychotic medications have been implicated in elevated rates of sudden death in elderly patients with dementia [22]. Nevertheless, they are frequently used to help with sleep and paranoia. Other sleep agents, such as benzodiazepines, are likely to cause a paradoxical disinhibition and should generally not be used in the elderly and cognitively impaired. The reorientation strategies like windows and reorientation—which reduce the incidence of delirium—do not appear to significantly decrease its duration. Coaching the family can, however, be crucial. By defining delirium and underlining its frequency and transience, family members can be both reassured and enlisted to help ensure the patient's safety. Further, they are more likely to effectively participate in the treatment and procedure planning that might otherwise get delayed while the patient is delirious.

## Postoperative Withdrawal and Intoxication

It is useful to try to anticipate which patients are likely to go into withdrawal; see discussion earlier in this chapter. Psychiatric issues often remain hidden until the hospitalized patient's symptoms become acutely problematic, and this is particularly true for substance abuse, which is often noticed only when withdrawal symptoms become prominently problematic [23].

The most common and potentially most dangerous type of withdrawal is from alcohol. Because of the potential catastrophe of delirium tremens (DTs), surgical teams should have a low threshold for beginning alcohol withdrawal precautions. These precautions generally include frequent vital signs and a brief neurological exam looking for objective signs of alcohol withdrawal. When alcohol withdrawal is detected, the response varies significantly between hospitals and between units at the same hospital, but they generally include the use of benzodiazepines at doses adequate to induce a light sedation and maintenance of normal vital signs. Most people who abuse alcohol can be discharged in comfort and without delay. It is possible to overmedicate, but the greater likelihood is undertreatment, which helps create—at best—an edgy, unhappy, and potentially noncompliant patient. In addition, early detection and treatment help identify those patients who are at risk of going into the sort of frank withdrawal that can lead to delirium, delayed discharge, and serious medical complications.

Assessment for opiate abuse and dependence is complicated by the reality that many orthopedic patients have considerable pain and a legitimate need for pain relief. Opiates are well known to induce dependence, a tolerance for increasing doses of the medication, and diminishing tolerance of pain. Many orthopedic surgeons are familiar with the former athlete whose previously high pain threshold has melted under years of opiate medication and who presents in middle age with a variety of orthopedic complaints, low tolerance of pain, and a robust dependence on high doses of opiates. Such a constellation is especially difficult in the perioperative period. That particular patient will likely need increased opiate dosages during and after surgery in order to control pain, but that same patient is also likely to appear to be a substance abuser with a triad of suspicious behaviors: detailed knowledge of opiate dosages and delivery methods, high dosage requirements, and desperation. The average-expectable reaction to this triad is to *reduce* pain medications, leading to an unhappy cycle of mutual hostility and mistrust between the patient and surgical team. Treatment of this *pseudo-addiction* during the perioperative period is to manage the pain commensurate with the need and to defer the opiate detoxification until after discharge. One common postoperative strategy is to add methadone 10–30 mg to the daily preoperative regimen, though specific strategies are often handled by pain specialists.

## Psychiatrically Difficult Patients

"Difficult" patients are those people whose behaviors interfere with the perioperative process. Using that broad definition, delirium, substance abuse, and questions of capacity can also make a patient "difficult," but those issues are so common that they warrant special discussions.

Anticipation of a wide variety of difficulties is not always easy. Few people intend to be difficult, and even those who have frequent interpersonal complications tend to underestimate their own role in the conflicts. Perhaps the most useful generalization would be for the surgeon to pay attention to variation from the usual. Many patients manifest some degree of anxiety, depression, agitation, interpersonal conflict, nonadherence, and/or some type of oddity. Sometimes, these characteristics are accompanied by a formal psychiatric diagnosis. At other times, the patient presents with a clear history of bumpy hospitalizations. Often, however, the primary team has no such clear guideposts. By simply paying attention to atypical presentations, however, the surgical team can often take proactive precautions.

The highly critical patient might soften, for example, with an unusually attentive response. Similarly, the unusually entitled patient might have narcissistic issues that can be successfully addressed by spending a few extra minutes with the senior surgeon. It is useful to recall that the average expectable staff response to highly critical and entitled patients might be avoidance or overt skepticism and that such typical responses might worsen the situation.

In working with a particularly difficult patient, it is useful for the surgical team to take its own pulse. Some patients are unusually difficult for almost anyone, but certain types of difficult patients can be specifically difficult. None of us responds equally well to the broad range of people we treat, and it is useful for the surgeon to recognize his or her own response to a wide variety of patients. By simply noticing that a patient's behavior is outside the norm, the surgical team can often step back, address the specific concern, and carry on in its usual professional fashion.

Some patients do have a psychiatric diagnosis, but it is explicitly situational to the orthopedic procedure. For example, many people are intensely worried about surgery and anesthesia. This can lead to apprehension and resistance to surgery. Many of these anxious patients are likable, well meaning, and without any other particular problems, but, as soon as their anxiety interferes with the surgical process, they fit the "difficult" definition. If a patient appears nervous or admits to anxiety, it is very useful for at least one member of the surgical team to tactfully discuss the concern. It is also useful to recall that some people will be just as reluctant to reveal a needle phobia as other patients might be of revealing substance abuse. Most concerns can be remedied by a simple explanation, while others might warrant such interventions as exposure to the surgical suite, an instructional video, or exercises to enhance calm (e.g., breathing, muscle relaxation, meditation, visualization). At other times, a single low dose of an antianxiety medication can allow the surgery to proceed smoothly.

Psychotic patients are an example of a potentially difficult psychiatric patient. Generally, however, the difficulty is not the psychosis. The predominant psychotic disorder is schizophrenia, and most people with schizophrenia are more disabled not by hallucinations or delusions but by the "negative" symptoms such as apathy and cognitive difficulties. These latter impairments can reduce their ability to understand the informed consent process as well as the ensuing need for rehabilitation. At the same time, people with schizophrenia are often model, dutiful patients who will respond well to the stress of surgery.

Another common type of difficult orthopedic patient is one who presents with a cluster of unusual symptoms following a trauma. Anxiety or substance abuse may be the most obvious symptom, but a careful history will reveal a characteristic cluster of stress-related symptoms: re-experiencing of the trauma through dreams and memories; avoidance of reminders of the trauma; and autonomic hyperarousal. Early psychiatric intervention can reduce the likelihood of the development of a full-blown post-traumatic stress disorder and can also bring clarity to what can be a bewildering array of symptoms.

Such psychological treatments are likely to be difficult for a solo practitioner, but large programs often have a designated nurse or patient educator to work with such patients before and after their procedures. Larger programs also tend to employ psychiatric consultants who can help when anxiety and other psychiatric disorders are outside the realm of the patient educator. As with consultants from neurology and the pain service, psychiatric consultants should not preempt the orthopedist's role as the patient's primary physician but rather make it more straightforward for the surgeon to focus on the care of the patient.

## Summary

While psychiatric issues are some of the most common complications of the perioperative period, they are routinely underdiagnosed on surgical services. Systematic evaluations and straightforward interventions can significantly reduce the burden of psychiatric issues, while the judicious use of psychiatric consultants and a psychosocial team can allow the surgical and anesthesiology teams to focus more fully on their work with patients.

The preoperative period allows the surgical and anesthesiology teams to anticipate problems. These can vary dramatically, from issues related to informed consent to virtually any psychiatric or behavioral condition. The best preoperative assessment combines the surgical team's intuition and clinical acumen with a set of relatively routine questions that can be asked by a selected member of the team. Evidence indicates that a single question is adequate to elicit useful information about many different psychiatric conditions. These can range from "Do you have worries about the surgery?" to "Have you ever had difficulties with alcohol or alcohol withdrawal?" Since people are not always forthcoming about their psychiatric issues, it can also be useful to search for additional information through lab results, old surgical/medical records, and family members. Perhaps the biggest concern with searching for problems is that they often require an intervention. If a cognitive problem is elicited, for example, it may become necessary to formally assess the capacity to sign informed consent and also to consider whether there might be something that can be done to reduce the likelihood of a pre- or a postoperative delirium. It is useful to recall that elicited problems are liable to cause complications even if they are ignored preoperatively and that the bulk of the intervention can be done by ancillary members of the team.

The day of surgery can be psychiatrically complicated for several predictable reasons. Anxiety about the surgery and/or the anesthesia is a common problem; if anticipated, such concerns can often be easily addressed. Problems with capacity and informed consent can stall surgery, so it is best to anticipate the problems prior to surgery by having someone available to make rapid capacity assessments (generally a psychiatrist or a member of the ethics committee) as well as someone who can become a proxy if no friends or family members are available and willing to serve as proxies (generally an administrator from patient services and specifically someone not from the primary surgical team).

The postoperative period generally goes smoothly for patients with psychiatric disorders. Nevertheless, several problems are common. Abuse of alcohol and illicit substances can complicate all aspects of the perioperative period and is particularly common in the orthopedic trauma population. Heavy use of opiates is very common in patients with chronic pain, and opiates can affect both the anesthesia needs and postoperative pain management. "Difficult" patients are defined here as any patients who complicate the perioperative period because of behavioral or interpersonal conflicts. These include a wide array of psychiatric disorders, including people with substance abuse, personality disorders, and PTSD. For most of these patients, their acute symptoms can dissipate with brief, tactful interventions [24, 25].

Regardless of whether or not they are recognized or addressed, psychiatric issues routinely affect orthopedic surgery. Anticipation can reduce disruption to the perioperative period. Ideally, the process of recognition and treatment of psychiatric issues is informed by psychiatric specialists while the orthopedic team can maintain its focus on surgery and the patient.

**Summary Bullet Points**

- Delirium, withdrawal from substances, and interpersonal difficulties commonly complicate the perioperative period.
- Psychiatric medications should generally be given throughout the perioperative period.
- Informed consent is routinely assessed by the surgery team. Psychiatrists, ethicists, and hospital administrators may get involved in complex capacity questions.
- The psychiatric consultant often works within a context of a psychosocial team composed of professionals with a range of relevant expertise.

## Case Studies

Case studies for this chapter are included in Appendix K at the end of this book.

## References


1. O'Regan NA, Fitzgerald J, Timmons S, O'Connell H, Meagher D. Delirium: a key challenge for perioperative care. Int J Surg. 2013; 11(2):136–44.
2. Zieger M, Schwarz R, Konig HH, et al. Depression and anxiety in patients undergoing herniated disc surgery: relevant but underresearched - a systematic review. Cent Eur Neurosurg. 2010; 71(1):26–34.
3. Bradley KA, Kivlahan DR, Williams EC. Brief approaches to alcohol screening: practical alternatives for primary care. J Gen Intern Med. 2009;24:881–3.
4. Kip MJ, Neumann T, Jugel C, et al. New strategies to detect alcohol use disorders in the preoperative assessment clinic of a German university hospital. Anesthesiology. 2008;109:171–9.
5. Terrell F, Zatzick DF, Jurkovich GJ, et al. Nationwide survey of alcohol screening and brief intervention practices at US Level 1 trauma centers. J Am Coll Surg. 2008;207:630–8.
6. Edelstein DM, Aharonoff GB, Karp A, Capla EL, Zuckerman JD, Koval KJ. Effect of postoperative delirium on outcome after hip fracture. Clin Orthop Relat Res. 2004;422:195–200.
7. Fick DM, Steis MR, Waller JL, Inouye SK. Delirium superimposed on dementia is associated with prolonged length of stay and poor outcomes in hospitalized older adults. J Hosp Med. 2013;8(9):500–5.
8. Cheung A, Thorogood NP, Noonan VK, Zhong Y, Fisher CG, Dvorak MF, Street J. Onset, risk factors, and impact of delirium in patients with traumatic spinal cord injury. J Neurotrauma. 2013; 30(21):1824–9.
9. McDaniel M, Brudney C. Postoperative delirium: etiology and management. Curr Opin Crit Care. 2012;18(4):372–6.
10. Khasraghi FA, Lee EJ, Christmas C, Wenz JF. The economic impact of medical complications in geriatric patients with hip fracture. Orthopedics. 2003;26:49–53.
11. Juliebo V, Bjoro K, Krogseth M, et al. Risk factors for preoperative ad postoperative delirium in elderly patients with hip fracture. J Am Geriatr Soc. 2009;57:1354–61.
12. Inouye SK. Predisposing and precipitating factors for delirium in hospitalized older patients. Dement Geriatr Cogn Disord. 1999; 10:393–400.
13. Inouye SK, Bogardus Jr ST, Charpentier PA, Leo-Summers L, Acampora D, Holford TR, Cooney Jr LM. A multicomponent intervention to prevent delirium in hospitalized older patients. N Engl J Med. 1999;340(9):669–76.
14. Teslyar P, Stock VM, Wilk CM, Camsari U, Ehrenreich MJ, Himelhoch S. Prophylaxis with antipsychotic medication reduces the risk of post-operative delirium in elderly patients: a meta-analysis. Psychosomatics. 2013;54(2):124–31.
15. Gillman PK. Monoamine oxidase inhibitors, opioid analgesics and serotonin toxicity. Br J Anaesth. 2005;95(4):434–41.
16. De Baerdemaeker L, Audenaert K, Peremans K. Anaesthesia for patients with mood disorders. Curr Opin Anaesthesiol. 2005;18(3): 333–8.
17. Robertson BD, Robertson TJ. Postoperative delirium after hip fracture. J Bone Joint Surg. 2006;88(9):2060–8.
18. Edlund A, Lundstrum M, Lundstrom G, et al. Clinical profile of delirium in patients treated for femoral neck fractures. Dement Geriatr Cogn Disord. 1999;10:325–9.
19. Clegg A, Young JB. Which medications to avoid in people at risk of delirium: a systematic review. Age Aging. 2011;40(1):23–9.
20. Shim JJ, Leung JM. An update on delirium in the postoperative setting: prevention, diagnosis and management. Best Pract Res Clin Anaesthesiol. 2012;26(3):327–43.
21. Ozbolt LB, Paniagua MA, Kaiser RM. Atypical antipsychotics for the treatment of delirious elders. J Am Med Dir Assoc. 2008;9(1): 18–28.

22. Mittal V, Kurup L, Williamson D, Muralee S, Tampi RR. Risk of cerebrovascular adverse events and death in elderly patients with dementia when treated with antipsychotic medications: a literature review of evidence. Am J Alzheimers Dis Other Demen. 2011;26 (1):10–28.
23. Findley JH, Sanders KB, Groves JE. The role of psychiatry in the management of acute trauma surgery patients. Prim Care Companion J Clin Psychiatry. 2003;5(5):195–200.
24. Tait RC, Chibnall JT, Luebbert A, Sutter C. Effect of treatment success and empathy on surgeon attributions for back surgery outcomes. J Behav Med. 2005;28(4):301–12.
25. Vranceanu AM, Elbon M, Ring D. The emotive impact of orthopedic words. J Hand Ther. 2011;24(2):112–6.

# Part IV

# Specific Perioperative Problems in Orthopedic Surgery

# Perioperative Care of the Elderly Orthopedic Patient

18

C. Ronald MacKenzie and Charles N. Cornell

**Objectives**

- To define the perioperative risks associated with advanced age.
- To provide strategies for optimizing the surgical risk for the elderly patient.
- To describe modifications of the surgical approach that benefit the elderly patient.
- To explore proven pathways of care and rehabilitation of the elderly patient.

**Key Points**

- Changing demographics of our society make it clear that elderly patients will predominate much of orthopedic practice in the future. The special needs and conditions of these patients must be anticipated (cognitive impairment, frailty, immobility and functional dependency, poor nutrition, among others).
- The concept of "homeostenosis" is useful in understanding the special risks associated with surgery in patients of advanced age. However, chronological age by itself is not an appreciable risk; rather, it is overall health. The elderly should be assessed as "fit" or "frail," and their care plan adjusted accordingly.
- Elderly patients have the same potential to benefit from orthopedic reconstructive procedures as the nonelderly, and they have the potential to greatly improve their overall health and quality of life with orthopedic reconstruction.
- When elective surgery is planned, the special needs of the elderly patient should be anticipated with preoperative medical optimization, preoperative physical conditioning, preoperative education, postoperative pain management, and planning for a prolonged recovery, physical therapy, and rehabilitation process.

## Introduction

It is projected that patients older than 65 years will become the largest segment of the surgical population by 2020 [1]. Further it is known that older patients have longer lengths of stay, account for greater costs of care, and experience more adverse outcomes related to surgery [2]. Among all surgery performed on older persons, the fractured hip makes a large contribution to the problem of surgery in the elderly. As such the perioperative care of those latter in life is highly relevant to the orthopedic surgery. This chapter introduces the topic of surgery in the elderly, exploring what makes the elderly "different." Important age-related risk factors for postoperative complications will be discussed as will the problem of postoperative cognitive dysfunction and delirium. The chapter concludes with a review of current approaches to the fractured hip, the orthopedic condition most associated with surgery on the elderly.

C.R. MacKenzie
Department of Medicine, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA
e-mail: mackenzier@hss.edu

C.N. Cornell (✉)
Clinical Orthopedic Surgery, Department of Orthopedic Surgery, Weill Cornell College of Medicine, New York, NY, USA
e-mail: cornellc@hss.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_18, © Springer New York 2014

**Table 18.1** Age-related perioperative risk factors

| |
|---|
| Cognitive impairment |
| Frailty |
| Immobility/functional dependency |
| Poor nutrition |
| Challenges of discharge (transitions) |

## Age-Related Perioperative Risk Factors

The significant patient-associated risk factors in elderly patients that correlate with postoperative adverse outcome [3] include the problems of cognitive impairment and delirium, frailty, immobility and functional dependency, poor nutritional status, and the challenges of discharge (transitions) (Table 18.1).

### Cognitive Impairment

Cognitive decline and memory dysfunction is a leading cause of functional impairment in the population at large, a problem that increases with age and heightened by hospitalization for critical illness and surgery [4]. Further, that patients >65 years are projected to become the largest segment of the surgical population by the year 2020 underscores the importance of this problem for the health care system at large [1]. Indeed, state-of-the-art symposia have been held concerning this problem, forecasting a veritable "epidemic" of postoperative cognitive dysfunction projecting forward [5]. The incidence of this problem is already high in some surgical populations. For example, in the orthopedic realm, patients undergoing emergent surgical repair of a fracture hip experience a 37 % rate of significant postoperative cognitive dysfunction among the nondemented fraction of this cohort [6]. The significance of this observation is highlighted by the observation that among patients who experience delirium after surgery, 69 % (vs. 20 %) developed frank dementia over a 5-year postoperative follow-up. Monk et al. have reported that patients with postoperative cognitive dysfunction at discharge were more likely to die within the first year after surgery as compared to those without such postoperative cognitive problems [7].

Numerous studies have sought to identify patient attributes and clinical factors that contribute to the development of postoperative cognitive dysfunction. These have included the exposure to anesthesia and various perioperative phenomena (hypoxemia, hypotension, hyperventilation, specific medications), the effects of aging, comorbidities (cancer, neurodegenerative and cerebrovascular disease), and even genetic considerations (*APOE4* polymorphisms). Indeed a basic science pertaining to this clinical problem is emerging focused on the role of inflammation and the activation of the immune system, both of which are associated with cognitive decline [5]. Animal models as well as preclinical studies suggest a causative role for various proinflammatory cytokines, specifically interleukin 1*B* [8–10]. These observations have parallels to a related syndrome known as *sickness behavior*. Arising as a consequence of acute illness, sickness behavior is a constellation of signs and symptoms—fever, anorexia, somnolence, hyperalgesia, fatigue—accompanied by a decline in cognitive function, mimicking what is often seen after surgery [11, 12].

Another putative mechanistic domain links the types of nervous system changes seen in neurodegenerative disease (i.e., Alzheimer's) in which the accumulation of abnormal proteins is believed to be responsible for the cognitive decline and disruption of memory [13]. In this regard relationships between anesthesia, *B*-amyloid, and tau protein phosphorylation have been suggested as potential mechanisms [14–16]. In addition, evidence suggests that anesthetics may affect memory and behavior, effects that may persist beyond the dissipation of the medications from the body [17]. Nonetheless the literature in support of such neurotoxic effects of anesthesia is complex, in evolution and, further, is challenged by the results of clinical trials involving older patients undergoing major noncardiac surgery. In these clinical studies, the rates of postoperative cognitive dysfunction after regional as compared to after general anesthesia were comparable [18, 19].

Many of the predictors of delirium both for hospitalized [20, 21] and for patients in the postoperative setting have been studied [22]. Patients are at an increased risk for the development of delirium after surgery due to a confluence of factors that arise in this clinical setting. Indeed a pneumonic has been described that enumerates the common causes of delirium (DELIRIUMS SPAC): *D*rugs, *E*motional/*D*epression, *L*ow pO2 states, *I*nfection, *R*etention of urine or feces, *I*mmobile, *I*ctal states, *U*ndernourished/or dehydrated states, *M*etabolic, *S*urgery specific, *S*ensory/Sleep deprivation, *P*ain, *A*ge, *C*ognitively impaired baseline [23]. In addition to the specific designation for surgery, consider how many of these clinical states arise in the perioperative setting.

Various interventions, the purpose of which is the reduction of risk for postoperative delirium, have been suggested and include supplemental O2, the restoration of electrolyte imbalances, the discontinuation of high-risk medication, the assurance of adequate nutrition, early mobilization, and aggressive pain management [3].

## Frailty

Frailty as a core concept of geriatric medicine has proven compelling for a number of reasons [24]. These include the perception that frail individuals, usually the elderly, constitute a group of individuals at high risk for dependency and disability, falls and injury (fracture), and slow and incomplete recovery after acute illness and hospitalization. As a group, they disproportionately require health care related and support services, often community based. Another related consideration, well known to clinicians, is the increased susceptibility to multiple chronic diseases that accompany the aging process and contribute to (or are possibly a consequence of) the problem of frailty. Further there is the mounting evidence suggesting that disease-mediated determinants alone do not provide a sufficient explanation for the functional consequences of the aging process. Finally given the high (and increasing) prevalence of frailty in the population (10–25 % >65 years, 30–45 % >85 years), the medical and social consequences of this clinical problem will present challenges to families and the health care system in general in perpetuity. These considerations have high relevance in the setting of caring for patients with an important geriatric syndrome—the patient who suffers hip fracture—a problem that begs for a redesign of care and reimbursement.

Indeed a simple, useful frailty scale has been developed that serves in the identification of such patients [25]. The scale employs a four-level classification across the spectrum of fitness to frailty: (0) Those able to walk without help, perform activities of daily living, are continent, and are not cognitively impaired; (1) bladder incontinence only; (2) one (two if incontinent) or more of needing assistance with mobility or activities of daily living, has cognitive impairment (but not dementia), or has bowel for bladder incontinence; (3) two (three if incontinent) or more of totally dependent for transfers or one or more activities of daily living, incontinent of bowel and bladder, and a diagnosis of dementia.

Those involved in the care of the elderly have long recognized the constellation of weakness, immobility, and poor tolerance to stress, accompanied by multiple comorbid conditions, as prevalent in older patient groups. This, the syndrome of frailty, results in a progressive decline in general function, a loss of physiologic reserve, and an increased vulnerability to disease and death; in addition, it predisposes to falls, disability, social isolation, and the need for institutionalization. Although as a concept it has proven challenging to define [26], frailty is not difficult to recognize as its markers are easily identified. Relevant characteristics include such age-associated declines in lean body mass, strength, endurance, balance, walking performance, and low levels of activity. Multiple components must be present in order to constitute frailty.

The progressive restriction of physiologic reserve that occurs as a function of aging is captured in the concept of "homeostenosis." A model well known to geriatricians, homeostenosis is a reduction in the maintenance of homeostasis resulting from even mild perturbations to the system at large. Figure 18.1 provides a schematic representation of this concept. In this depiction, younger individuals are on the left while the older are on the right. Homeostasis corresponds to the line separating physiologic reserves already in use from those still available to meet health challenges; the "precipice" is the point of inflexion where adverse outcomes begin to occur. Thus, according to this conception, the object of medical care is to avoid reaching the precipice. According to recent interpretations, younger individuals deal with challenge readily owing to the physiological reserves conferred by their youth and overall good health. With aging, however, greater proportions of our physiological reserve are siphoned off, directed to the maintenance of homeostasis, leaving less capacity to address health challenges. It is therefore self-evident that extraneous perturbations such as surgery may impel individuals, particularly the frail elderly, away from optimal homeostasis toward a state of vulnerability (the precipice).

## Immobility and Functional Dependency

Inextricably connected to the concept of frailty, the problem of immobility and functional dependency is a common characteristic of the elderly. This is especially true of the patient with chronic orthopedic and rheumatic disease, conditions that independently produce such compromise. Thus, prior to surgery, patients may be struggling to ambulate and perform activities of daily living. Thus significant postoperative difficulty related to such challenges as weight-bearing, transfers, and independent ambulation can be anticipated.

## Poor Nutrition

Elderly patients are often determined to be at high nutritional risk for numerous reasons. Some elderly patients may be diagnosed with malnutrition due to inadequate food intake, or may present with physical/functional impairments. Conditions affecting patients' functional capacity to effectively chew and swallow food, prepare meals, and independently feed themselves can greatly impact nutritional status. As a result of declining physical and cognitive function, poorly fitting dentures, missing teeth, alterations in taste sensation, and reduced salivary flow, elderly patients may find it difficult to meet nutritional needs via oral intake.

Such patients should be identified immediately upon admission so that proper nutritional care can be initiated as

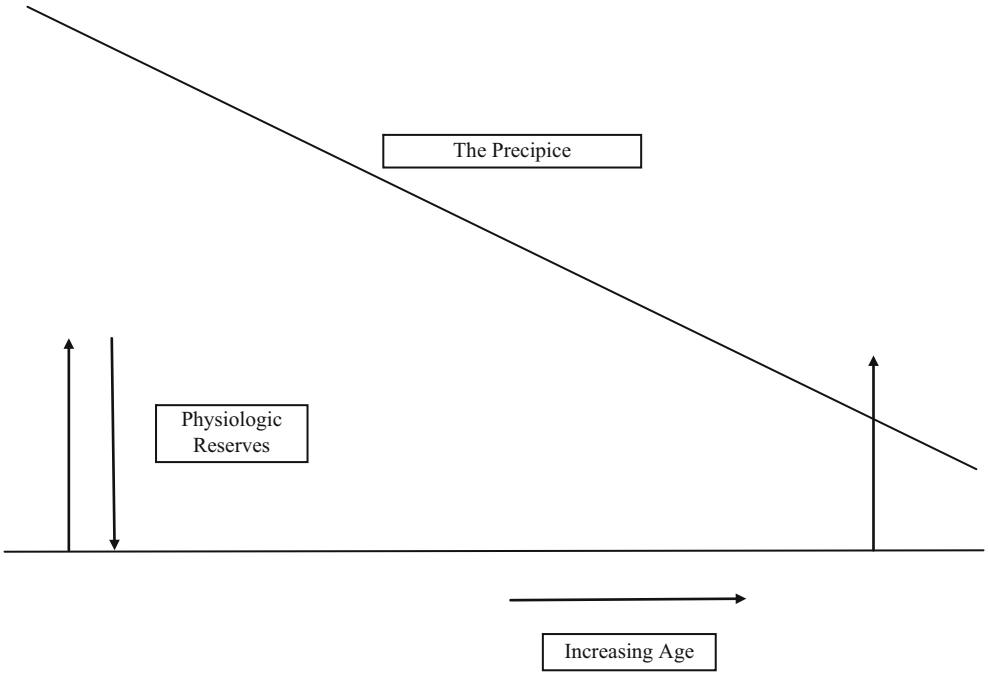


**Fig. 18.1** Standard schematic of homeostenosis. As the individual ages, there is no change in homeostasis, but the amount of physiologic reserves available to counter any challenge to homeostasis decreases with aging. Challenges to homeostasis are depicted as *arrows* moving away from the baseline. The precipice may be any clinically evident marker such as death, confusion, or cardiac arrest (Used with permission from Taffert GE. Physiology of Aging. In: Geriatric Medicine: An Evidence-Based Approach. Eds: Cassel CK, Leipzig R, Cohen HF, et al. New York: Springer, 2003)

early as possible. Additionally, elderly patients may need assistive devices to overcome difficulty grasping utensils or cups, they may require assistance with meals, or their conditions may necessitate the use of altered food and beverage consistencies to reduce risk of aspiration in the hospital.

As a result of the physiologic stress response brought about by physical trauma, the nutrient needs of a trauma patient presenting for orthopedic surgery may be greatly increased. Caloric needs postoperatively can be as high as two times the amount normally required for weight maintenance and the support of basic physical functioning. The greatly increased needs for protein and calories to support healing postoperatively and following trauma are often difficult for patients to achieve.

Furthermore, the perioperative fasting regimen as well as the side effects that are commonly experienced from medications may result in a negative net nutrient balance in the patient. Additionally, there has been considerable research to suggest that nutrition is closely linked with health outcomes of the trauma patient. Malnutrition is not only frequently found among trauma patients, but it has also been identified as an independent risk factor for morbidity, mortality, and length of hospitalization. See Chap. 21 on Nutrition.

## Transitions

With the increasing pressures to shorten hospital length of stay, it has become uncommon for patients to receive the entire care for their major illnesses and surgery in the acute care hospital setting. This is particularly true of the elderly with whom the complexities of care often include transfers from one team of providers to another, often to other health care setting. One recent study of Medicare beneficiaries found that over the 30-day period following hospital discharge, 60 % of such patients made a single transfer, 18 % two transfers, 9 % three transfers, and 4 % made for or more. This pattern is particularly common in the orthopedic setting, as the rehabilitative requirement of this population after surgery often outstrips the capacity of the acute care hospital to provide the necessary physical therapy needs.

Risk factors for unsuccessful transitions of care have been identified among which are advanced age, serious illness, various psychosocial considerations such as insufficient support, and a history of prior hospitalizations [27]. Recognizing the implications associated with poor health care transitions, Coleman et al. have published a patient-focused instrument for the assessment this clinical domain. Developed as a quality improvement measure, the specific

**Table 18.2** Transitions of care: consequence of poor execution

| |
|---|
| Adverse events in the peri-discharge period |
| Recidivism to the emergency room or hospital |
| Reduced patient, family, and provider satisfaction |
| Increased cost of care |

domains of care employed in the Care Transitions Measure (CTM) are instructive as they identify the broad areas of concern. They include the reliability and timeliness of the information transferred; the preparation of the patient, family, and the caregiver; the support to insure successful patient self-management; and the need to empower patients to define and assert their individual goals and preferences. Lower scores on the CTM at discharge predict subsequent emergency room use and rehospitalization.

Inferred from this brief discussion, the attention to transitional care has evolved from the convergence of two contemporary health care movements—patient safety and patient-centered care [28]. The recognition of the adverse consequences of poorly executed care transitions (Table 18.2) has led to considerable body of work directed at improving this domain of health care delivery. Many approaches have been studied all of which emphasize the role of patient education (often provided by nurses), the provision of home care follow-up (social worker), dietary intervention, medication review (often involving pharmacists), and prompt follow-up with the patient's primary care physician. Regardless of the extent and nature of the systems employed, efficient information transfer remains a key component of successful transitional care. Managing the transfer of relevant information is challenging as a well-coordinated, and orderly transfer of responsibility of care involves the provision of information to multiple health care settings as well as various providers among which may include physicians, nurses, physician assistants, physical therapists, social workers and ultimately, the patient and their family.

## Specific Clinical Problems

### Postoperative Delirium

Postoperative cognitive decline (POCD) generally follows two disparate patterns: acute cognitive dysfunction, known as early postoperative delirium, and a later onset and more persistent form [29]. Delirium is often seen in older patients developing once hospitalized or after surgery and presents as an acute change in mental status, inattention, disorganized thinking, and altered consciousness [30]. Behaviors range from a placid inactivity to frank agitation. Although generally a transient phenomenon, delirium is associated with increased mortality [31], higher costs [32], and prolonged hospitalization [33]. In the surgical setting, risk factors [34] and scoring systems [22, 35] have been developed and validated for the prediction of delirium after surgery. In elective noncardiac, nonorthopedic surgery the reported incidence of postoperative delirium is 9 %; this incidence increases to 41 % after orthopedic procedures [36].

As compared to delirium after surgery, postoperative cognitive dysfunction is a more subtle and prolonged alteration in cognition [5]. Vaguely defined as a "more than expected" deterioration in cognitive function the syndrome may involve a range of impairments including memory (short and long term), mood, consciousness, and circadian rhythm (often manifested by a severe disturbance in the normal sleep-wake cycle) [37]. First noted after cardiac surgery (so-called pump-brain), such declines in cognitive function may arise after noncardiac procedures as well. As with delirium, postoperative cognitive dysfunction is associated with longer hospitalizations and higher mortality [38]. Further there appear to be prolonged, even permanent, consequences with several studies demonstrating cognitive difficulties for months, even a year after surgery [39–41]. There are additional implications as patients with postoperative cognitive dysfunction at discharge appear more likely to die within a year of the surgery [7].

In the realm of orthopedic surgery, the implication of postoperative cognitive dysfunction has been studied extensively in the hip fracture setting. In this surgical setting, the incidence of cognitive decline is as high as 37 % in nondemented patients; further one study has reported that 69 % of such patients developed frank dementia over a subsequent 5-year period (as compared with a 20 % incidence in those without postoperative delirium) [42]. Thus, the implications of this problem are profound.

### Hip Fracture

Hip fracture is a major public health care problem with far reaching consequences [43]. Worldwide over 1.6 million older adults sustain hip fractures annually, with over 300,000 of these in the United States; the prevalence will certainly increase in the years to come owing to the aging of the population. Indeed adults over the age of 85 years are 10 times more likely to sustain a fractured hip as compared to younger cohorts. Risk factors are well defined and include osteoporosis and falls, problems particularly common in elderly women. Older adults who experience hip fracture have poor outcomes, including permanent functional declines, higher rates of institutionalization, and death. In older cohort, 13.5 % of hip fracture patients die within 6 months of the event, and 24 % within a year [44, 45]. Further following hip fracture, older patients are five times more likely to be institutionalized at 1 year [46]. These

statistics are well known to Orthopedic Surgeons and Geriatricians and serves to underscore the seriousness of this problem at both the patient and the health care systems level.

The goal of hip fracture surgery is to return patients to their pre-fracture level of functional status, the achievement of which produces daunting challenges. As such surgery should proceed as soon as the patient's clinical status is regarded as optimized as the beneficial effects of early surgery have been well documented. These include decreased pain, fewer postoperative complications, and shortened lengths of acute hospital stay [47]. For example, in one large cohort study (367 patients), a delay in surgery of >2 days resulted in a doubling of the 1-year mortality, especially in those patients with comorbid conditions [48, 49].

## Surgical Management

The 2000 population census confirmed that the predicted graying of the US population is occurring. The evolving demographics of our society will have an important impact on the practice of orthopedic surgery and related musculoskeletal specialties. By the year 2040, 20 % of the population or approximately 77.2 million citizens will be >65 years of age. The current estimate of the demand for joint replacement surgery in citizens older than 65 is 15 per 10,000. In the year 2000 approximately 500,000 total knee replacements were performed and 375,000 hip fractures were repaired. With the projected growth of the elderly population the demand for these procedures will increase sevenfold. Thus, by 2040, 3.5 million citizens will seek total knee replacement. Such developments will require a shift in the focus of the orthopedic workforce as well as efforts to improve the delivery of care to the elderly population. Of additional interest is the fact that the oldest segment of the population is the part expanding most rapidly. By 2040, the over 85 year old population will double in size to 3 % of the overall population. While recent studies are informing guidelines and principles for treatment in this age group, the results of surgical intervention in this population remain largely uncharted territory.

Much of what has been learned concerning the perioperative care of the elderly patient has been gained from the study of surgical outcomes of fractures of the hip over the past 20 years. Through this study a new paradigm for the approach to care and the evaluation of outcomes has emerged. Traditional reports of hip fracture treatment focused largely on surgical aspects of care and emphasized traditional wisdom. For instance it was widely held that preservation of the femoral head was the most desirable outcome of treatment. This was because it seemed logical that, in the absence of visible arthritic change, the patient's own femoral head, the native bone, would be a better bearing surface than an artificial or metallic prosthetic replacement. Most of the studies viewed the hip fracture population as homogeneous, stratifying outcomes according to age and sex. Since then, clear evidence has emerged suggesting that the most important predictor of outcome in the elderly hip fracture patient is their pre-injury overall health status [50]. As such hip fracture patients should be stratified according to pre-injury health status and that the choice of surgical procedure should largely be based on this stratification. Past and recent studies all conclude that, although overall perioperative mortality has improved, an increased mortality risk during the first year after hip fracture persists. This mortality rate ranges from 12 to 25 %. Further, for those surviving the first postfracture year, mortality predictably returns to that of the age-matched general population. After the first year, the 5-year predicted survival is 50 % [50]. Indeed, there appears to be two distinct groups: those that die within the first year after surgery versus those that recover and experience a life expectancy similar to aged match citizens (who have not sustained a hip fracture). The best predictor for which group a patient will fall is their overall pre-fracture health status [50].

This new understanding has helped to clarify what was considered contradictory findings of past studies. For instance, it has been observed that the outcome of hip fracture surgery can be predicted from the nutritional status of patients on admission [51, 52]. In our own experience one-third of our patients admitted with hip fractures had clear evidence of acute and chronic protein malnutrition, and that this group of patients predictably suffered more complications and an increased risk of 1-year mortality. The data clearly demonstrate two populations: one group was malnourished while the other was not. Of great frustration, however, has been the disappointing observation that nutritional supplementation fails to alter the outcomes in these two populations [53, 54]. It would therefore appear that nutritional deficiency per se is not a predictor of outcome. It is, however, associated with poorer overall health status and physical function, both of which can act as independent predictors of outcome. Analyzing this population for their nutritional status reveals nutrition to be a vital element of overall health status and it is through this linkage that malnutrition exerts its negative influences. One-third of our patients present with poor overall health and suffer poor outcomes of treatment. Therefore it is now clear that elderly patient populations are not homogeneous but rather should be categorized as falling into a fit versus an unfit group. Nutritional status is an important indicator of pre-injury fitness.

In the elderly it is clear that fitness cannot be judged by chronological age. Rather it is judged based on several factors. Fit elderly patients have fewer than three medical comorbidities, are competent community ambulators,

routinely engage in sports or other social activity, and participate in the management of their social and financial affairs. Also comorbidity, as measured by the Charlson Comorbidity Index, is a consistent indicator of recovery from the hip fracture experience. Since recent studies analyzing the outcome of hip fracture care confirm the inhomogeneity of this population, surgical management must take into account the "fitness" of the patient, not just their chronological age or fracture classification [50, 52, 55]. The two procedures once felt to be the gold standard for displaced femoral neck fractures (closed pinning and hemiarthroplasty) have now been shown to carry a higher risk for reoperation and ultimately higher morbidity and cost as compared to total hip replacement in the active and "fit" elderly patient. A prospective, randomized study has now shown that for patients with displaced femoral neck fractures, total hip replacement, traditionally considered "overkill," is actually the ideal procedure [56]. Compared to hip pinning and partial hip replacement, THR patients subsequently require fewer revisions surgeries, have better function, and superior overall perceived health status. The fitter or more active the patient, the greater the advantage for THR.

This experience points out that the elderly need surgical procedures that minimize the risk of reoperation, result in excellent pain relief, and restore anatomy sufficiently to permit return of function and ambulation. This approach has led to a new evidence-based algorithm for treatment of femoral neck fractures in the elderly. Non-displaced fractures are treated by pinning in situ in both fit and unfit patients as the results of this procedure are excellent. However, for displaced fractures, fit elderly patients are best treated with THR. Unfit patients, typically the nursing home patient or those limited to household ambulation, can be most safely treated by hemiarthroplasty.

The principles outlined previously also pertain to total joint arthroplasty in the elderly population. The demand for arthroplasty in the oldest portion of the population is growing rapidly. Among nonagenarians the demand for total hip replacement is approximately 136 per 10,000 population. In 1995 33,000 were performed in the USA. The perioperative mortality was 2.3 % [57].

There are several reported studies examining the outcome of total joint replacement in this oldest population. Berend et al. [58] reviewed their experience with hip and knee replacement and found a higher incidence of post-op complications and longer hospital stays but low perioperative mortality and excellent outcomes. L'Insalata [59] examined results for TKR in the above 80 population and had similar findings. Shah et al. [60] looked specifically at frail elderly patients undergoing THR and found excellent outcomes with low mortality. Several key findings are consistent in these three studies:

1. Elderly patients with adequate preparation can safely undergo arthroplasty and achieve improvements in hip and knee scores that are comparable to younger patients.
2. There is an increased risk of perioperative complication including post-op delirium, pneumonia, UTIs, and decubitus ulcers.
3. Aseptic loosening did not occur in any of these series suggesting that the prostheses outlive the patients. This justifies the routine use of constrained prostheses in this population to reduce the risk of instability and dislocation.

In spite of the higher risk of morbidity, perioperative mortality was low and the successful elimination of pain and restoration of mobility justify the procedures.

## Postoperative Pain Management in Elderly Patients

Orthopedic procedures are painful unless appropriate and adequate pain management is employed. The elderly present a particular challenge in that poorly controlled pain can result in a delirious, immobile uncooperative patient that is prone to venous thromboembolism, pressure sores, decubitus ulceration, abdominal ileus, and poor response to mobilization. On the other hand, the elderly are especially sensitive to the side effects of narcotic medications that can produce delirium, constipation, and respiratory depression. The current approach to pain management in the elderly attempts to minimize reliance on narcotics while avoiding medications that predictably result in delirium or somnolence as well as those that are prone to produce harmful side effects or adverse drug reactions. Demerol and benzodiazepines are particularly to be avoided. Nonsteroidal and COX-2-inhibitors are useful for pain management but their dose must be adjusted to each patient's renal function or risk from GI complications. Multimodal strategies are especially useful in the elderly as they attack pain through multiple pathways and allow lower doses of narcotics but predictably good pain relief.

The multimodal approach to pain management has been enthusiastically embraced in hopes that the undesirable side effects and consequences of traditional reliance on narcotic medications can be overcome. In the past two decades, techniques of continuous infusion of narcotics, partially controlled by the patient (PCA), either by an intravenous route or through the continuation of the epidural route after surgery, have been very successful in helping to manage postoperative pain. Epidural PCA is especially attractive for lower extremity surgery because narcotics can be mixed with local anesthetics lowering the dose and toxicity of the narcotic while achieving very dramatic pain control.

**Table 18.3** Special considerations for the rehabilitation of elderly, hip fracture patients

| |
|---|
| High likelihood of multiple medical comorbidities that must be addressed |
| Cognitive and sensory impairments must be assessed |
| Reduced muscle mass and strength, decreased joint mobility, and reduced aerobic capacity may be present |
| There is usually an increased risk for falls and future injury |
| Many elderly live alone with inadequate social support |

Unfortunately, this excellent control of pain has unwanted consequences. Patients who are comfortable on epidural PCA often require a urinary catheter, suffer nausea presumably from the epidural narcotic, and experience significant postural hypotension limiting their ability to mobilize optimally while their pain is being controlled. The unintended consequence is an acceptable level of pain but discomfort from nausea and an in-hospital stay lengthened by relative immobility in the immediate postoperative period.

Multimodal and preemptive strategies to prevent postoperative pain have benefitted from recent advances in the understanding of neuronal plasticity and how undertreated acute pain can lead to chronic pain. Also, clarifying the role that inflammation plays in the injured tissue that is increasing the sensitization of nociceptors has led to drug therapies incorporating NSAIDs and COX-2 agents in preemptively controlling post-op pain. Blocking the pain signal by a variety of methods including perioperative administration of narcotics, anti-inflammatories, and peripheral nerve blockade (multimodal) has improved postoperative pain management and has improved the overall quality and efficiency of care [61–63]. One drug that may be underutilized in the elderly is acetaminophen. Intravenous acetaminophen has been widely used in Europe with great success and its recent approval for use in the United States has made perioperative use of this drug a new tool in pain management of the elderly patient. At Hospital for Special Surgery multimodal pain management strategies have also been dramatically effective in helping elderly patients' recovery from total knee replacement. Our protocol is based on the successful experience using intra-articular continuous infusion of local anesthetic rather than reliance on epidural analgesia in total knee replacement patients [64]. In this protocol patients are pretreated with a COX-2 inhibitor and decadron. Intraoperatively spinal or epidural anesthesia is augmented with a peripheral nerve block and additional NSAID or acetaminophen. Prior to wound closure an indwelling catheter is placed in the knee or a high volume local infiltration of a pain cocktail is given. If a catheter is placed, continuous infusion of local anesthetic (ropivacaine) is administered for 48 h after surgery. Further patient controlled analgesia is avoided and usually only small doses of oral narcotics are required for the first several weeks following surgery. We remain enthusiastic about this approach which moves the target of the pain intervention from central to the peripheral site of pain, thereby decreasing the centrally mediated side effects which are so counterproductive in the elderly patient.

## Physical Therapy and Rehabilitation of the Elderly

Rehabilitation of the elderly patient following major orthopedic surgery should be aimed to optimize physical, intellectual, psychological, and social function. A multidisciplinary approach involving physical and occupational therapy is needed, and the rehabilitation process should be expected to take 6–12 months depending on the type of surgery performed. Expectations for recovery must assess the pre-surgical health of the patient again emphasizing that the relative fitness or frailty of the patient is more important than their chronological age.

Rehabilitation following hip fracture repair is an especially complex task. It is well recognized that prompt surgical treatment of the hip fracture patient is usually associated with improved survival with fewer postoperative complications. The benefit of early surgery is attributed to relief of pain and restoration of mobility [47–49]. It follows that prompt surgery leads to prompt rehabilitation. Early mobilization out of bed and gait training are the early goals but later physical therapy should target the restoration of joint mobility and muscle strength, improvement in balance the aim of which is falls prevention. Ultimately, every effort should be made to help train the elderly hip fracture patient to regain their pre-injury level of function so that they can once again enjoy life and resume their pre-injury lifestyle.

Elderly hip fracture patients face many challenges in the rehab process (Table 18.3). Nonetheless it is well established that elderly patients respond well to the rehabilitation effort. Frailty and sarcopenia result in reduced muscle strength and contribute to poor balance and physical function in the elderly. Indeed these phenomena are often the root cause of the fall that produced the hip fracture and such deficits must be addressed in order to maximize recovery following hip fracture surgery. Following the initial period of healing, which usually takes 6–12 weeks, a physical therapy program directed at improvement in muscle strength, endurance, coordination, and balance should be instituted. Improvement in function is usually evident for at least 6 months after fracture [50] justifying a prolonged and progressive program. Although no specific

regimen has been documented to be superior [65], combinations of exercises incorporating strength and endurance training are the most effective. Several recent studies clearly document the benefit of aggressive and prolonged training programs for the elderly as they result in better muscle strength, endurance, and improved balance [66–68].

Rehabilitation following total joint arthroplasty is also needed for patients to achieve the optimal benefits of these procedures. Because TJA is elective, the process of rehabilitation should be multidisciplinary, structured, and should address all the contextual factors of these patients. These factors include coping skills, the home environment, social supports, and self-efficacy of these elderly patients. Education and preoperative training programs are effective and structured goals for the recovery period should be well defined. Milestones for recovery have been used to document the important aspects of post-TJA rehabilitation programs [69, 70]. When patients and their families are educated as to these goals during their preoperative preparation for surgery, they can perform preoperative fitness training, undertake adjustments to their living environment in anticipation of the post-op recovery, and become overall more engaged in the rehabilitation process.

The lessons learned from rehabilitation of the elderly hip fracture patient also apply to the elderly joint replacement patient. Age-related musculoskeletal, cognitive, and sensory impairments should be taken into account. As opposed to the hip fracture setting, the elective aspect of TJA allows prospective planning along the continuum of postoperative recovery and should include factors which aim to improve enjoyment of quality of life, activities that promote mobility, leisure time, and sports. Resistance exercises, endurance, and falls prevention training should all be included. Recovery following TJA especially TKR is prolonged with improvement possible over the entire first year. Patients should be fully aware of the slow nature of this recovery and their rehabilitation program should be designed with this in mind [71].

## Summary

The changing demographics of our society make it clear that elderly patients will predominate much of orthopedic practice in the future. As such the special needs of these patients must be anticipated. The concept of "homeostenosis" is useful in understanding the special risks associated with surgery in patients of advanced age. Also important, however, is the understanding that chronological age by itself is not an appreciable risk; rather it is overall health. The elderly should be assessed as "fit" or "frail," and their care plan adjusted accordingly. Elderly patients have the same potential to benefit from orthopedic reconstructive procedures, and they have the potential to greatly improve their overall health and quality of life with orthopedic reconstruction. When elective surgery is planned the special needs of the elderly patient should be anticipated with preoperative medical optimization, preoperative physical conditioning, preoperative education, and planning for a prolonged recovery process. Current evidence strongly suggests that with appropriate care the elderly benefit from orthopedic reconstruction to the same degree as younger counterparts.

**Summary Bullet Points**

- Special considerations related to aging (homeostenosis) must be addressed when elderly patients require orthopedic surgery.
- Assessment of risk and surgical planning should be based on the elderly patient's "fitness" as opposed to their chronological age.
- Modifications of surgical technique which take into account the lower demands of the elderly can help eliminate potential postoperative risks. An example of this would include use of constrained THR components which prevent postoperative dislocation.
- The elderly patient has the potential to benefit as much from orthopedic reconstruction as younger counterparts but special rehabilitation strategies should be incorporated into their treatment plans.

## References

1. Etzioni DA, Liu JH, Maffart MA, Ko CY. The aging population and its impact on the surgery workforce. Ann Surg. 2003;238(2):170–7.
2. Kozak LJ, Owings MF, Hall MJ. National Hospital Discharge Survey: 2002 annual summary with detailed diagnosis and procedure data. Vital Health Stat. 2005;158:1–199.
3. Palmer RM. Perioperative care of the elderly patient. Cleve Clinic J Med. 2006;73:S106–10.
4. Ehlenbach WJ, Hough CL, Crane PK, et al. Association between acute care and critical illness hospitalization and cognitive function in older adults. JAMA. 2010;303(8):763–70.
5. Terrando N, Brzezinski M, Degos V, et al. Perioperative cognitive decline in the aging population. Mayo Clin Proc. 2011;86(9):885–93.
6. Lundstom M, Bucht EA, Karlsson S, et al. Dementia after delirium in patient with femoral neck fractures. J Am Geriatr Soc. 2003;51:1002–6.
7. Monk TG, Weldon BC, Garvan CW, et al. Predictors of cognitive dysfunction after major noncardiac surgery. Anesthesiology. 2008;108(1):18–30.
8. Terrando N, Monaco C, Ma D, et al. Tumor necrosis factor-*alpha* triggers a cytokine cascade yielding postoperative cognitive decline. Proc Natl Acad Sci U S A. 2010;107(47):20518–50522.
9. Cibelli M, Figalgo AR, Terrando N, et al. Role of interleukin-1*B* in postoperative cognitive dysfunction. Ann Neurol. 2010;68(3):360–8.

10. Beloosesky Y, Hendel D, Weiss A, et al. Cytokines and C-reactive protein production in hip-fracture-operated elderly patients. J Gerontel A Biol Sci Med Sci. 2007;62(4):420–6.
11. Konsman JP, Parnet P, Dantzer R. Cytokine-induced sickness behavior: mechanisms and implications. Trends Neurosci. 2002; 25(39):154–9.
12. Kelley K, et al. Cytokine-induced sickness behavior. Brain Behav Immun. 2007;17:S112–8.
13. Xie Z, Tanzi RE. Alzheimer's disease and post-operative cognitive dysfunction. Exp Gerontol. 2006;41(4):346–59.
14. Eckenhoff RG, Johansson JS, Wei H, et al. Inhaled anesthetic enhancement of amyloid-*B* oligomerization and cytotoxicity. Anesthesiology. 2004;101(3):703–7709.
15. Dong Y, Zhang G, Zhang B, et al. The common inhalational anesthetic sevoflurane induces apoptosis and increased *B*-amyloid protein levels. Arch Neurol. 2009;66(5):620–31.
16. Zhen Y, Dong Y, Wu X, et al. Nitrous oxide plus isoflurane induces apoptosis and increases *B*-amyloid protein levels. Anesthesiology. 2009;111(4):741–52.
17. Wang DS, Orser BA. Inhibition of learning and memory by general anesthetics. Can J Anaesth. 2011;58(2):167–77.
18. Williams-Russo P, Sharrock NE, Mattis S, et al. Cognitive effects after epidural vs general anesthesia in older adults: a randomized trial. JAMA. 1995;274(1):44–50.
19. Rasmussen LS, Johnson T, Kuipers HM, et al. Does anaesthesia cause postoperative cognitive dysfunction? A randomized study of regional versus general anaesthesia in 438 elderly patients. Acta Anaesthesiol Scand. 2003;47(3):260–6.
20. Inouye SK, Viscoli CM, Horwitz RI, et al. A predictive model for delirium in hospitalized elderly medical patients based on admission characteristics. Ann Int Med. 1992;119:474–81.
21. Inouye SK, Charpentier PA. Precipitating factors for delirium in hospitalized elderly persons. Predictive model and interrelationship with baseline vulnerability. JAMA. 1996;275:852–7.
22. Marcantonio ER, Goldman L, Mangione CR, et al. A clinical prediction rule for delirium after elective noncardiac surgery. JAMA. 1994;271:134–9.
23. Kapoor A, Fixley J. Postoperative delirium. In: Cohen SL, editor. Perioperative medicine. New York, NY: Springer; 2010. Chapter 44.
24. Fried LP, Walston JD, Ferrucci L. Frailty. In: Hazzard WR et al., editors. Principles of geriatric medicine and gerontology. 6th ed. New York, NY: McGraw Hill; 2009.
25. Rockwood K, Stadnyk K, MacKnight C, et al. A brief clinical instrument to classify frailty in elderly people. Lancet. 1999; 353:205–6.
26. Fried LP, Tangen CM, Walston J, et al. Frailty in older adults: evidence for a phenotype. J Gerontol. 2001;56A(3):M146–56.
27. Coleman EA, Sj M, Chomiak A, et al. Posthospital care transitions: patterns, complications, and risk identification. Health Serv Res. 2004;39(5):1449.
28. Lyons WL, Coleman EA. Transitional care. In: Hazzard WR et al., editors. Principles of geriatric medicine and gerontology. 6th ed. New York, NY: McGraw-Hill; 2009.
29. Cohendy R, Brougere A, Cuvillon P. Anesthesia in the older patient. Curr Opin Clin Nutr Metab Care. 2005;8(1):17–21.
30. Fong TG, Tulebaev SR, Inouye SK. Delirium in elderly adults: diagnosis, prevention and treatment. Nat Rev Neurol. 2009;5(4): 210–20.
31. Ely EW, Shintani A, Truman B, et al. Delirium as a predictor of mortality in mechanically ventilated patients in the intensive care unit. JAMA. 2004;291(14):1753–62.
32. Milbrandt EB, Deppen S, Harrison PL, et al. Costs associated with delirium in mechanically ventilated patients in the intensive care unit. Crit Care Med. 2004;32(4):955–62.
33. Ely EW, Gautam S, Margolin R, et al. The impact of delirium in the intensive care unit on hospital length of stay. Intensive Care Med. 2001;27(12):1892–900.
34. McNicoll L, Pisani MA, Zhang Y, Ely EW, et al. Delirium in the intensive care unit: occurrence and clinical course in older patients. J Am Geriatr Soc. 2003;51(50):591–8.
35. Williams-Russo P, Urquhart BL, Sharrock NE, et al. Post-operative delirium: predictors and prognosis in elderly orthopedic patients. J Am Geriatr Soc. 1992;40(8):759–67.
36. Dyer CB, Ashton CM, Teasdale TA. Postoperative delirium: a review of 80 primary data-collection studies. Arch Intern Med. 1995;155(5):461–5.
37. Caza N, Taha R, Qi Y, et al. The effects of surgery and anesthesia on memory and cognition. Prog Brain Res. 2008;169:409–22.
38. Steinmetz J, Christensen KB, Lund T, et al. Long-term consequences of postoperative cognitive dysfunction. Anesthesiology. 2009;110 (3):548–55.
39. Moller JT, Cluitmans P, Rasmussen LS, et al. Long-term postoperative dysfunction in the elderly. ISPOCD1 study. ISPOCD investigators. Lancet. 1998;351(9106):857–61.
40. Price CC, Garvan CW, Monk TG. Type and severity of cognitive decline in older adults after noncardiac surgery. Anesthesiology. 2008;108(1):8–17.
41. Abildstrom H, Rassmussen LS, Rentowl P, et al. Cognitive dysfunction 1-2 years after non-cardiac surgery in the elderly. ISPOCD group. Acat Anaesthesiol Scand. 2000;44(10):1246–51.
42. Lundstrom M, Bucht EA, Karlsson S, et al. Dementia after delirium in patients with femoral neck fractures. J Am Geriatr Soc. 2003; 51:1002–6.
43. Hung WW, Egol KA, Zuckerman JD, Siu AL. Hip fracture management: tailoring care for the older patient. JAMA. 2012;307 (20):2185–94.
44. Hannan EL, Magaziner J, wang JJ, et al. Mortality and locomotion 6 months after hospitalization for hip fracture: risk factors and risk-adjusted hospital outcomes. JAMA. 2001;285(21):2736–42.
45. Lu-Yao GL, Baron JA, Barrett JA, Fisher ES. Treatment and survival among elderly Americans with hip fractures: a population-based study. Am J Public Health. 1994;84(8):1287–91.
46. Cumming RG, Klineberg R, Katelaris A. Cohort study of risk of institutionalization after hip fracture. Aust N A J Public Health. 1996;20(6):579–82.
47. Orosz GM, Magaziner J, Hannan EL, et al. Association of timing of surgery for hip fracture and patient outcome. JAMA. 2004;291 (14):1738–43.
48. Zuckerman JD, Skovron ML, Koval KJ, et al. Postoperative complication and mortality associated with operative delay in older patients who have a fracture of the hip. J Bone Joint Surg Am. 1995;77(10):1551–6.
49. Vidan MT, Sanchez E, Gracia Y, et al. Causes and effects of surgical delay in patients with hip fracture: a cohort study. Ann Intern Med. 2011;155(4):226–33.
50. Peterson M, Cornell CN, Paget SA, Allegrante JP. Five year survival of a cohort of hip fracture patients: the predictive role of preinjury health status. HSS J. 2008;4:43–7.
51. Patterson BM, Cornell CN, Carbone EA, Levine B, Chapman D. Protein depletion and metabolic stress in elderly patients who have a fracture of the hip. J Bone Joint Surg. 1992;74-A (2):251–60.
52. Koval KJ, Maurer SG, Su ET, Aharonoff GB, Zuckerman JD. The effects of nutritional status on outcome after hip fracture. J Orthop Trauma. 1999;13(3):164–9.
53. Wyers CE, Reijven PL, Evers SM, Willems PC, Heyligers IC, Verburg AD, van Helden S, Dagnelie PC. Cost-effectiveness of nutritional intervention in elderly subjects after hip fracture. A randomized controlled trial. Osteoporos Int. 2013;24(1):151–62.
54. Avenell A, Handoll HH. Nutritional supplementation for hip fracture aftercare in the elderly. Cochrane Database Syst Rev 2004;(1): CD001880
55. Lyons AR. Clinical outcomes and treatment of hip fractures. Am J Med. 1997;103(2A):51S–63. discussion 63S–64S.

56. Blofeldt R, Tornkvist H, Ponzer S, Soderqvist A, Tidermark J. Comparison of internal fixation with total hip replacement for displaced femoral neck fractures. J Bone Joint Surg. 2005; 87A: 1680–8.
57. Jacobs JJ, Andersson GBJ, Bell JE, Weinstein SL, editors. The burden of musculoskeletal diseases in the United States. Rosemont, IL: American Acad of Ortho Surg; 2008. Chapter 2.
58. Berend ME, Thong AE, Faris GW, Newbern G, Pierson JL, Ritter MA. Total joint arthroplasty in the extreme elderly. J Arthroplasty. 2003;18:817–21.
59. L'Insalata J, Stern SH, Insall JN. Total knee arthroplasty in elderly patients. J Arthroplasty. 1992;7:261–6.
60. Shah AK, Celestin J, Parks M, Levy R. Long term results of total joint arthroplasty patients who are frail. CORR. 2004;425:106–9.
61. Ekman EF, Koman LA. Acute pain following musculoskeletal injuries and orthopedic surgery: mechanisms and management. Inst Course Lect. 2005;54:21–33.
62. Hebl JR, Dilger JA, Byer DE, Kopp SL, Stevens SR, Pagnano MW, Hansen AD, Harlocker TT. A pre-emptive mutimodal pathway featuring peripheral nerve blockade improves post-operative outcomes after major orthopedic surgery. Reg Anesth Pain Manag. 2008;33:510–7.
63. Pagnotto MR, Pagnano MW. Multimodal pain management with peripheral nerve blocks for total knee arthroplasty. Instr Course Lect. 2012;61:389–95.
64. Gómez-Cardero P, Rodríguez-Merchán EC. Postoperative analgesia in TKA: ropivacaine continuous intraarticular infusion. Clin Orthop Relat Res. 2010;468(5):1242–7.
65. Crotty M, Unroe K, Cameron ID, Miller M, Ramirez G, Couzner L. Rehabilitation interventions for improving physical and psychosocial functioning after hip fracture in older people. Cochrane Database Syst Rev 2010;(1):CD007624
66. Leenders M, Verdijk LB, van der Hoven L, van Kranenburg J, Nilwik R, van Loon LJ. Elderly men and women benefit equally from prolonged resistance-type exercise training. J Gerontol A Bio Med Sci. 2013;68(7):769–79.
67. Lee HC, Chang KC, Tsauo JY, Huang YC, Lin SI. Effects of a multifactorial fall prevention program on fall incidence and physical function in community-dwelling elderly with risk of fall. Arch Phys Med Rehabil. 2013;94(4):606–15. 615.e1.
68. Busch JC, Lillou D, Wittig G, Bartsch O, Willemsen D, Oldridge N, Bjarnason-Weherns B. Resistance and balance training improves functional capacity in very old participants attending cardiac rehabilitation after coronary bypass surgery. J Am Geriatr Soc. 2012;60:2270–6.
69. Munin MC, Rudy TE, Glynn NW, Crossett LS, Rubash HE. Early inpatient rehabilitation after elective hip and knee arthroplasty. Early inpatient rehabilitation after elective hip and knee arthroplasty. JAMA. 1998;279:847–52.
70. Juliano K, Edwards D, Spinello D, Capizzano Y, Epelman E, Kalowitz J, Lempel A, Ghomrawi H. Initiating physical therapy on the day of surgery decreases length of stay without compromising functional outcomes following total hip arthroplasty. HSS J. 2011; 7:16–20.
71. Westby MD. Rehabilitation and total joint arthroplasty. Clin Geriatr Med. 2012;28:489–508.

# Venous Thromboembolism and Orthopedic Surgery

19

Anne R. Bass

**Objectives**

- To review the problem of venous thromboembolism in orthopedic surgery.
- To review risk factors and screening strategies for venous thromboembolism.
- To review prevention strategies for venous thromboembolism.
- To review current treatment options in various orthopedic surgical settings.

**Key Points**

- Thromboembolism is an important perioperative consideration in orthopedic surgery.
- Well-established strategies have been developed for the prevention, detection, and treatment of these complications.
- There are an evolving range of anticoagulants that can be employed both for the prevention and treatment of thromboembolic events.

## Introduction

Venous stasis, endothelial injury, and hypercoagulability (Virchow's triad) can all contribute to thrombosis and all three are often present in orthopedic patients. It should come as no surprise then that venous thromboembolism (VTE) is a frequent complication of orthopedic surgery.

A.R. Bass (✉)
Department of Medicine, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA
e-mail: bassa@hss.edu

Risk factors for VTE can be separated into those that are patient-related, and those that are procedure-related. Patient-related factors can include the inherited and acquired thrombophilias listed in Table 19.1. While these genetic conditions can be associated with a greatly increased risk of thrombosis, they are present in only a small percentage of the population (0.1–5 %) [1–5]. Although thrombophilic allelic variants are enriched in arthroplasty patients experiencing pulmonary embolism (PE) [6], they do not explain most cases of postoperative VTE. Clinical risk factors for VTE are listed in Table 19.2. While these factors carry less risk than the inherited thrombophilias, they are far more prevalent in the general population [7–12].

Although patient-related risk factors are important in the genesis of thrombosis, it is the procedure itself that places orthopedic patients at such high risk for VTE. VTE rates following orthopedic surgery are higher than after almost any other type of procedure. Historically, in the absence of pharmacological prophylaxis, rates of PE following hip fracture surgery were 4–24 % (3.6–12.9 % fatal) and that following hip or knee arthroplasty 0.9–28 % (0.1–2 % fatal) [13]. Although these rates have come down thanks to modern surgical and anesthetic techniques, there is no question that bone and joint surgery strongly activate the coagulation cascade. In hip arthroplasty, prothrombin fragment levels peak during femoral bone preparation [14, 15]. Intraoperative limb positioning and the use of tourniquets also contribute to VTE risk by inducing venous stasis and endothelial injury [16]. Additional arthroplasty-related VTE risk factors are listed in Table 19.3 [10, 17–21].

## Diagnosis of VTE

Symptoms of deep vein thrombosis (DVT) include calf or thigh pain and swelling, symptoms that can sometimes be difficult to interpret in patients who have undergone lower extremity surgery. D-dimer levels are elevated in most patients following orthopedic surgery making them of

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_19, 

**Table 19.1** Thrombophilias

| |
|---|
| Factor V Leiden |
| Prothrombin *G20210A* mutation |
| Methyltetrahydrofolate reductase mutation |
| Plasminogen activator inhibitor-1 mutation |
| Protein S deficiency |
| Protein C deficiency |
| Antithrombin III deficiency |
| Antiphospholipid antibody syndrome (acquired) |

**Table 19.2** Patient-related risk factors for VTE[a]

| |
|---|
| Advanced age |
| African American race |
| Cancer |
| Central venous access (IV or pacemaker) |
| Chronic lung disease |
| Congestive heart failure |
| Estrogen |
| History of VTE |
| Immobility |
| Inflammatory bowel disease |
| Myeloproliferative diseases |
| Non-O ABO(H) blood type |
| Obesity |
| Rheumatic disease |
| Sleep apnea |
| Smoking |
| Venous insufficiency |

*VTE* venous thromboembolism
[a]Protective: Asian or Pacific Islander race, statin therapy

**Table 19.3** Arthroplasty-related risk factors for VTE[a]

| |
|---|
| General anesthesia |
| Bilateral |
| Revision |
| Fracture as indication |

*VTE* venous thromboembolism
[a]Protective: Autologous blood donation

limited utility in this setting [22]. Ultrasound (USG) of the lower extremities has largely supplanted venography for the diagnosis of DVT because it is noninvasive and less expensive. Although USG is less sensitive (83 %) than venography (the gold standard), particularly for distal clots [23], over 85 % of patients with symptomatic DVT have proximal vein thrombosis [24]. Color echo-Doppler USG is more sensitive than compression USG for the detection of calf clots, but it is also more expensive [25].

Symptoms of PE include shortness of breath, hypoxemia, tachycardia, chest pain, syncope, or in rare cases sudden death. The diagnosis can be made by ventilation perfusion scan, CT angiography, or angiogram. CT angiography has largely supplanted ventilation perfusion scanning because it is easier to perform and provides additional clinical information to treating physicians, such as the presence or absence of pneumonia or fluid overload. CT angiography detects more clots than ventilation perfusion scanning, however, and the significance of isolated subsegmental clots has been questioned [26].

## Screening for VTE in Asymptomatic Patients

Historically, studies of hip and knee arthroplasty in which mandatory venography was performed demonstrated DVT in well over half of patients in the absence of prophylaxis; the rate of clinically apparent DVT is much lower, however [27]. Clinically apparent PE also represents only a subset of all PE. In a study in which mandatory ventilation perfusion scanning was performed in all patients who had undergone hip or knee arthroplasty, PE was found in 5–19 % but only 1–3 % of them were symptomatic [28, 29]. The rational for radiographic screening for DVT in clinical trials (as distinct from clinical practice) is to increase the number of patients achieving the trial endpoint, thus lessening the number of patients needed to power the study. The rate of subclinical DVT serves as a surrogate marker for the outcome of interest, that is, clinically apparent VTE. It would be impractical to design a prospective orthopedic trial using PE or death as its end point, although these are the outcomes of interest to clinicians, because the number of patients needed to treat (to demonstrate a difference in the two study arms) would be prohibitively large. This is important to recognize when interpreting the results of clinical trials. Some prophylaxis studies are quoted as demonstrating "equal" rates of PE or death in two study arms when in fact the studies are inadequately powered to do so [30, 31]. In future, studies using orthopedic registries and administrative databases may allow for analyses of these important outcomes.

Neither the American College of Chest Physicians (ACCP) nor the American Academy of Orthopedic Surgeons (AAOS) recommends screening asymptomatic patients postoperatively for DVT in clinical practice [32, 33]. The sensitivity of lower extremity USG in asymptomatic patients is only 47 %, far lower than in symptomatic patients [34]. This may relate to the localization and quality of clots in asymptomatic versus symptomatic patients. Sixty-six percent of DVT are in the calf in asymptomatic patients versus 15 % in symptomatic patients. In addition, when proximal DVT is present in an asymptomatic patient, it is often less extensive than in symptomatic patients. Finally, asymptomatic thrombi tend to be more recent in onset and less organized, which makes them harder to image [34].

Two studies have suggested that the use of screening USG at the time of discharge after arthroplasty does not predict who will develop future VTE. In one study of almost

2,000 hip and knee arthroplasty patients who received low molecular weight heparin (LMWH) postoperatively, predischarge USG demonstrated clots in only 0.15 % of patients [35]. Nonetheless, VTE occurred in 2 % of patients after discharge (and one patient died of a PE despite a negative predischarge USG). In another study, 1,026 hip and knee arthroplasty patients who received warfarin postoperatively were randomized to predischarge USG or sham USG [36]. There were asymptomatic DVT in 3.7 % of the screened group (they were treated). After discharge symptomatic VTE occurred in 0.87 % of the USG group, and 1 % of the sham USG group, suggesting no benefit to screening.

### Baseline VTE Risk

Advances in surgical and anesthetic technique as well as early mobilization in the postoperative period have helped to dramatically reduce the risk of postoperative VTE following orthopedic surgery. This has forced a reappraisal of the true risk of VTE in the absence of prophylaxis. Current prophylaxis trials in arthroplasty patients typically lack a placebo arm and instead use LMWH as the "gold standard" against which newer agents are compared. In order to determine the contemporary risk of VTE in the absence of prophylaxis, investigators have had to extrapolate from on-prophylaxis VTE rates in patients receiving LMWH in current trials. Off-prophylaxis rates are estimated based on the assumption (from older studies) that LMWH cuts the risk of DVT by about half and of PE by two-thirds [33].

The risk of VTE following various types of orthopedic surgery in the absence of prophylaxis is listed in Table 19.4 [33, 37–46]. Although the risk of VTE is highest in patients with hip fracture and in patients undergoing hip or knee arthroplasty, patients undergoing other orthopedic procedures can also experience VTE, particularly if they have additional thrombosis risk factors.

**Table 19.4** Risk of VTE without prophylaxis

| Procedure | DVT[a] (%) | PE (%) | Fatal PE (%) |
|---|---|---|---|
| Hip arthroplasty | 41–85 | 1.5[b] | 0.15 (THR, TKR)[c] |
| Knee arthroplasty | | | |
| Hip fracture surgery | | | |
| Spine surgery | 0.3–15.5 | 0.02–2.4 | 0–0.6 |
| Knee arthroscopy | 3.2–17.9 | 0–0.3 | 0 |
| Shoulder arthroplasty | 13 | 0.2–0.7 | 0–1 |
| Foot/ankle surgery | 3.5 | 0–0.15 | 0 |

*VTE* venous thromboembolism, *TKR* total knee replacement, *THR* total hip replacement
[a]Symptomatic and asymptomatic DVT (as detected by mandatory venographic or ultrasound screening on all patients)
[b]Estimate of contemporary rates [33]
[c]Estimate based on usual ratio of total to fatal PE

**Table 19.5** Nonpharmacological approaches to VTE prophylaxis

| |
|---|
| Autologous blood donation |
| Epidural anesthesia |
| Intermittent pneumatic compression |
| Early ambulation |

*VTE* venous thromboembolism

## Prevention of VTE

### Nonpharmacological Approaches

Most prospective, randomized clinical trials of VTE prophylaxis address pharmacological approaches, but the nonpharmacological approaches, listed in Table 19.5, can also have a major impact on VTE risk [17, 47–49]. For example, small prospective controlled trials have demonstrated that intermittent pneumatic compression (plus aspirin) is effective in preventing VTE following knee replacement surgery [49–51], and a retrospective trial demonstrated that patients who underwent autologous blood donation had a 30 % lower rate of DVT following hip replacement surgery [17].

### Inferior Vena Cava Filters

Inferior vena cava (IVC) filter placement is a nonpharmacological approach that is indicated for VTE *treatment* in patients with a contraindication to anticoagulation, or who have recurrent thromboembolism despite adequate anticoagulation [52]. Nonetheless, a recent study demonstrated that IVC filters are placed in almost 1 % of orthopedic surgery patients, and that in over 60 % of cases they are placed for VTE *prophylaxis* [53]. IVC filter placement can be associated with vena cava perforation, filter migration, and filter thrombosis [54]. Although they reduce the risk of PE, IVC filters increase the risk of DVT [55]. Although retrievable filters can obviate some of these risks, only 40 % of patients with retrievable filters have them removed, and filter removal is associated with complications in 11 % of patients [53]. Although well-designed studies are lacking, there may be a rationale for placing IVC filters in patients with a very high risk for VTE (e.g., those with hip fracture or multiple trauma) who also have a contraindication to pharmacological anticoagulation. When possible, retrievable filters should be used and care should be taken to assure filter removal. Patients with a retained filter will benefit from life-long anticoagulation (unless contraindicated) to reduce the risk of filter thrombosis and DVT.

## Pharmacological Options

Aspirin (acetylsalicylic acid) irreversibly inactivates cyclooxygenase (COX) and blocks the formation of thromboxane A2, a mediator of platelet aggregation and vasoconstriction. After a single dose of aspirin, platelet function remains impaired for 4–7 days, but bleeding times generally return to normal within 24–48 h because new, unaffected platelets are released from the bone marrow.

Warfarin inhibits the synthesis of vitamin K-dependent clotting factors, which include Factors II, VII, IX, and X, and the anticoagulant proteins C and S. Although there is an anticoagulant effect by 24 h after warfarin initiation, peak effect is usually delayed 72–96 h. In the immediate postoperative period this has the advantage of lowering the rate of hemorrhage, as compared to more rapidly acting agents such as LMWH, and warfarin remains the anticoagulant of choice of most U.S. orthopedic surgeons [56–58]. A variety of factors influence patient responsiveness to warfarin including age, nutritional status, concomitant medication, and genetic polymorphisms in cytochrome P450 enzymes (CYP2C9) and the vitamin K receptor (VKORC1). Warfarin dosing requires close monitoring of the international normalization ratio (INR), especially during initiation of therapy. Warfarin use can be made safer through the use of a dosing nomogram [59, 60] or by pharmacogenetic dosing [61]. A pharmacogenetic dosing algorithm is available at www.warfarindosing.org. When warfarin is used for VTE prophylaxis, the first dose can be given either the night before or the night of surgery.

Heparin potentiates antithrombin's inhibition of activated Factor X (Factor Xa) and thrombin. Thus it is an "indirect Factor Xa inhibitor." LMWH, such as enoxaparin, is expensive and must be given by subcutaneous injection, but does not require daily blood test monitoring, greatly simplifying its use in the perioperative period. Maximum anticoagulant effect occurs 3–5 h after subcutaneous injection of enoxaparin. Because LMWH is 30 % excreted through the kidneys, its dose should be modified in the presence of renal insufficiency and it should be used with great caution, if at all, in patients with renal failure. LMWH is generally started 12–24 h postoperatively assuming adequate surgical hemostasis. LMWH can, however, be started as early as 6 h after minor procedures, such as an arthroscopic "wash-outs," and in Europe LMWH is started at half dose preoperatively. The use of LMWH in conjunction with an epidural catheter has been associated with epidural and spinal hematomas. Therefore, LMWH should not be used 24 h prior to epidural catheter placement or with an epidural catheter in place, and should not be instituted until 4 h after removal of an epidural catheter [62].

Fondaparinux is a synthetic pentasaccharide that, like heparin, binds to antithrombin and potentiates its inhibition of Factor Xa. Thus it is also an indirect Factor Xa inhibitor. Because it is comprised of a very short polysaccharide chain it does not inhibit thrombin, it does not bind to platelets, and it is generally not associated with heparin-induced thrombocytopenia. Fondaparinux is excreted by the kidneys and should not be used in patients with significant renal impairment. Fondaparinux should also be avoided in patients with an epidural catheter in place [62].

Two new anticoagulants were FDA-approved in 2010: rivaroxaban, which was approved for use as VTE prophylaxis, and dabigatran, which was approved for stroke prevention in patients with atrial fibrillation. These agents have the advantage of being administered orally and at a fixed dose without need for blood test monitoring.

Dabigatran binds directly to the catalytic site of thrombin, blocking its function. Thus it is a "direct thrombin inhibitor." Dabigatran can be associated with dyspepsia and may increase the risk of myocardial infarction [63, 64]. Dabigatran's $t½$ is normally 12–17 h, but it is 80 % excreted by the kidneys so dose reduction should be strongly considered in patients with even mild renal disease, and the drug should be avoided in patients with significant renal impairment. Dabigatran has no antidote.

Rivaroxaban (Xarelto) binds directly to Factor Xa, inhibiting its function (it is a "direct Factor Xa inhibitor"). Its $t½$ is 7–11 h and it is 33 % cleared by the kidneys. It should be avoided in patients with significant renal impairment. Apixaban is another direct Factor Xa inhibitor that was approved by the FDA in 2014 for use in arthroplasty patients.

## VTE Prophylaxis in Orthopedic Patients

### Hip and Knee Arthroplasty

VTE is a common complication of hip and knee arthroplasty, and both PE and DVT are risk factors for postoperative mortality in this setting [65]. There are many prospective randomized controlled trials of VTE prophylaxis in patients undergoing hip and knee arthroplasty; some examples of which are shown in Table 19.6. Although LMWH is more effective than warfarin in preventing VTE in this setting, particularly following TKR, many orthopedists prefer to avoid it because of higher rates of hemorrhage [66–68]. In the United States, warfarin is the form of VTE prophylaxis most commonly prescribed to arthroplasty patients because of its low cost, oral bioavailability, and high effectiveness [56–58]. When either warfarin or LMWH is used, the duration of prophylaxis should be at least 10–14 days, but prolongation of therapy to 4–6 weeks will further reduce the risk of VTE [69–71].

Although aspirin is less efficacious than warfarin or LMWH [33], it was shown to reduce the risk of PE by 30 % in 4,088 arthroplasty patients randomized to aspirin or placebo (in addition to standard of care, which could

**Table 19.6** VTE prophylaxis in hip arthroplasty, knee arthroplasty, and hip fracture

| Study | Reference | Patients | Drug | Total VTE and mortality | Sympto-matic VTE | Major bleeding |
|---|---|---|---|---|---|---|
| Lotke 1996 | [29] | 338 TKR and THR | Aspirin vs low-dose warfarin | 56.6 % vs 53.4 % | Not noted | 3.6 % vs 0.7 % |
| Westrich 2006 | [73] | 275 TKR | Aspirin vs enoxaparin 30 mg bid started 48 h postoperatively, plus IPC | 17.8 % vs 14.1 % | Not noted | None |
| Hull 1993 | [68] | 1,436 TKR and THR | Warfarin vs logiparin (LMWH), 10 days | 44.4 % vs 38.4 %, $P = 0.03$ | 0.4 % vs 1 % | 1.2 % vs 2.8 %, $P = 0.04$ |
| PENTA-THALON | [86] | 2,275 THR | Fondaparinux 2.5 qd vs enoxaparin 30 mg bid, 5–10 days | 6.5 % vs 8.2 % | 1 % vs 0.1 %, $P = 0.006$ | 2.2 % vs 0.9 % |
| PENTA-SACCHA-RIDE | [87] | 1,711 Hip fracture | Fondaparinux 2.5 qd vs enoxaparin 40 mg qd, 5–10 days | 8.3 % vs 19.1 % (VTE only), $P < 0.001$ | 0.5 % vs 0.5 % | 2.2 % vs 2.1 % |
| RE-MODEL | [82] | 2,076 TKR | Dabigatran 150 mg qd vs enoxaparin 40 mg qd, 6–10 days | 40.5 % vs 37.7 % | 0.5 % vs 1.3 % | 1.3 % vs 1.3 % |
| RE-NOVATE | [83] | 3,494 THR | Dabigatran 150 mg qd vs enoxaparin 40 mg qd, 28–35 days | 8.6 % vs 6.7 % | 0.9 % vs 0.4 % | 1.3 % vs 1.6 % |
| RECORD-3 | [81] | 2,531 TKR | Rivaroxaban 10 mg qd vs enoxaparin 40 mg qd, 10–14 days | 9.6 % vs 18.9 %, $P < 0.001$ | 0.7 % vs 2 %, $P = 0.005$ | 0.6 % vs 0.5 % |
| RECORD-1 | [78] | 4,433 THR | Rivaroxaban 10 mg qd vs enoxaparin 40 mg qd, 35 days | 1.1 % vs 3.7 %, $P < 0.001$ | 0.3 % vs 0.7 % | 0.3 % vs 0.1 % |
| ADVANCE | [90] | 3,195 TKR | Apixaban 2.5 mg bid vs enoxaparin 30 mg bid, 10–14 days | 9.0 % vs 8.8 % | 1.2 % vs 0.8 % | 0.7 % vs 1.4 % |
| ADVANCE-3 | [91] | 5,407 THR | Apixaban 2.5 mg bid vs enoxaparin 40 mg qd, 35 days | 1.4 % vs 3.9 % $P < 0.001$ | 0.1 % vs 0.4 % | 0.8 % vs 0.7 % |

include heparin) [72]. In that study, however, and in an early study comparing aspirin to warfarin prophylaxis [29], aspirin therapy was associated with an increased risk of bleeding complications. A small study in knee arthroplasty patients showed aspirin to be as effective as enoxaparin (started 48 h after surgery) when used in conjunction with IPC, without any difference in bleeding complications [73].

"Multimodal prophylaxis" following hip replacement surgery refers to the use of nonpharmacological interventions such as autologous blood donation and IPC; administration of unfractionated heparin intraoperatively (before femoral preparation) [74]; expeditious surgery; minimization of femoral vein occlusion and blood loss, plus the use of aspirin for pharmacological prophylaxis [75]. Although the "multimodal prophylaxis" approach has not been subjected to a randomized prospective controlled trial, advocates argue that it obviates the need for potent anticoagulants such as warfarin or LMWH [76, 77].

New oral anticoagulants promise to greatly expand our approach to VTE prophylaxis. For example, the oral direct Factor Xa inhibitor rivaroxaban has greater efficacy than enoxaparin in preventing postoperative VTE [78, 79]. Although rivaroxaban was not found to increase bleeding risk in these trials, post-marketing data suggest that the bleeding risk may in fact be higher than with LMWH [80, 81]. Dabigatran had an efficacy and safety profile comparable to that of enoxaparin in preclinical orthopedic trials [82, 83] but is not approved in the United States for this indication.

In practice, many arthroplasty surgeons risk stratify their patients and prescribe aspirin to low-risk patients and warfarin (or LMWH) to higher-risk patients. Although risk stratification has not been subjected to a controlled trial, a recent analysis of a large administrative database suggested that lower-risk patients undergoing TKR who received aspirin had lower rates of VTE than patients prescribed warfarin [84].

## Hip Fracture Surgery

Ninety-day mortality following hip fracture was historically as 18 % but is significantly reduced when any form of VTE prophylaxis is used [85]. Elderly patients with hip fracture represent a particularly debilitated cohort. Many are admitted from nursing facilities, and many suffer from dementia. As a consequence, some physicians consider them poor candidates for anticoagulation. Unfortunately, these same patients are at high risk for VTE by virtue of their age and comorbidities. Most debilitated elderly patients are discharged to a supervised facility where they can continue to be monitored closely while receiving anticoagulants.

LMWH, warfarin, or fondaparinux should generally be used as VTE prophylaxis in hip fracture patients. Although fondaparinux is associated with a higher rate of major bleeding than LMWH following arthroplasty [86], it has greater efficacy and equal safety to LMWH in patients with hip fracture [87] (Table 19.6).

Aspirin is less efficacious than warfarin or indirect Factor Xa inhibitors [13], but aspirin did reduce the risk of clinical VTE by 30 % in a study of 13,356 hip fracture patients randomized to aspirin or placebo in addition to usual care (which included heparin in 44 % of patients). This came at the price of more wound and gastrointestinal bleeding complications, however. Although aspirin reduced the rate of fatal PE by 50 % in this trial, other vascular deaths were higher in aspirin-treated patients so overall mortality was not reduced [72].

## Spine Surgery

Among patients undergoing spine surgery, VTE rates are lowest in those undergoing lumbar discectomy, and highest in those undergoing instrumentation and in patients with cancer [37]. There are no prospective randomized controlled trials of VTE prophylaxis in spine surgery patients, but the lowest rates of VTE are reported in cohort studies in which mechanical prophylaxis or heparin is used [38]. Because major hematoma (requiring surgical evacuation) has been reported in 0.4–0.7 % of spine surgery patients receiving heparin or LMWH [88, 89], we recommend prophylaxis be limited to early ambulation and mechanical devices such as IPC in spine surgery patients unless they are at extremely high risk for VTE.

## Knee Arthroscopy

The term "knee arthroscopy" encompasses a wide variety of surgical procedures ranging from simple knee "washout" or meniscectomy to ligament repairs and other procedures involving bone drilling. These differences in surgical invasiveness as well as differences in tourniquet use/duration, type of anesthesia, and duration of postoperative immobility are important procedure-related risk factors to consider, in addition to patient-related risk factors, in assessing the likelihood of postoperative VTE.

LMWH has been shown to reduce the risk of VTE following knee arthroscopy but at the expense of an increased risk of hemorrhage [39–41]. Warfarin has not been studied as VTE prophylaxis following arthroscopy, and is impractical for short-term use in the outpatient setting. There are no studies of aspirin for VTE prophylaxis following knee arthroscopy.

Given the low risk of VTE following knee arthroscopy, we do not recommend routine prophylaxis except in patients with additional risk factors.

## Shoulder Arthroplasty

There are no prospective studies of VTE prophylaxis in patients undergoing shoulder arthroplasty. Because the risk of postoperative VTE is relatively low (Table 19.4), we do not recommend routine pharmacological prophylaxis except in patients with additional VTE risk factors.

## Foot and Ankle Procedures

There are no studies of VTE prophylaxis in patients undergoing elective foot and ankle surgery. Although the risk of postoperative VTE is low following standard podiatric procedures (Table 19.4), it may be higher following the more complex and prolonged procedures performed by orthopedic surgeons. Some patients require prolonged casting and immobilization following these surgeries that also may place them at increased VTE risk. These factors should be considered in deciding whether to recommend pharmacological prophylaxis. Patients with additional VTE risk factors who will be casted for a prolonged period of time may benefit from anticoagulation.

## Summary

VTE is a common complication of orthopedic surgery, particularly hip and knee arthroplasty and hip fracture surgery. Although there are procedural and patient-specific factors that can impact on VTE risk in this setting, no trial has validated VTE risk stratification in these patients. There is a plethora of therapeutic options for VTE prevention, both pharmacological and nonpharmacological, and newly available oral anticoagulants are likely to transform our approach to VTE risk reduction over the coming decade.

**Summary Bullet Points**

- Venous thromboembolism is one of the most common and feared complications of orthopedic surgery.
- Clinical strategies directed at the prevention, surveillance, and treatment of such complications are supported by a prodigious literature.
- The pharmacology for the prevention and treatment of postoperative thromboembolism is evolving

with newer agents recently added to the armamentarium.
- Multimodal approaches to prophylaxis are often employed in the setting of lower extremity arthroplasty.

## References


1. Margaglione M, Grandone E. Population genetics of venous thromboembolism. A narrative review. Thromb Haemost. 2010;105 (2):221–31.
2. Rosendaal FR, Doggen CJ, Zivelin A, Arruda VR, Aiach M, Siscovick DS, Hillarp A, Watzke HH, Bernardi F, Cumming AM, Preston FE, Reitsma PH. Geographic distribution of the 20210 G to A prothrombin variant. Thromb Haemost. 1998;79(4):706–8.
3. Rosendaal FR. Venous thrombosis: the role of genes, environment, and behavior. Hematology Am Soc Hematol Educ Program 2005:1–12.
4. Delluc A, Gourhant L, Lacut K, Mercier B, Audrezet MP, Nowak E, Oger E, Leroyer C, Mottier D, Le Gal G, Couturaud F. Association of common genetic variations and idiopathic venous thromboembolism. Results from EDITh, a hospital-based case-control study. Thromb Haemost. 2010;103(6):1161–9.
5. Wahlander K, Larson G, Lindahl TL, Andersson C, Frison L, Gustafsson D, Bylock A, Eriksson BI. Factor V leiden (G1691A) and prothrombin gene G20210A mutations as potential risk factors for venous thromboembolism after total hip or total knee replacement surgery. Thromb Haemost. 2002;87(4):580–5.
6. Westrich GH, Weksler BB, Glueck CJ, Blumenthal BF, Salvati EA. Correlation of thrombophilia and hypofibrinolysis with pulmonary embolism following total hip arthroplasty: an analysis of genetic factors. J Bone Joint Surg Am. 2002;84-A(12):2161–7.
7. Cushman M. Epidemiology and risk factors for venous thrombosis. Semin Hematol. 2007;44(2):62–9.
8. Caprini JA, Arcelus JI, Reyna JJ. Effective risk stratification of surgical and nonsurgical patients for venous thromboembolic disease. Semin Hematol. 2001;38(2 Suppl 5):12–9.
9. White RH, Zhou H, Gage BF. Effect of age on the incidence of venous thromboembolism after major surgery. J Thromb Haemost. 2004;2(8):1327–33.
10. Memtsoudis S, Liu SS, Ma Y, Chiu YL, Walz JM, Gaber-Baylis LK, Mazumdar M. Perioperative pulmonary outcomes in patients with sleep apnea after noncardiac surgery. Anesth Analg. 2011;112 (1):113–21.
11. Imberti D, Bianchi C, Zambon A, Parodi A, Merlino L, Gallerani M, Corrao G. Venous thromboembolism after major orthopaedic surgery: a population-based cohort study. Intern Emerg Med. 2012;7(3):243–9.
12. Pedersen AB, Sorensen HT, Mehnert F, Overgaard S, Johnsen SP. Risk factors for venous thromboembolism in patients undergoing total hip replacement and receiving routine thromboprophylaxis. J Bone Joint Surg Am. 2010;92(12):2156–64.
13. Geerts WH, Pineo GF, Heit JA, Bergqvist D, Lassen MR, Colwell CW, Ray JG. Prevention of venous thromboembolism: the seventh ACCP conference on antithrombotic and thrombolytic therapy. Chest. 2004;126(3 Suppl):338S–400.
14. Dahl OE, Pedersen T, Kierulf P, Westvik AB, Lund P, Arnesen H, Seljeflot I, Abdelnoor M, Lyberg T. Sequential intrapulmonary and systemic activation of coagulation and fibrinolysis during and after total hip replacement surgery. Thromb Res. 1993;70(6):451–8.
15. Sharrock NE, Go G, Harpel PC, Ranawat CS, Sculco TP, Salvati EA. The John Charnley award. Thrombogenesis during total hip arthroplasty. Clin Orthop Relat Res 1995;(319):16–27.
16. Nishiguchi M, Takamura N, Aoyagi K. Ximelagatran versus warfarin after total knee replacement. N Engl J Med. 2004;350 (6):616–7. author reply 616–7.
17. Bae H, Westrich GH, Sculco TP, Salvati EA, Reich LM. The effect of preoperative donation of autologous blood on deep-vein thrombosis after total hip arthroplasty. J Bone Joint Surg Br. 2001;83 (5):676–9.
18. Memtsoudis SG, Gonzalez Della Valle A, Besculides MC, Gaber L, Sculco TP. In-hospital complications and mortality of unilateral, bilateral, and revision TKA: based on an estimate of 4,159,661 discharges. Clin Orthop Relat Res. 2008;466(11):2617–27.
19. Warwick D, Friedman RJ, Agnelli G, Gil-Garay E, Johnson K, FitzGerald G, Turibio FM. Insufficient duration of venous thromboembolism prophylaxis after total hip or knee replacement when compared with the time course of thromboembolic events: findings from the global orthopaedic registry. J Bone Joint Surg Br. 2007;89 (6):799–807.
20. Woller SC, Stevens SM, Jones JP, Lloyd JF, Evans RS, Aston VT, Elliott CG. Derivation and validation of a simple model to identify venous thromboembolism risk in medical patients. Am J Med. 2011;124(10):947–954.e2.
21. Restrepo C, Parvizi J, Dietrich T, Einhorn TA. Safety of simultaneous bilateral total knee arthroplasty. A meta-analysis. J Bone Joint Surg Am. 2007;89(6):1220–6.
22. Bounameaux H, Miron MJ, Blanchard J, de Moerloose P, Hoffmeyer P, Leyvraz PF. Measurement of plasma D-dimer is not useful in the prediction or diagnosis of postoperative deep vein thrombosis in patients undergoing total knee arthroplasty. Blood Coagul Fibrinolysis. 1998;9(8):749–52.
23. Kearon C, Julian JA, Newman TE, Ginsberg JS. Noninvasive diagnosis of deep venous thrombosis. McMaster diagnostic imaging practice guidelines initiative. Ann Intern Med. 1998;128 (8):663–77.
24. Hull R, Hirsh J, Sackett DL, Powers P, Turpie AG, Walker I. Combined use of leg scanning and impedance plethysmography in suspected venous thrombosis. An alternative to venography. N Engl J Med. 1977;296(26):1497–500.
25. Palareti G, Cosmi B, Legnani C. Diagnosis of deep vein thrombosis. Semin Thromb Hemost. 2006;32(7):659–72.
26. Anderson DR, Kahn SR, Rodger MA, Kovacs MJ, Morris T, Hirsch A, Lang E, Stiell I, Kovacs G, Dreyer J, Dennie C, Cartier Y, Barnes D, Burton E, Pleasance S, Skedgel C, O'Rouke K, Wells PS. Computed tomographic pulmonary angiography vs ventilation-perfusion lung scanning in patients with suspected pulmonary embolism: a randomized controlled trial. JAMA. 2007;298 (23):2743–5.
27. Geerts WH, Bergqvist D, Pineo GF, Heit JA, Samama CM, Lassen MR, Colwell CW, American College of Chest Physicians. Prevention of venous thromboembolism: American College of Chest Physicians evidence-based clinical practice guidelines (8th edition). Chest. 2008;133(6 Suppl):381S–453.
28. Haas SB, Tribus CB, Insall JN, Becker MW, Windsor RE. The significance of calf thrombi after total knee arthroplasty. J Bone Joint Surg Br. 1992;74(6):799–802.
29. Lotke PA, Palevsky H, Keenan AM, Meranze S, Steinberg ME, Ecker ML, Kelley MA. Aspirin and warfarin for thromboembolic disease after total joint arthroplasty. Clin Orthop Relat Res. 1996; (324):251–8.
30. AAOS. Deep vein thrombosis: from the American Academy of Orthopaedic Surgeons. 2007. Accessed on November 24, 2010.
31. Eikelboom JW, Karthikeyan G, Fagel N, Hirsh J. American association of orthopedic surgeons and American College of Chest Physicians guidelines for venous thromboembolism prevention in

hip and knee arthroplasty differ: what are the implications for clinicians and patients? Chest. 2009;135(2):513–20.
32. AAOS. Guideline on preventing venous thromboembolic disease in patients undergoing elective hip and knee arthroplasty. 2011.
33. Falck-Ytter Y, Francis CW, Johanson NA, Curley C, Dahl OE, Schulman S, Ortel TL, Pauker SG, Colwell Jr CW. Prevention of VTE in orthopedic surgery patients: antithrombotic therapy and prevention of thrombosis, 9th ed: American College of Chest Physicians evidence-based clinical practice guidelines. Chest. 2012;141(2 Suppl):e278S–325.
34. Kearon C. Noninvasive diagnosis of deep vein thrombosis in postoperative patients. Semin Thromb Hemost. 2001;27(1):3–8.
35. Leclerc JR, Gent M, Hirsh J, Geerts WH, Ginsberg JS. The incidence of symptomatic venous thromboembolism during and after prophylaxis with enoxaparin: a multi-institutional cohort study of patients who underwent hip or knee arthroplasty. Canadian collaborative group. Arch Intern Med. 1998;158(8):873–8.
36. Robinson KS, Anderson DR, Gross M, Petrie D, Leighton R, Stanish W, Alexander D, Mitchell M, Flemming B, Gent M. Ultrasonographic screening before hospital discharge for deep venous thrombosis after arthroplasty: the post-arthroplasty screening study. A randomized, controlled trial. Ann Intern Med. 1997;127(6):439–45.
37. Smith JS, Fu KM, Polly Jr DW, Sansur CA, Berven SH, Broadstone PA, Choma TJ, Goytan MJ, Noordeen HH, Knapp Jr DR, Hart RA, Donaldson 3rd WF, Perra JH, Boachie-Adjei O, Shaffrey CI. Complication rates of three common spine procedures and rates of thromboembolism following spine surgery based on 108,419 procedures: a report from the scoliosis research society morbidity and mortality committee. Spine (Phila Pa 1976). 2010;35(24):2140–9.
38. Sansone JM, del Rio AM, Anderson PA. The prevalence of and specific risk factors for venous thromboembolic disease following elective spine surgery. J Bone Joint Surg Am. 2010;92(2):304–13.
39. Wirth T, Schneider B, Misselwitz F, Lomb M, Tuylu H, Egbring R, Griss P. Prevention of venous thromboembolism after knee arthroscopy with low-molecular weight heparin (reviparin): results of a randomized controlled trial. Arthroscopy. 2001;17(4):393–9.
40. Michot M, Conen D, Holtz D, Erni D, Zumstein MD, Ruflin GB, Renner N. Prevention of deep-vein thrombosis in ambulatory arthroscopic knee surgery: a randomized trial of prophylaxis with low-molecular weight heparin. Arthroscopy. 2002;18(3):257–63.
41. Camporese G, Bernardi E, Prandoni P, Noventa F, Verlato F, Simioni P, Ntita K, Salmistraro G, Frangos C, Rossi F, Cordova R, Franz F, Zucchetta P, Kontothanassis D, Andreozzi GM, KANT (Knee Arthroscopy Nadroparin Thromboprophylaxis) Study Group. Low-molecular-weight heparin versus compression stockings for thromboprophylaxis after knee arthroscopy: a randomized trial. Ann Intern Med. 2008;149(2):73–82.
42. Demers C, Marcoux S, Ginsberg JS, Laroche F, Cloutier R, Poulin J. Incidence of venographically proved deep vein thrombosis after knee arthroscopy. Arch Intern Med. 1998;158(1):47–50.
43. Willis AA, Warren RF, Craig EV, Adler RS, Cordasco FA, Lyman S, Fealy S. Deep vein thrombosis after reconstructive shoulder arthroplasty: a prospective observational study. J Shoulder Elbow Surg. 2009;18(1):100–6.
44. Sperling JW, Cofield RH. Pulmonary embolism following shoulder arthroplasty. J Bone Joint Surg Am. 2002;84-A(11):1939–41.
45. Felcher AH, Mularski RA, Mosen DM, Kimes TM, DeLoughery TG, Laxson SE. Incidence and risk factors for venous thromboembolic disease in podiatric surgery. Chest. 2009;135(4):917–22.
46. Solis G, Saxby T. Incidence of DVT following surgery of the foot and ankle. Foot Ankle Int. 2002;23(5):411–4.
47. Davidson HC, Mazzu D, Gage BF, Jeffrey RB. Screening for deep venous thrombosis in asymptomatic postoperative orthopedic patients using color doppler sonography: analysis of prevalence and risk factors. AJR Am J Roentgenol. 1996;166(3):659–62.
48. White RH, Gettner S, Newman JM, Trauner KB, Romano PS. Predictors of rehospitalization for symptomatic venous thromboembolism after total hip arthroplasty. N Engl J Med. 2000;343(24):1758–64.
49. Westrich GH, Sculco TP. Prophylaxis against deep venous thrombosis after total knee arthroplasty. Pneumatic plantar compression and aspirin compared with aspirin alone. J Bone Joint Surg Am. 1996;78(6):826–34.
50. Haas SB, Insall JN, Scuderi GR, Windsor RE, Ghelman B. Pneumatic sequential-compression boots compared with aspirin prophylaxis of deep-vein thrombosis after total knee arthroplasty. J Bone Joint Surg Am. 1990;72(1):27–31.
51. Colwell Jr CW, Froimson MI, Mont MA, Ritter MA, Trousdale RT, Buehler KC, Spitzer A, Donaldson TK, Padgett DE. Thrombosis prevention after total hip arthroplasty: a prospective, randomized trial comparing a mobile compression device with low-molecular-weight heparin. J Bone Joint Surg Am. 2010;92(3):527–35.
52. Buller HR, Agnelli G, Hull RD, Hyers TM, Prins MH, Raskob GE. Antithrombotic therapy for venous thromboembolic disease: the seventh ACCP conference on antithrombotic and thrombolytic therapy. Chest. 2004;126(3 Suppl):401S–28.
53. Bass AR, Mattern CJ, Voos JE, Peterson MG, Trost DW. Inferior vena cava filter placement in orthopedic surgery. Am J Orthop (Belle Mead NJ). 2010;39(9):435–9.
54. Young T, Aukes J, Hughes R, Tang H. Vena caval filters for the prevention of pulmonary embolism. Cochrane Database Syst Rev 2007;(3):CD006212.
55. Decousus H, Leizorovicz A, Parent F, Page Y, Tardy B, Girard P, Laporte S, Faivre R, Charbonnier B, Barral FG, Huet Y, Simonneau G. A clinical trial of vena caval filters in the prevention of pulmonary embolism in patients with proximal deep-vein thrombosis. Prevention du risque d'embolie pulmonaire par interruption cave study group. N Engl J Med. 1998;338(7):409–15.
56. Mesko JW, Brand RA, Iorio R, Gradisar I, Heekin R, Leighton R, Thornberry R. Venous thromboembolic disease management patterns in total hip arthroplasty and total knee arthroplasty patients: a survey of the AAHKS membership. J Arthroplasty. 2001;16(6):679–88.
57. Friedman RJ, Gallus AS, Cushner FD, Fitzgerald G, Anderson Jr FA, Global Orthopaedic Registry Investigators. Physician compliance with guidelines for deep-vein thrombosis prevention in total hip and knee arthroplasty. Curr Med Res Opin. 2008;24(1):87–9.
58. Berry DJ, Bozic KJ. Current practice patterns in primary hip and knee arthroplasty among members of the American association of hip and knee surgeons. J Arthroplasty. 2010;25(6 Suppl):2–4.
59. Anderson DR, Wilson SJ, Blundell J, Petrie D, Leighton R, Stanish W, Alexander D, Robinson KS, Burton E, Gross M. Comparison of a nomogram and physician-adjusted dosage of warfarin for prophylaxis against deep-vein thrombosis after arthroplasty. J Bone Joint Surg Am. 2002;84-A(11):1992–7.
60. Asnis PD, Gardner MJ, Ranawat A, Leitzes AH, Peterson MG, Bass AR. The effectiveness of warfarin dosing from a nomogram compared with house staff dosing. J Arthroplasty. 2007;22(2):213–8.
61. Gage BF. Pharmacogenetics-based coumarin therapy. Hematology Am Soc Hematol Educ Program. 2006:467–73.
62. Horlocker TT, Wedel DJ, Rowlingson JC, Enneking FK, Kopp SL, Benzon HT, Brown DL, Heit JA, Mulroy MF, Rosenquist RW, Tryba M, Yuan CS. Regional anesthesia in the patient receiving antithrombotic or thrombolytic therapy: American Society of Regional Anesthesia and Pain Medicine evidence-based guidelines (third edition). Reg Anesth Pain Med. 2010;35(1):64–101.
63. Adam SS, McDuffie JR, Ortel TL, Williams Jr JW. Comparative effectiveness of warfarin and new oral anticoagulants for the

management of atrial fibrillation and venous thromboembolism: a systematic review. Ann Intern Med. 2012;157(11):796–807.
64. Uchino K, Hernandez AV. Dabigatran association with higher risk of acute coronary events: meta-analysis of noninferiority randomized controlled trials. Arch Intern Med. 2012;172 (5):397–402.
65. Guijarro R, Montes J, San Roman C, Arcelus JI, Barillari G, Granero X, Monreal M. Venous thromboembolism and bleeding after total knee and hip arthroplasty. Findings from the spanish national discharge database. Thromb Haemost. 2010;105(4):610–5.
66. Freedman KB, Brookenthal KR, Fitzgerald Jr RH, Williams S, Lonner JH. A meta-analysis of thromboembolic prophylaxis following elective total hip arthroplasty. J Bone Joint Surg Am. 2000;82-A(7):929–38.
67. Sharrock NE, Gonzalez Della Valle A, Go G, Lyman S, Salvati EA. Potent anticoagulants are associated with a higher all-cause mortality rate after hip and knee arthroplasty. Clin Orthop Relat Res. 2008;466(3):714–21.
68. Hull R, Raskob G, Pineo G, Rosenbloom D, Evans W, Mallory T, Anquist K, Smith F, Hughes G, Green D. A comparison of subcutaneous low-molecular-weight heparin with warfarin sodium for prophylaxis against deep-vein thrombosis after hip or knee implantation. N Engl J Med. 1993;329(19):1370–6.
69. Prandoni P, Bruchi O, Sabbion P, Tanduo C, Scudeller A, Sardella C, Errigo G, Pietrobelli F, Maso G, Girolami A. Prolonged thromboprophylaxis with oral anticoagulants after total hip arthroplasty: a prospective controlled randomized study. Arch Intern Med. 2002;162(17):1966–71.
70. Hull RD, Pineo GF, Stein PD, Mah AF, MacIsaac SM, Dahl OE, Butcher M, Brant RF, Ghali WA, Bergqvist D, Raskob GE. Extended out-of-hospital low-molecular-weight heparin prophylaxis against deep venous thrombosis in patients after elective hip arthroplasty: a systematic review. Ann Intern Med. 2001;135 (10):858–69.
71. Sobieraj DM, Lee S, Coleman CI, Tongbram V, Chen W, Colby J, Kluger J, Makanji S, Ashaye AO, White CM. Prolonged versus standard-duration venous thromboprophylaxis in major orthopedic surgery: a systematic review. Ann Intern Med. 2012;156 (10):720–7.
72. PEP. Prevention of pulmonary embolism and deep vein thrombosis with low dose aspirin: pulmonary embolism prevention (PEP) trial. Lancet. 2000;355(9212):1295–302.
73. Westrich GH, Bottner F, Windsor RE, Laskin RS, Haas SB, Sculco TP. VenaFlow plus lovenox vs VenaFlow plus aspirin for thromboembolic disease prophylaxis in total knee arthroplasty. J Arthroplasty. 2006;21(6 Suppl 2):139–43.
74. Huo MH, Salvati EA, Sharrock NE, Brien WW, Sculco TP, Pellicci PM, Mineo R, Go G. Intraoperative heparin thromboembolic prophylaxis in primary total hip arthroplasty. A prospective, randomized, controlled, clinical trial. Clin Orthop Relat Res 1992; (274):35–46.
75. Salvati EA. Multimodal prophylaxis of venous thrombosis. Am J Orthop (Belle Mead NJ). 2002;31(9 Suppl):4–11.
76. Salvati EA, Sharrock NE, Westrich G, Potter HG, Valle AG, Sculco TP. The 2007 ABJS Nicolas Andry award: three decades of clinical, basic, and applied research on thromboembolic disease after THA: rationale and clinical results of a multimodal prophylaxis protocol. Clin Orthop Relat Res. 2007;459:246–54.
77. Westrich GH, Menezes A, Sharrock N, Sculco TP. Thromboembolic disease prophylaxis in total knee arthroplasty using intraoperative heparin and postoperative pneumatic foot compression. J Arthroplasty. 1999;14(6):651–6.
78. Eriksson BI, Borris LC, Friedman RJ, Haas S, Huisman MV, Kakkar AK, Bandel TJ, Beckmann H, Muehlhofer E, Misselwitz F, Geerts W, RECORD1 Study Group. Rivaroxaban versus enoxaparin for thromboprophylaxis after hip arthroplasty. N Engl J Med. 2008;358(26):2765–7.
79. Lassen MR, Ageno W, Borris LC, Lieberman JR, Rosencher N, Bandel TJ, Misselwitz F, Turpie AG, RECORD3 Investigators. Rivaroxaban versus enoxaparin for thromboprophylaxis after total knee arthroplasty. N Engl J Med. 2008;358(26):2776–8.
80. Jameson SS, Rymaszewska M, Hui AC, James P, Serrano-Pedraza I, Muller SD. Wound complications following rivaroxaban administration: a multicenter comparison with low-molecular-weight heparins for thromboprophylaxis in lower limb arthroplasty. J Bone Joint Surg Am. 2012;94(17):1554–8.
81. Jensen CD, Steval A, Partington PF, Reed MR, Muller SD. Return to theatre following total hip and knee replacement, before and after the introduction of rivaroxaban: a retrospective cohort study. J Bone Joint Surg Br. 2011;93(1):91–5.
82. Eriksson BI, Dahl OE, Rosencher N, Kurth AA, van Dijk CN, Frostick SP, Kalebo P, Christiansen AV, Hantel S, Hettiarachchi R, Schnee J, Buller HR, RE-MODEL Study Group. Oral dabigatran etexilate vs. subcutaneous enoxaparin for the prevention of venous thromboembolism after total knee replacement: the RE-MODEL randomized trial. J Thromb Haemost. 2007;5(11):2178–85.
83. Eriksson BI, Dahl OE, Rosencher N, Kurth AA, van Dijk CN, Frostick SP, Prins MH, Hettiarachchi R, Hantel S, Schnee J, Buller HR, RE-NOVATE Study Group. Dabigatran etexilate versus enoxaparin for prevention of venous thromboembolism after total hip replacement: a randomised, double-blind, non-inferiority trial. Lancet. 2007;370(9591):949–56.
84. Bozic KJ, Vail TP, Pekow PS, Maselli JH, Lindenauer PK, Auerbach AD. Does aspirin have a role in venous thromboembolism prophylaxis in total knee arthroplasty patients? J Arthroplasty. 2010;25(7):1053–60.
85. Todd CJ, Freeman CJ, Camilleri-Ferrante C, Palmer CR, Hyder A, Laxton CE, Parker MJ, Payne BV, Rushton N. Differences in mortality after fracture of hip: the East Anglian audit. BMJ. 1995;310(6984):904–8.
86. Turpie AG, Bauer KA, Eriksson BI, Lassen MR, PENTATHALON 2000 Study Steering Committee. Postoperative fondaparinux versus postoperative enoxaparin for prevention of venous thromboembolism after elective hip-replacement surgery: a randomised double-blind trial. Lancet. 2002;359(9319):1721–6.
87. Eriksson BI, Bauer KA, Lassen MR, Turpie AG, Steering Committee of the Pentasaccharide in Hip-Fracture Surgery Study. Fondaparinux compared with enoxaparin for the prevention of venous thromboembolism after hip-fracture surgery. N Engl J Med. 2001;345(18):1298–304.
88. Wen DY, Hall WA. Complications of subcutaneous low-dose heparin therapy in neurosurgical patients. Surg Neurol. 1998;50 (6):521–5.
89. Gerlach R, Raabe A, Beck J, Woszczyk A, Seifert V. Postoperative nadroparin administration for prophylaxis of thromboembolic events is not associated with an increased risk of hemorrhage after spinal surgery. Eur Spine J. 2004;13(1):9–13.
90. Lassen MR, Raskob GE, Gallus A, Pineo G, Chen D, Portman RJ. Apixaban or enoxaparin for thromboprophylaxis after knee replacement. N Engl J Med. 2009;361(6):594–604.
91. Lassen MR, Gallus A, Raskob GE, Pineo G, Chen D, Ramirez LM, ADVANCE-3 Investigators. Apixaban versus enoxaparin for thromboprophylaxis after hip replacement. N Engl J Med. 2010;363(26):2487–98.

# Coagulation Disorders and Orthopedic Surgery 20

C. Ronald MacKenzie

**Objectives**

- To appreciate the importance of coagulation problems in the perioperative setting.
- To develop an approach to the assessment of bleeding risk that emphasizes information obtained for the medical history, deemphasizing the role of screening laboratory assessment.
- To understand the physiological processes underlying hemostasis.
- To develop an orderly method for the detection of coagulation disorders preoperatively.
- To review the hematological basis for the disorders of primary and secondary hemostasis.

**Key Points**

- Bleeding problems are amongst the greatest fears of the surgeon.
- Hemostasis as a physiological process is well understood.
- Disorders of hemostasis can be the result of primary (platelet related) dysfunction or secondary (clotting factor related).
- Patients at increased risk can be identified based on approaches that rely on the patient's history, deemphasizing the reliance on the laboratory.

C.R. MacKenzie (✉)
Department of Medicine, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA
e-mail: mackenzier@hss.edu

## Introduction

Hematological problems are not uncommon in the perioperative setting. Indeed the bleeding complications of surgery are amongst the greatest of a surgeon's concerns threatening not only the patient but also the success of the surgical procedure. Conversely, thrombosis is a particular fear to the orthopedic surgeon. As a problem commanding a prodigious literature, the thromboembolic complications of orthopedic surgery are reviewed separately in Chap. 19. This chapter will focus on disorders and processes that enhance the risk of bleeding. A practical method for their detection prior to surgery will be developed emphasizing an approach utilizing information derived from the patients' history, deemphasizing a reliance on the laboratory. As such the content of this chapter complements the aforementioned discussion concerning thrombosis but does not represent a comprehensive discourse of the full range of hematological issues that may be seen in the surgical setting.

## The Preoperative Evaluation

The methodologies currently employed for the preoperative identification of patients at risk for bleeding in the setting of surgery have followed two distinct strategies [1]. The traditional approach has been to rely on the laboratory, utilizing routine testing such as the platelet count (primary hemostasis) and the prothrombin (PT) and activated thromboplastin times (aPTT) for the secondary disorders of hemostasis. Despite the persistence of this practice, its shortcomings in the prediction of postoperative bleeding are well recognized and predictable based on the complex physiology of bleeding, a multifactorial process not well assessed in the laboratory. Indeed these laboratory studies were not developed to determine the risk of postoperative bleeding but rather for the detection of clotting factor deficiencies.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_20, 

**Table 20.1** Questionnaire for detection of bleeding risk

| |
|---|
| Have you ever experienced strong nose bleeding without prior reason? |
| Did you ever have—without trauma—"blue spots" (hematoma) or "small bleedings" (at the torso or other unusual regions of the body)? |
| Did you ever have bleeding of the gums without apparent reason? |
| How often do you have bleedings or "blue spots": more than 1–2 times a week or 1–2 times a week? |
| Do you have the impression that you have prolonged bleedings after minor wounds (e.g., razor cuts)? |
| Did you have prolonged or grave bleedings during or after operations (e.g., tonsillectomy, appendectomy, or during labor)? |
| Did you have prolonged or grave bleedings after a tooth extraction? |
| Did you ever receive blood packs or blood products during an operation? If so, please define the operation? |
| Is there a history of bleeding disorders in your family? |
| Do you take analgesic drugs or drugs against rheumatic disease? If so, please specify? |
| Do you take other drugs? If so, please specify? |
| Do you have the impression that you have prolonged menstruation (>7 days) or a high frequency of tampon change? |

Used with permission from Koscielny J, Ziemer S, Radtke H, et al. A Practical Concept for Preoperative Identification of Patients with Impaired Primary Hemostasis Clin Appl Thromb Hemost 2004;10:195–204

**Table 20.2** Distinguishing characteristics of bleeding disorders

| Acquired | Hereditary |
|---|---|
| Negative family history | ≥1 family member affected |
| Presence of associated diseases | Hereditary pattern |
| Variable in time | Fixed pattern of bleeding |
| Variable in aspect and type | History of blood transfusion |
| Onset in middle age or later | Early onset |

Adapted with permission from Girolami A, Luzzatto G, Varvarikis C, et al. Main clinical manifestations of a bleeding diathesis: an often disregarded aspect of medical and surgical history taking. Haemophilia 2005;11:193–202

**Table 20.3** Differential diagnosis based on physical findings

| | |
|---|---|
| *Cutaneous* | |
| Purpura | Coagulation disorders, cryoglobulinemia, steroids vasculitis, Henoch–Schonlein, systemic infection |
| Petechiae | Thrombocytopenia |
| Ecchymosis | Thrombocytopenia, steroids, senile, trauma |
| *Mucosal* | Osler-Weber-Rondu, Von Willebrand's |
| *Hematomas* | Coagulation factor deficiencies |
| | Circulating anticoagulants |
| | Trauma |
| *Hemarthrosis* | Hemophilias |
| | Factor II, VII, X deficiencies |

When a blood vessel is injured the vascular, platelet, coagulation, and fibrinolytic systems react in concert to mitigate the loss of blood; simultaneously thrombus forms, localizing to the site of injury. Bleeding may arise from a disruption in any of these hemostatic mechanisms, operating alone or in combination. The physiology is multifaceted and how such physiological processes play out in the clinical setting is not well assessed by the commonly employed in vivo assessments [2]. Indeed a recent extensive review of the literature, from which practical guidelines have been derived, recommended the discontinuation of such indiscriminate testing favoring a more selective approach in which patients are selected for further evaluation based on their bleeding history. Nonetheless, despite these challenges, the laboratory approach to the assessment of bleeding risk remains a remarkably enduring practice.

The second, more recent method for the risk assessment of bleeding involves the identification of patients at risk based on their medical history and physical examination with targeted laboratory testing performed only on those with specific risk factors. Supported by the observations of Girolami et al. stressing the role of the clinical examination [3], Koscielny et al. have enhanced and systematized this view with the development of a bleeding risk questionnaire (Table 20.1) used to identify patients who should undergo further laboratory testing of their coagulation [4]. The questionnaire, developed retrospectively, has been validated in a large prospective study [5]. Using this methodology, 88 % (5,021/5,649) possessed no risk factors for bleeding; contemporaneous laboratory studies revealed a prolonged aPTT in 9 of these patients, all the result of a lupus anticoagulant (which increases the risk of thrombosis, not hemorrhage). No other laboratory test (PT, platelet count, platelet function study, and von Willebrand factor assay) uncovered any bleeding disorder. With respect to the questionnaire the most reliable (sensitive) questions related to bleeding of minor wounds (85 %), frequent bruising (73 %), and use of nonsteroidal anti-inflammatory agents (62 %); if any four of the questions were answered in the affirmative, the positive predictive value for the presence of a bleeding diathesis was 99%.

Further in distinguishing between acquired and hereditary disorders, the clinical history is helpful [1, 3]. Table 20.2 summarizes these considerations emphasizing the presence or absence of a family history of bleeding, age of onset of bleeding, the pattern of bleeding, comorbidities, and a history of transfusion as historically important. Physical findings also provide important clues to diagnosis. Table 20.3 attempts to make this point. Employing a number of bleeding presentations, largely based on the site involved, various etiologies are implied though as Girolami describes there is considerable overlap [3]; further a distinct differential diagnosis could be structured around the organ system involved in the bleeding. Nonetheless while imprecision in terminology and semantics may somewhat cloud the discussion, certain bleeding patterns are generally appreciated by clinicians and are of some importance in diagnosis.

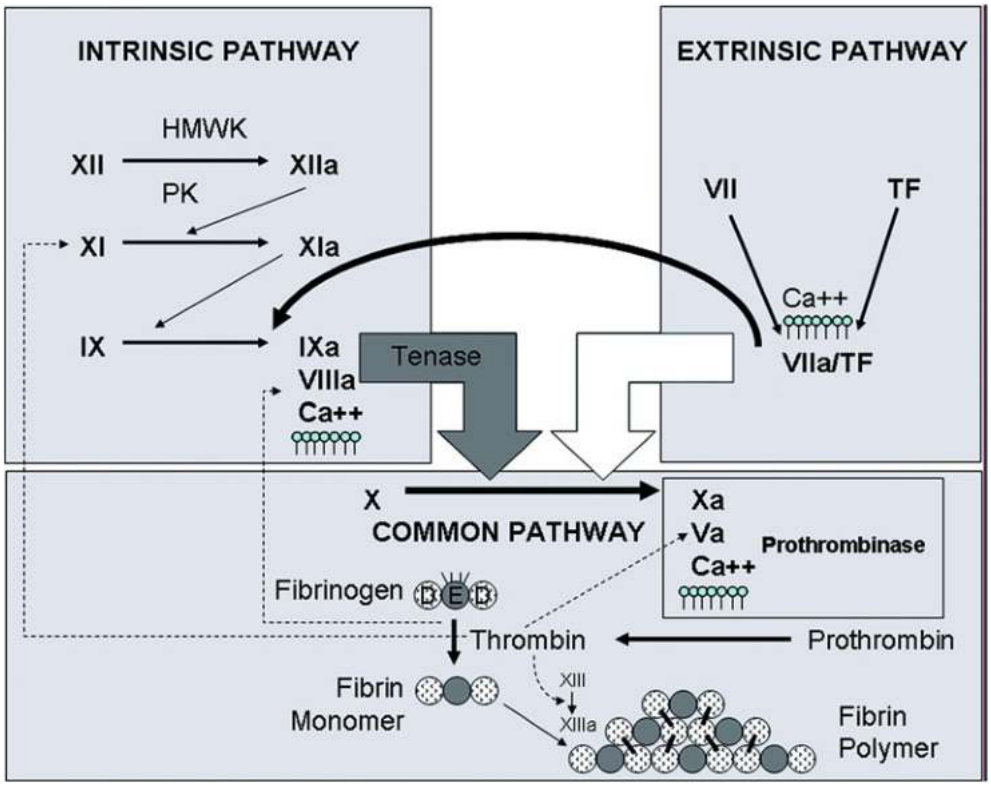


**Fig. 20.1** Diagram of the coagulation cascade, depicting the intrinsic and extrinsic pathways of activation. The extrinsic pathway of activation is started with exposure of tissue factor (TF), coupled with factor VIIa that leads to the activation of factor X. The intrinsic pathway is started by the contact activation factors (factor XII, high molecular weight kininogen (HMWK), and prekallikrein (PK)) with eventual activation of factor X by the tenase complex (factors IXa, VIIIa, calcium ($Ca^{2+}$), and phospholipid). Activated factor X (Xa) participates in the prothrombinase complex (factor Xa, Va, $Ca^{2+}$, phospholipids) for the conversion of prothrombin to thrombin, which converts fibrinogen to fibrin monomer. Fibrin then polymerizes and is cross-linked by factor XIIIa. Further activation of coagulation is fostered by thrombin's activation of factors V, VIII, and XI (Used with permission from Kottke-Marchant K. The Role of Coagulation in Arterial and Venous Thrombosis. In Askari AT, Lincoff AM (eds): Antithrombotic Drug Therapy in Cardiovascular Disease. New York: Springer Science; 2010)

Whether identified by a history and physical examination, or via screening laboratory testing, once concerns have been raised about a patient's hemostatic capacity a work-up is indicated. Hemostasis is conceptualized as primary (platelet related) or secondary (coagulation factors), and its evaluation can be developed according to these distinctions.

## Hemostasis

When a blood vessel is damaged, the process of hemostasis is activated in order to arrest bleeding. The process has three phases:

1. Vascular phase: involves a transient, localized vasoconstrictor response in the damaged blood vessel thus stopping the flow of blood.
2. Platelet phase: damaged endothelial cells release von Willebrand's factor resulting in "sticky" endothelial cells, a process known as platelet *adhesion*. Platelets that adhere to the blood vessel wall in this manner secrete adenosine diphosphate (ADP), a chemical that causes nearby free platelets to attach to each other and to those already fixed to the vessel wall, thereby forming a platelet plug. This "clumping" phenomenon served a number of important functions: the plug may seal the defect in the vessel wall; aggregated platelets release Platelet Thromboplastin (Factor III) which activates the clotting process; further the clumped platelets secrete thromboxane, a potent vasoconstrictor.
3. Coagulation Phase (Fig. 20.1): this phase, which begins within minutes of the initiation of the vascular and platelet phases, involves the formation of insoluble protein Fibrin (from Fibrinogen via the action of the enzyme Thrombin). Once formed Fibrin produces a network of fibers that traps blood cells and platelets thereby forming the clot. This process depends on the presence of 11 different clotting factors and calcium (Factor V), factors required to generate the production of Prothrombin Activator (Factor X). Two distinct pathways with different triggers may be activated.

The Extrinsic pathway is initiated by the material tissue Thromboplastin (Factor III). Released by the damaged tissue and thus "outside" (extrinsic) the blood, this process is rapid and provides a shortcut to the clotting process. The resultant clot is small and thus considered a "quick patch" phenomenon. Alternatively there is the second Intrinsic pathway which is initiated when the blood itself comes in contact with the exposed collagen of the damaged blood vessel. Although a slower (5–10 min) process, it results in the formation of much larger amounts of thrombin and thus more robust clots. This process involves the sequential activation of multiple clotting factors: Factor XI, activated by contact with the exposed endothelium, activates Factor XI, which in concert with Factor XI activates Factor IX leading to the production of Factor VIII. It is Factor VIII, coupled with calcium and Factor II (derived from platelets), that ultimately activates Factor X (Prothrombin Activator). This is the point in the hemostatic process where the two pathways converge following the same course (Common Pathway) to Fibrin formation: a composite of clotting factors (Factor V, $Ca^{2+}$, and platelet-derived phospholipids) engage Factor X creating the Factor V Complex which initiates the conversion of Prothrombin to the active enzyme Thrombin. Thrombin completes the cascade by accelerating the formation of Fibrin thread from Fibrinogen (Factor I).

4. Clot Retraction: this process occurs several days later mediated by contractile proteins contained in the platelets pulling the edges of the wound together and assisting in the reparative process.
5. Fibrinolysis: this refers to the dissolution of the clot a process driven by the proteolytic enzyme Plasmin.

## Evaluation and Approach of Primary Hemostasis: Platelet Deficiency

The assessment of primary hemostasis focuses on the platelet. While the platelet count is a dependable test it does not provide information concerning platelet function and thus is not a sufficient assessment of the bleeding risk attributable to platelet-mediated problems. The normal platelet count is in the 140–160/$mm^3$ though bleeding problems do not occur until substantial reductions (i.e., <50,000/$mm^3$) are present although there is one important caveat. Anesthesiologists require higher counts (i.e., >70,000/$mm^3$) in order to employ neuraxial blockage, an important consideration in orthopedic surgery where such techniques are often employed. Indeed the American Society of Regional Anesthesia (ASRA) has published recommendations (Table 20.4) concerning such blocks the intent of which is a reduction in the risk of paraspinal hematomas [6]. Nonetheless platelet counts of <100K are likely to represent an underlying platelet disorder and warrant investigation. The underlying mechanisms of thrombocytopenia can be divided into three broad categories: impaired production, peripheral consumption, and redistribution/dilution (Table 20.5). Further there is also pseudothrombocytopenia, a relatively common laboratory phenomenon occurring in approximately 1.9 % of hospitalized patients [7, 8], resulting from the ethylenediamine tetra-acetic acid or EDTA, a chelating agent used in blood collection tubes for CBC determinations. The in vitro agglutination of platelets produced by the EDTA results in low platelet counts but no bleeding tendency. Last congenital thrombocytopenia is a rare condition potentially treated with a number of agents including desmopressin (DDAVP), antifibrinolytics, platelet transfusions, and recombinant factor VIIIa.

**Table 20.4** ASRA recommendations concerning neuraxial blockade

| |
|---|
| Coadministration of antiplatelet and anticoagulant medication is contraindicated with indwelling epidural catheters. Clopidogrel must be held for 7 days before neuraxial block |
| Spinal or epidural anesthesia should occur at least 12 h after the last thromboprophylaxis dose of LMWH and at least 12 h after the last full dose of LMWH |
| An epidural catheter should not be removed no sooner that 2 h after the last prophylactic dose of LMWH |
| The first dose of LMWH should be administered no sooner that 2 h after the catheter is removed |
| Delay LMWH administration if the patient experienced excessive trauma during attempted epidural or spinal anesthesia |

Data from www.asra.com

**Table 20.5** Etiology of thrombocytopenia

| |
|---|
| *Impaired platelet production* |
| Congenital |
| Acute leukemia, Myelodysplasia |
| Osteopetrosis |
| Toxins (Chemotherapy, Alcohol) |
| Infection (HIV) |
| *Peripheral destruction* |
| Autoimmune disease |
| Primary (Idiopathic thrombocytopenia purpura, ITP) |
| Secondary |
| Disseminated intravascular coagulation (DIC) |
| Thrombotic thrombocytopenic purpura (TTP) |
| Hemolytic-uremic syndrome |
| *Redistribution and dilution* |
| Massive transfusion |
| Splenomegaly |
| *Pseudothrombocytopenia* |

Adapted with permission from Marcucci C, Chassot PG, Asmis LM et al. Hematologic Risk Assessment. In: Perioperative Medicine: Managing for Outcome. Eds: Newman MF, Fleisher LA, Fink MP. Philadelphia: Saunders Elsevier, 2008

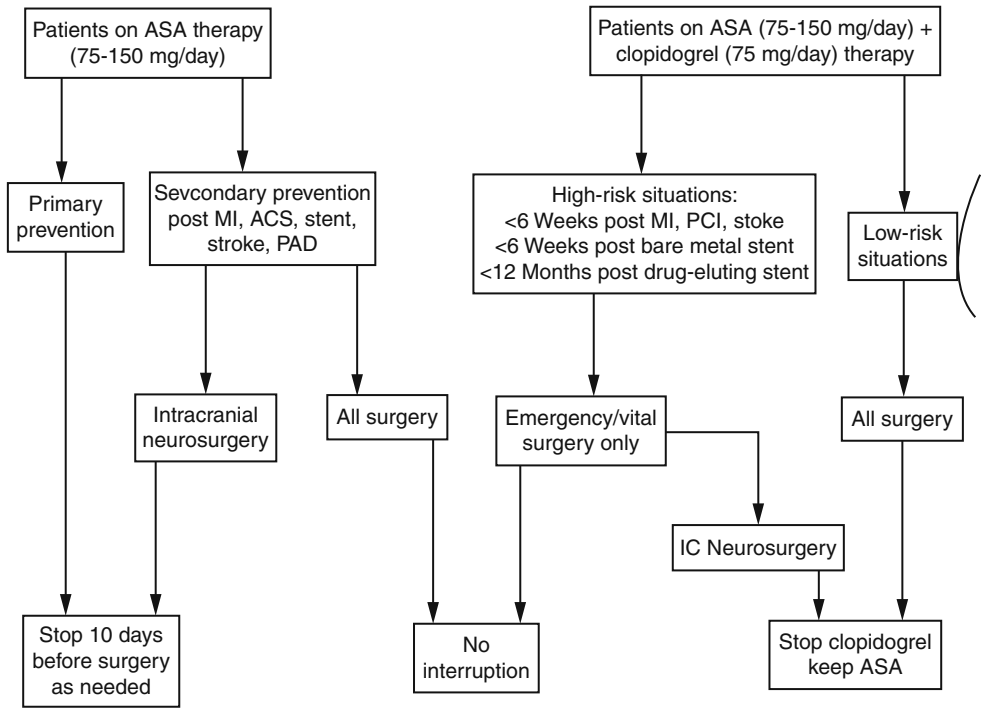


**Fig. 20.2** Algorithm for patients receiving antiplatelet agents. *ASC* acute coronary syndrome, *ASA* acetyl-salicylic acid, *IC* intracranial, *MI* myocardial infarction, *PAD* peripheral arterial disease, *PCI* percutaneous coronary intervention (Used with permission from Marcucci C, Chassot PG, Asmis LM et al. Hematologic Risk Assessment. In: Perioperative Medicine: Managing for Outcome. Eds: Newman MF, Fleisher LA, Fink MP. Philadelphia: Saunders Elsevier, 2008)

More commonly asymptomatic thrombocytopenia is caused by the presence of antibodies to circulating platelets. Most often arising as a consequence of autoimmune platelet destruction, a primary form of the disease known as Idiopathic Thrombocytopenic Purpura (ITP) has been long known. In contrast, secondary ITP may arise as autoimmune sequelae of infection (HIV), systemic lupus erythematosus (SLE), antiphospholipid syndrome, or B-cell malignancies [3]. Heparin-induced thrombocytopenia (HIT), another important platelet-related disorder, arises as a consequence of prolonged heparin administration ($\geq$5 days). Although not often seen after orthopedic surgery, HIT is a serious problem resulting in severe thrombocytopenia coupled with a prothrombotic state (arterial and venous thrombosis, pulmonary embolism, cerebral sinus thrombosis). It is a very serious condition that should be suspected in patients who experience a drop of $>$50 % in their platelet count in the setting of heparin therapy, usually 5–10 days after the initiation of such therapy [9].

Due to their widespread use in the primary and secondary prevention of cardiac and cerebrovascular, the most common cause of platelet dysfunction in the perioperative setting is the use of antiplatelet agents; aspirin and thienopyridine agents (primarily clopidogrel) are amongst the most prevalent. The former, ASA, irreversibly acetylates platelet cyclooxygenase-1 (COX-1) inhibiting thromboxane $A_2$ thus inhibiting platelet function (for the life of the platelet, 5–7 days), while the more potent clopidogrel inhibits (also permanently) platelet aggregation; the recovery time for its effect is approximately 7 days. The impact of ASA on bleeding risk in association with surgery appears mild and outweighed by its influence on graft patency in patients with known coronary artery and cerebrovascular disease. Further, the continuation of ASA in patients undergoing neuraxial block is not associated with bleeding risk [10]. The perioperative management of these agents is fully discussed in Chap. 11. Algorithms for the perioperative management of patients receiving antiplatelet agents have been published. One useful decision tree is shown in Fig. 20.2.

Last another important disorder of the platelet, occasionally encountered in the perioperative setting, is *von Willebrand's disease* (*vWD*). The most common of the inherited bleeding disorders, its prevalence is approximately 1 % in the general population [11]. The hallmark of this condition is a deficiency of von Willebrand factor; while not an intrinsic platelet defect, this deficiency reduces platelet adhesion and aggregation, thereby producing a bleeding tendency. Given the usual absence of laboratory markers,

*vWD* is diagnosed from the history of abnormal bleeding in the setting of surgical and dental procedures. Several subtypes exist, an important consideration as therapy varies according to the form of the disease. An array of agents is employed perioperatively and includes desmopressin (DDAVP), cryoprecipitate, or purified plasma factor concentrates under the guidance of a hematologist.

## Evaluation and Approach to Secondary Hemostasis: Clotting Factor Deficiency

Amongst the various tests of secondary hemostasis, the prothrombin (PT) and partial thromboplastin times (aPTT) are the most commonly employed preoperatively in spite of a prodigious literature demonstrating their poor predictive value for the development of postoperative bleeding [3]. Indeed as implied by the Koscielny algorithm, an unsuspected bleeding diathesis is very unlikely to be uncovered by such testing preoperatively in patients with a negative bleeding history [4, 5]. Indeed in this extensive study, none of the commonly employed screening studies (platelet count, PT, aPTT) identified a single patient without a suspicion of a preexisting bleeding problem based on their history. Further, with respect to the aPTT specifically, the prolongation of this parameter is a fairly common circumstance resulting from either a mild Factor XII deficiency or the presence of a lupus anticoagulant; indeed in the Koscielny study, all patients with this laboratory abnormality (and negative bleeding history) were found to have of a lupus inhibitor. The lupus anticoagulant, a phenomenon known to increase the risk of thrombosis not the risk of bleeding, is itself relatively common being found in 1.2–3.8 % of healthy individuals, though its incidence increases with age and chronic disease, most significantly in patients with systemic lupus erythematosus [12].

Of course, specific clotting factor deficiencies do exist and in those rare patients with severe deficiencies their risk of surgery-related bleeding may be significantly increased. Deficiencies of factors II, V, VII, XI, and XII are well known to hematologists. Clinical clues to the presence of such disorders include that Factor VII deficiency is the only hereditary clotting factor deficiency with a prolonged PT and normal aPTT; Factor XI deficiency occurs in its highest frequency among Ashkenazi Jews (its incidence outside that population is about 1 per 1 million) and is a condition that may be unrecognized until excessive bleeding occurs in the setting of surgery; and Factor XII (Hageman) deficiency results in an elevated aPTT but not a bleeding diathesis. Rather such patients experience thromboembolic phenomenon.

Although generally not an occult disease process, the hemophilias should be mentioned as important hereditary disorders of coagulation. There are two forms: Hemophilia A (Factor VIII deficiency) and Hemophilia B (Factor IX deficiency). Owing to their propensity for intra-articular hemorrhage and ultimately joint destruction, these have been important conditions to the orthopedist. Nonetheless modern clotting factor replacement therapy has significantly mitigated the chronic joint destruction formerly experienced by these patients. Treatment paradigms for the chronic as well as perioperative management of these conditions are well established.

## Specific Chronic Diseases

Perhaps most relevant to a discussion of coagulation in the perioperative setting is the contribution made by kidney and liver disease.

In patients with chronic renal failure the most common clotting related abnormality is platelet dysfunction, a problem unrelated to the platelet itself but rather a consequence of the uremic state. Thus, in the patient with renal insufficiency accompanied by low platelet counts, platelet transfusions are generally not indicated though dialysis may be appropriate in certain settings.

In contrast, patients with chronic hepatic failure are particularly worrisome in the perioperative setting where clotting factor deficiency and portal venous insufficiency contribute to an increased risk of bleeding. Deficiencies of the liver-dependent factors (II, VII, IX, X) result in a coagulopathy identified by a prolonged prothrombin time (PT). In such individuals, particularly those who are poorly nourished, vitamin K may be indicated preoperatively. However, in this clinical setting the primary problem may be insufficient hepatic synthesis, a state likely to be unresponsive to vitamin K and require repletion of clotting factors with fresh frozen plasma (FFP) or specific factor concentrates. Large dosages of FFP are often required; near normalization of the PT is the desired outcome.

## Summary

In conclusion, problems of coagulation are important considerations to the orthopedic surgeon, anesthesiologist, and particularly to the medical consultant who serves as the first line of defense in the recognition of such conditions. Suspicions concerning their presence can generally be gleaned from the patient's history though a general understanding of the processes underlying normal hemostasis is also necessary and forms the basis upon which a logical approach to the detection, characterization, and treatment of these conditions is formulated.

**Summary Bullet Points**

- Coagulation problems are amongst the surgeons' most feared complication of surgery.
- The presence of disordered coagulation can be determined with a targeted medical history.
- Available preoperative laboratory assessments of coagulation do not predict postoperative bleeding complications and should be deemphasized in practice.
- Disordered coagulation can be divided into primary and secondary forms.
- Diseases of the kidney and liver contribute significantly to the risk of postoperative bleeding.

## References


1. Marcucci C, Chassot PG, Asmis LM, et al. Hematologic risk assessment. In: Newman MF, Fleisher LA, Fink MP, editors. Perioperative medicine: managing for outcome. Philadelphia, PA: Saunders Elsevier; 2008.
2. Chee YL, Crawford JC, Watson HG, et al. Guidelines on the assessment of bleeding risk prior to surgery or invasive procedures: British Committee for Standards in Hematology. Br J Hematol. 2008;140:496–504.
3. Girolami A, Luzzatto G, Varvarikis C, et al. Main clinical manifestations of a bleeding diathesis: an often disregarded aspect of medical and surgical history taking. Haemophilia. 2005;11:193–202.
4. Koscielny J, Ziemer S, Radtke H, et al. A practical concept for preoperative identification of patients with impaired primary hemostasis. Clin Appl Thromb Hemost. 2004;10:195–204.
5. Koscielny J, von Tempelhoff GF, Ziemer S, et al. A practical concept for preoperative management of patient with impaired primary hemostasis. Clin Appl Thromb Hemost. 2004;10:155–66.
6. http://www.asra.com
7. Payne BA, Pierre RV. Pseudothrombocytopenia: a laboratory artifact with potentially serious consequences. Mayo Clin Proc. 1982;59:123–5.
8. Vicari A, Banfi G, Bonini PA. EDTA-dependent pseudothrombocytopenia: a 12-month epidemiological study. Scand J Clin Lab Invest. 1988;48:5370542.
9. Bartholomew JR, Begelman SM, Almahameed A. Heparin-induced thrombocytopenia: principles for early recognition and management. Cleve Clin J Med. 2005;72(Suppl):S31–6.
10. Horlocker TT, Wedel DJ, Benzon H, et al. Regional anesthesia in the anticoagulated patient: defining the Risks (Second ASRA Consensus Conference on Neuraxial Anesthesia and Anticoagulation). Reg Anesth Pain Med. 2003;28:172–97.
11. Ramasamy I. Inherited bleeding disorders: disorders of platelet adhesion and aggregation. Crit Rev Oncol Hematol. 2004;49 (1):1–35.
12. Petri M. Epidemiology of the antiphospholipid antibody syndrome. J Autoimmue. 2000;15:145–51.

# Perioperative Nutrition in the Orthopedic Surgical Patient

21

Christie L. Custodio-Lumsden and Sotiria Everett

**Objectives**

- To recognize the Role of Nutrition in Orthopedic Surgical Patients
- To understand Malnutrition Indicators
- To explore Consequences and Outcomes of High Nutrition Risk Patients
- To define Goals and Strategies of Perioperative Nutrition Interventions
- To understand the Role of Nutrition in the Management of Postoperative Ileus
- To recognize micronutrients that may be indicated in the perioperative setting

**Key Points**

- Maintaining adequate nutrition status in the orthopedic patient promotes wound healing, preserves lean body mass, and prevents postoperative complications.
- Patients who are malnourished or at high nutrition risk should be identified and treated early to minimize risk of complications.
- Malnutrition in the orthopedic surgical patient can lead to poor wound healing, increased risk for infection, pressure ulcers, increased morbidity and mortality, increased medical costs, and prolonged hospitalization.
- Orthopedic patients should be screened early, within 24 h of admission, in order to establish a timely nutrition intervention plan.
- Elderly, trauma patients, diabetic patients, and patients undergoing complex orthopedic surgeries present with unique nutritional challenges and should be identified promptly for initiation of an appropriate nutrition care plan.
- Nutrition screening tools, anthropometric measures, and laboratory markers are often used to identify patients at nutrition risk.
- Registered dietitians (RDs) should be consulted for the assessment and intervention of orthopedic patients who present at nutrition risk.
- Patients should resume nutrient intake as early as possible postoperatively to minimize delayed feeding.
- Early feeding may be a potential strategy to prevent postoperative ileus.
- Oral nutritional supplements, enteral nutrition therapy, and/or parenteral nutrition therapy may be utilized in the perioperative period to meet the nutritional goals.
- Current guidelines for nutrition support indicate that enteral nutrition is preferred over parenteral nutrition and early enteral nutrition has several benefits, including promotion of GI motility, preservation of gut integrity, improved tolerance to feedings, improved immunity, reduced inflammation, reduction in infectious complications, and decreased length of hospital stay.
- In addition to providing adequate protein and calories, micronutrients such as calcium, vitamin D, zinc, arginine, and glutamine may be indicated in perioperative nutrition interventions.

C.L. Custodio-Lumsden (✉)
Section of Social and Behavioral Sciences, Columbia, University College of Dental Medicine, New York, NY, USA

Department of Food and Nutrition Services, Hospital for Special Surgery, New York, NY, USA
e-mail: Clc2123@columbia.edu

S. Everett
Department of Food and Nutrition Services, Hospital for Special Surgery, New York, NY, USA
e-mail: everetts@hss.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_21, © Springer New York 2014

## Introduction

Nutrition status is a significant factor in the perioperative care of the orthopedic patient. Adequate nutrition is critical for optimal recovery and prevention of postoperative complications. With regard to perioperative nutrition optimization, the goals are to promote wound healing, preserve lean body mass, favorably modulate the immune response, and prevent morbidity and mortality associated with poor nutrition status [1, 2]. Nutrition status can also impact insulin metabolism and glycemic control, a significant factor in wound healing potential for patients. Furthermore, adequate nutrition may assist with the physical rehabilitation and ambulation of orthopedic patients [3].

Preoperatively, clinicians should ensure that orthopedic patients are in the best possible condition nutritionally and continue to focus on the nutritional state of the patients in the perioperative period. Factors that affect nutrition status in the orthopedic patient include but are not limited to weight status (underweight or overweight), major weight fluctuations, presence of chronic illness, trauma, age, and type of surgical procedures. Details of these factors will be addressed in this chapter. Markers of nutrition status include anthropometric measures, laboratory values, medical history, and psychosocial history.

Patients undergoing orthopedic surgery should be encouraged to maintain a healthy weight in the preoperative period by following a well-balanced diet that provides adequate micronutrients and macronutrients. Both underweight and obese status can impact a patient's ability to heal and increase chance of wound complications. Patients who are underweight may experience delayed postoperative wound healing [4]. Obese patients are at risk for developing wound complications and thrombotic events [5]. Weight status should be addressed by clinicians due to potential negative outcomes associated with weight.

It is estimated that 23–33 % or more of patients undergoing orthopedic surgery are malnourished or at risk for malnutrition [6]. Malnutrition results from inadequate food and nutrient intake or decreased nutrient absorption. Orthopedic surgical patients can present with malnutrition before the surgery or develop malnutrition after the surgery [7]. Malnutrition, combined with the catabolic response, may lead to muscle wasting, which impairs postoperative rehabilitation.

Certain types of patients undergoing orthopedic surgery, such as polytrauma patients or patients with active infections, may already be hypermetabolic with increased energy expenditure and enhanced protein metabolism before the surgery, adding to the postoperative catabolic stress. Additionally, the period of being "nil per os" (NPO) before and after surgery adds to the duration of inadequate nutrition. Clinical malnutrition can occur in the context of acute illness or injury if energy intake is $\leq$50 % of estimated energy requirement for $\geq$5 days [8]. Therefore it is essential to monitor the duration of inadequate nutrient intake and prevent decreased nutrition stores. Early identification of patients who present with malnutrition or are at risk for poor nutrition status is essential and can lead to timely nutrition interventions.

This chapter will outline the role that nutrition plays in orthopedic surgery patients, including the importance of adequate nutrition and how perioperative nutrition interventions can help reduce nutrition-related complications. The benefits of early postoperative feedings will also be presented in this chapter.

## Identifying Malnutrition

### Indicators of Malnutrition and Poor Nutrition Status

Nutrition status has been shown to significantly impact overall health and postoperative outcomes. Patients who are at high nutrition risk are particularly vulnerable to postoperative complications, including infection. Research has shown that undernourishment results in muscle wasting, impaired cardiac function, and mental apathy, all of which may result in prolonged hospitalization and decreased mobility. Limited mobility, particularly postoperatively, increases the likelihood of patients developing pneumonia, pressure ulcers, and thrombosis, all of which may impair postoperative recovery. Thus, the nutrition status of all patients should be determined preoperatively to identify those who may be at elevated nutrition risk. A basic nutrition screen should be conducted on all patients in preparation for surgery to identify those who may be at highest risk nutritionally. A comprehensive nutrition assessment is then recommended for all patients who are identified at risk via initial nutrition screen. Commonly used nutrition assessment techniques include evaluation of anthropometric measures, laboratory markers, and immunological indicators.

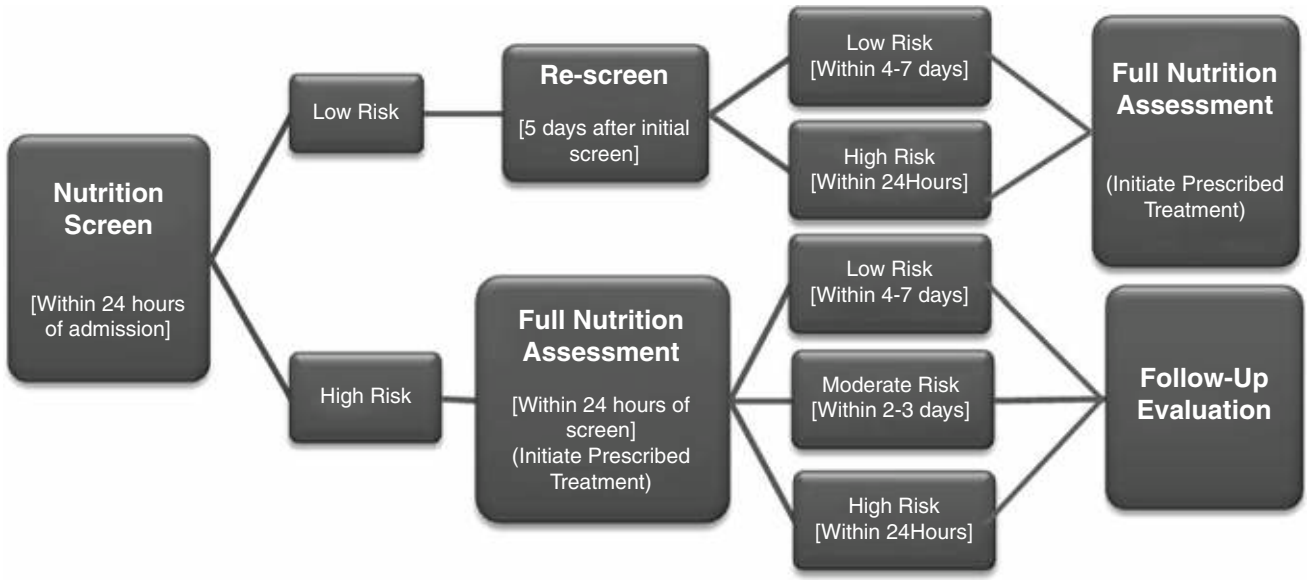


**Fig. 21.1** Nutrition screening and assessment protocol (SAMPLE MODEL)

## Identifying Risk: Nutrition Screening and Assessment

The nutrition status of all patients undergoing orthopedic surgery should be carefully evaluated in order to identify those at high nutrition risk, and to coordinate appropriate nutrition care. A brief, yet thorough, nutrition screening should be conducted to identify patients who are malnourished prior to surgery or who may be at risk of malnourishment postoperatively. The term "malnutrition" has been used to define conditions of nutritional deficiency (e.g., inadequate intake of protein, energy, vitamins), as well as conditions of excess (e.g., overweight, obesity, hypervitaminosis). Within the context of preoperative nutrition screening, the state of malnutrition representing undernourishment is of greatest concern. Thus, for the purposes of this text, the term malnutrition will henceforth refer to patients who are undernourished. Prompt identification of patients who present for surgery in a malnourished state, due to inadequate intake of calories, protein, and other vital nutrients, is essential in developing an appropriate care plan.

Nutrition screening tools should be used to classify patients according to risk level and to inform the subsequent nutrition treatment protocol for patients. Each institution should have an established nutrition assessment protocol in place to ensure that all patients receive appropriate and timely nutrition evaluation and treatment. This protocol will vary according to a hospital's patient demographic and length of stay.

In the United States, healthcare institutions that wish to acquire Joint Commission accreditation must screen all patients for nutrition risk within 24 h of hospital admission. Typically, the initial nutrition screening tool will identify a specific evaluation and treatment pathway that is appropriate for each patient (Fig. 21.1).

Numerous screening tools have been validated for use with hospitalized patients. One such tool is the Nutritional Risk Screening 2002 (NRS 2002). This tool was developed by the European Society of Parenteral and Enteral Nutrition (ESPEN) to detect the risk of developing malnutrition in the hospital setting and to identify patients who can be treated via nutrition intervention or who may likely benefit from nutrition support. The NRS 2002 screening tool determines nutrition risk based on a patient's Body Mass Index (BMI), recent changes in weight, and reported recent decrease in dietary intake. The NRS 2002 is easily administered and provides a quick, low-cost method of identifying patients at high nutrition risk. NRS 2002 has been shown to be highly sensitive in identifying malnourished patients undergoing orthopedic surgery; see NRS 2002: Appendix 1 at the end of this chapter [9].

A multitude of nutrition assessment tools and models exist to guide the practice of an RD conducting a complete evaluation of a patient's nutrition status. An example of one such assessment model is the Subjective Global Assessment (SGA); see Subjective Global Assessment (SGA): Appendix 2 at the end of this chapter [10]. SGA is a widely used method for assessing nutrition status of patients in clinical settings.

SGA was initially developed for use with surgical patients, but is now recognized as a useful tool applicable to a variety of patient populations. SGA is used to identify chronic or established malnutrition, evaluating signs/symptoms persisting for greater than 2 weeks, and should therefore not be used to evaluate acute alterations in nutrition status. Thus, SGA is best utilized during an early preoperative screening or for patients hospitalized for a prolonged period of time. SGA includes evaluation of information from the patient's past medical history as well as physical examination and should be used in conjunction with other markers of nutrition status. According to SGA, patients are classified as (a) well nourished, (b) moderately (or suspicion) malnourished, and (c) severely malnourished based on physical assessments performed by an RD or health practitioner [11]. Physical evaluations include loss of subcutaneous fat (i.e., orbital, triceps, fat overlying ribcage), muscle depletion (i.e., loss of muscle in temples, clavicles, shoulders, scapula, thigh, and calf), fluid accumulations (i.e., general or local fluid accumulation in extremities, ascites, or vulvar/scrotal edema), and functional assessment (i.e., handgrip strength).

Patients who are identified as being at high nutrition risk upon screening should be promptly referred to a Registered Dietitian (RD) for a more complete nutrition evaluation. The RD will then conduct a thorough nutrition assessment, indicate an appropriate nutrition diagnosis, and outline a specific intervention and treatment plan for patient care. The full nutrition assessment will typically expand upon the screening, to include evaluation of past medical history, current health conditions and laboratory values, use of medications and supplements, dietary habits, functional feeding abilities, recent alterations in appetite and intake, as well as a review of psychosocial variables that may impact nutrition status.

## Anthropometrics: Classifying Height and Weight Measures

Anthropometric measurements play an integral role in both nutrition screening and assessment. Anthropometrics are used to quantitatively assess body composition in terms of the proportion of lean muscle, bone, and adipose tissue. Anthropometric measurements allow for the classification of patients according to weight status. This information is invaluable to the orthopedic healthcare professional because it allows for the initiation of early nutrition intervention to maximize surgical outcomes.

By identifying overweight or obese patients with ample time prior to surgery, referrals can be made to an RD for nutrition counseling to encourage weight loss. In contrast, those patients who are classified as underweight can receive early nutrition intervention to increase body weight and encourage the maintenance of lean body mass during the postoperative recovery period. In the case of trauma or unplanned surgical procedures, there is often little time to initiate nutrition counseling; however, referrals can be made to an RD for immediate postoperative care.

**Table 21.1** BMI[a] and % IBW calculations[b]

| |
|---|
| *BMI metric formula* |
| BMI = (weight in kilograms)/(height in meters)$^2$ |
| *BMI imperial formula* |
| BMI = (weight in pounds × 703)/(height in inches)$^2$ |
| *% IBW formula* (*females*) |
| *Step 1*: Calculate ideal body weight: 100 lb for first 5 ft + 5 lb for each inch over 5 ft (medium frame) [Small frame (−10 %), Large frame (+10 %)] |
| *Step 2*: Calculate % IBW: (actual body weight)/ideal body weight |
| *% IBW formula* (*males*) |
| *Step 1*: Calculate ideal body weight: 106 lb for first 5 ft + 6 lb for each inch over 5 ft (medium frame) [Small frame (−10 %), Large frame (+10 %)] |
| *Step 2*: Calculate % IBW: (actual body weight)/ideal body weight |

[a]BMI (Quetelet's Index) calculations based on National Institutes of Health Guidelines [9]
[b]% IBW based on Hamwi Method [65]

Although accurate methods to assess body composition exist (i.e., dual X-ray absorptometry (DEXA), computerized tomography (CT), magnetic resonance imaging (MRI)), they are expensive and are not accessible to most healthcare professionals. Thus, several alternative methods of anthropometric assessment may be used to guide clinical practice. A preoperative anthropometric assessment should include evaluation of a patient's current height and weight, body mass index (BMI), and percent ideal body weight (% IBW) and identify occurrence of unintentional weight loss (Table 21.1). Self-reported measures should be avoided whenever possible and patients' height and weight should be measured by trained healthcare professionals for accuracy of anthropometric assessment.

Calculation of a patient's BMI is a very useful method in the classification of weight and nutrition risk status. BMI must be interpreted with caution and within the context of the individual patient's condition. Presence of edema, high muscularity, short stature, and muscle wasting are some conditions which may skew the accuracy of BMI values [12]. Moreover, individual factors, such as ethnicity, may influence interpretation of BMI values. Despite these limitations, BMI has been proven to be a valid tool in monitoring weight status in clinical settings [13].

Additionally, calculation of patients' %IBW is recognized as a clinically useful evaluation of weight status. There are multiple methods of determining IBW (i.e., Metropolitan Life Tables, Hamwi Method); however, little evidence exists to support the accuracy of such measures. Despite limited validation studies of these methods, calculation of IBW and

**Table 21.2** BMI and waist circumference weight status classification and associated risk

| Classification of BMI values[a] | | Associated disease risk[b] (Relative to normal weight and waist circumference) | |
|---|---|---|---|
| | | Men ≤40 in (≤102 cm) | Men >40 in (>102 cm) |
| Weight status | BMI | Women ≤35 in (≤88 cm) | Women >35 in (>88 cm) |
| Underweight | <18.5 | – | – |
| Normal weight | 18.5–24.9 | – | – |
| Overweight | 25–29.9 | Increased | High |
| Obesity (Class 1) | 30–34.9 | High | Very high |
| Obesity (Class 2) | 35–39.9 | Very high | Very high |
| Extreme obesity (Class 3) | ≥40 | Extremely high | Extremely high |

[a]Values adapted from Centers for Disease Control (CDC) Guidelines
[b]Adapted from Preventing and Managing the Global Epidemic of Obesity. Report of the World Health Organization. Consultation of Obesity. WHO, Geneva, June 1997

%IBW is still regarded as a clinically useful method of anthropometric assessment. Similarly to BMI, interpretation of %IBW must be made with caution and should include additional methods of nutrition assessment. Patients who are determined to have a BMI below 18.5 and/or % IBW below 85 % are classified as underweight and at high risk nutritionally (Table 21.2).

Waist-to-hip ratio and waist circumference are two additional anthropometric measures that are often used in nutrition assessment. Elevated waist measures are indicative of adipose accumulation in the abdominal area, which has been strongly linked to increased risk for a variety of obesity-related diseases, including type 2 diabetes, dyslipidemia, hypertension, and cardiovascular disease secondary to excess abdominal fat [12]. Waist measurements vary by gender; thus the risk criteria is different for men and women. A waist-to-hip ratio of 1.0 or greater in men and 0.8 or greater in women is representative of android obesity, a condition which places the individual at elevated risk for chronic disease. In regard to waist circumference measures, men are encouraged to maintain a circumference <40 in. (102 cm) and women <35 in. (88 cm) to minimize obesity-related chronic disease risk.

Assessing a patient's weight loss over time can also determine nutritional risk, regardless of BMI or % IBW status. In the context of acute or chronic illness, injury, or periods of prolonged suboptimal intake, significant weight loss is a serious concern. Recent, unintentional weight loss is an indicator that a patient may have a significantly compromised nutrition status. Patients who present for surgery reporting recent significant weight loss should immediately be referred to an RD for further evaluation (Table 21.3).

**Table 21.3** Malnutrition indicators

| Weight loss malnutrition indicators[a] | | |
|---|---|---|
| Condition | % Weight loss | Within |
| Acute illness or injury | >2 | 1 week |
| | >5 | 1 month |
| | >7.5 | 3 months |
| Unintentional suboptimal intake or chronic illness (disease/condition lasting ≥3 months) | >5 | 1 month |
| | >7.5 | 3 months |
| | >10 | 6 months |
| | >20 | 1 year |

[a]Values based on Academy of Nutrition and Dietetics and National Institutes of Health Guidelines [9]

## Nutrition-Related Laboratory Values

Another important component of the nutrition assessment is a review of pertinent laboratory values. This portion of the assessment is largely designed to evaluate the current state of a patient's visceral protein stores, as opposed to somatic protein which is primarily made up of skeletal muscle and is principally evaluated via anthropometric measures. However, there are several key laboratory values that are useful in conjunction with anthropometrics to evaluate somatic protein levels.

As a reflection of somatic protein levels, RDs often calculate a patient's creatinine height index (CHI) and nitrogen balance using biochemical test results. In healthy patients, creatinine is formed at a constant rate as a by-product of creatine phosphate used in the energy-producing ATP cycle in muscle. Creatine phosphate is stored and used in the muscle to provide the necessary phosphate group to regenerate ATP, but the resulting creatinine is cleared and excreted by the kidney. Thus, daily urinary output of creatinine is a useful measure in the estimation of total muscle mass in the body. In order to calculate CHI, a 24-h urine collection is performed, and then the total amount of excreted creatinine is compared to a standard reference value based on height (from a table of reference values). A CHI within normal limits is generally between 60 and 80 % of the standard reference value. Moderate skeletal muscle depletion may be indicated by a CHI of between 40 and 59 %, whereas a CHI below 40 % is often indicative of severe skeletal muscle depletion and thus high nutrition risk status.

**Table 21.4** Common nutrition-related laboratory values

| Normal laboratory values for common indicators of nutrition status[a] | |
|---|---|
| Prealbumin | 15–36 mg/dL |
| Transferrin | 215–380 mg/dL |
| Albumin | 3.5–5 g/dL |
| Hemoglobin | 12–17 g/dL |
| Total lymphocyte count | 1.2–3.3 k/cu mm |

[a]Values adapted from Krause's Food, Nutrition and Diet Therapy [47]

Nitrogen balance is another biochemical calculation used to assess somatic protein levels. Nitrogen balance is a state of equilibrium in the healthy individual in which nitrogen excretion is equal to nitrogen intake. In order to calculate nitrogen balance, dietary intake of protein is measured for 24 h, and excretion of nitrogen is calculated via 24-h urine collection and estimation of other sources of nitrogen loss (including estimation of fecal excretion, skin breakdown, and wound drainage). When a patient is identified to be in a state of negative nitrogen balance, the excretion of nitrogen is greater than intake, thus indicating a state of catabolism or inadequate intake. Nitrogen balance is an important method of assessing overall protein status as well as effectiveness of nutrition intervention, but may be difficult to assess in a traditional hospital setting.

The laboratory markers most frequently used to evaluate a patient's nutrition status with regard to visceral protein stores and immunocompetence assess measures of circulating protein and cell-mediated immunity. The most commonly assessed laboratory measures include prealbumin, albumin, transferrin, hemoglobin, and total lymphocyte count (TLC) (Table 21.4). Despite the fact that these laboratory measures are influenced by fluid shifts and physiologic responses to injury, they have been found to identify risk of postoperative complications and outcomes. These markers, particularly albumin and TLC, have been found to be useful indicators in the identification of patients with protein-energy malnutrition (PEM) [5]. Albumin and TLC may be used in the clinical setting as inexpensive, easily evaluated markers of nutrition status in lieu of a complete nutrition assessment, when such a thorough evaluation is not feasible. Albumin, prealbumin, and transferrin are indicators of visceral protein stores, whereas TLC indicates immunologic status. Serum transferrin and prealbumin levels are more sensitive indicators of visceral protein depletion than albumin because of their shorter half-lives [14]. In a preoperative nutrition assessment, patients may be considered malnourished or at elevated nutrition risk if these laboratory markers are below normal value.

Although below normal values for albumin, prealbumin, total protein, and transferrin may inform classification of malnutrition or altered nutrition status in preoperative patients, they may not accurately depict postoperative nutrition status. These laboratory values may be altered as a result of postoperative increases in physiological stress, inflammatory response, changes in medications, and alterations in fluid balance. Recent evidence suggests that albumin and prealbumin may not reflect improvement in nutrient intake and nutrition status in the presence of inflammation [15]. Therefore, changes in laboratory values should always be evaluated and reported relative to the patient's preoperative baseline values, rather than standard laboratory guidelines when assessing postoperative nutrition status [16].

Several serum laboratory tests, including prealbumin, have been shown to be effective in quantifying short-acting measures to better inform classification of current nutrition status. In determining chronicity of malnutrition, a beneficial characteristic of the various visceral proteins is their diversity of half-lives. In contrast, serologic tests that measure TLC and hemoglobin can help determine the long-term nutrition status of patients.

## Overview of Key Nutrition-Related Labs

*Prealbumin*, also known as transthyretin is an acute phase transport protein that is synthesized by the liver. This measure of visceral protein status has a short half-life of just 2 days and a standard reference value of 15–36 mg/dL. As a result of its short half-life, prealbumin is a sensitive marker of recent, short-term changes in nutrition status which can be particularly valuable during the postoperative period. Despite its utility as a measure of current nutrition status, prealbumin levels can be affected by non-nutrition factors which are frequently present in surgical patients. Prealbumin values may be influenced by inflammation, hydration status, and acidemia. Additionally, prealbumin has been found to have an inverse relationship with levels of acute phase proteins, including C-reactive protein [17]. Thus it is important to consider this laboratory value within the context of the individual patient's overall health condition, nutrient intake, and other laboratory findings.

Another serologic measure useful in the identification of sensitive changes in nutrition status is the visceral protein *Transferrin*. Transferrin is synthesized by the liver, and acts as a transporter for iron throughout the body. Like prealbumin, transferrin has a relatively short half-life of 8–10 days, thus serving as an indicator of current protein status. Reference levels for transferrin are between 215 and 380 mg/dL. A transferrin level below 200 mg/dL is considered abnormal, and levels tend to increase when iron stores are low, in the body's attempt to meet the need for increased iron transport. Research suggests that abnormally low levels of transferrin postoperatively may increase risk of wound infection in fracture patients, therefore making it an

important measure to consider in the evaluation of orthopedic surgery patients [4, 18].

*Albumin* is a third visceral protein that is particularly useful in evaluating nutrition status. In contrast to prealbumin and transferrin, albumin has a significantly longer half-life of 20 days. As a result of the long half-life of albumin, it is not an indicator of recent changes in nutrition status or short-term nutrition interventions, but instead reflects the result of long-term nutrition behaviors [19, 20]. As such, albumin is not a sensitive marker of current alterations in the body's protein stores. Albumin is the most abundant serum protein, and has been identified in several studies as a useful predictor of postoperative complications [14]. The reference value for a normal albumin level is between 3.5 and 5.0 g/dL. A preoperative albumin level less than 3.5 g/dL is suggestive of visceral protein depletion and is a strong indicator of suboptimal nutrition [14, 18, 21–24]. Furthermore, a preoperative albumin level below 3.5 g/dL in orthopedic patients undergoing major surgery has been shown to be associated with an increased length of hospital stay, impaired wound healing, increased incidence of wound infection, pneumonia, sepsis, postoperative complications, delayed physical rehabilitation, and mortality [18, 21, 25–27].

Evaluation of *hemoglobin* levels is also helpful in identifying nutritionally at-risk patients. Hemoglobin is a useful measure in the diagnosis of anemia, and is helpful in identifying PEM. A hemoglobin level below 13.0 g/dL for males and 12.0 g/dL for females is indicative of mild anemia, whereas a level below 10 g/dL for either gender represents severe anemia [28]. Various studies showed that anemia was predictive for increased hospital stay, poor wound healing, and greater mortality rate within 6 and 12 months after major orthopedic surgery [28]. Hemoglobin levels below 10.0 g/mL may delay soft tissue healing [28]. In addition, mildly anemic patients were 2.5 times more likely to die, and severely anemic patients were 5 times more likely to die than patients without anemia [28–30].

Another highly researched serologic nutrition indicator is *TLC*. TLC is calculated by multiplying white blood cell count by percent lymphocytes. Immunocompetence is an important component in the evaluation of protein stores and overall nutrition status of a patient. In order to maintain proper immune function, patients must maintain proper protein stores and adequate nutrition. Nutrition status greatly impacts the function and number of lymphocytes, mainly T cells, in the body. As expected, when the number of white blood cells is limited, a patient is at a greater risk of developing postoperative complications. A TLC less than 1,500 cells/$mm^3$ indicates protein depletion and less than 1,000 cells/$mm^3$ is considered severe protein depletion. Patients with a TLC less than 1,500 cells/$mm^3$ have been found to be more prone to wound infections and more likely to die within 1 year of major orthopedic surgery compared to patients with TLC values within normal limits [4, 25, 31]. Much like the previously reviewed serologic measures, TLC may be affected by the presence of infection, stress, trauma, as well as immunosuppressant diseases and medications; therefore interpretation of this marker should be considered carefully in these patients.

Research has indicated that patients undergoing major orthopedic surgery who had low TLC and low albumin levels were 2.9 times as likely to have a length of stay greater than 2 weeks compared to patients with normal levels of both parameters [5, 21]. Furthermore, patients with low TLC and low albumin levels were 3.5 times more likely to die within 1 year of surgery [4, 24]. There has also been evidence to suggest that patients with low levels of TLC and albumin were less likely to recover to their pre-fracture level of independence in basic activities of daily living [4, 26]. Thus, there is compelling evidence to suggest that patients with altered nutrition-related laboratory values are at significantly increased risk for postoperative complications. As a result of such findings, it has been argued that surgery should be delayed, if possible, when a patient's albumin level is below 3.5 g/dL and TLC is less than 1,500 cells/$mm^3$, pending further tests [14].

Performing tests to assess these clinical markers can be extremely beneficial toward identifying nutritionally at-risk patients. Although blood testing is relatively costly, the well-being of the patient is at stake, and the treatment of postoperative complications is, in most cases, more detrimental financially. Thus, it is recommended that patients undergoing major orthopedic surgery, especially elective patients, be assessed nutritionally prior to surgery to make appropriate suggestions such as postponement if possible, or perioperative nutritional supplementation if necessary.

## Past Medical History: Importance and Implications

A major component of the nutrition screening and assessment is evaluation and review of past medical history. It is imperative for the RD to have an understanding of pre-existing medical conditions and past surgical experiences in order to properly evaluate a patient's current nutrition status and subsequently develop an appropriate plan of care. Patients presenting for surgery with a history of postoperative gastrointestinal complications, feeding difficulties, or delayed wound healing are at particularly elevated nutrition risk.

Additionally, a patient's past medical history often provides the RD with a framework in which to properly evaluate current nutrition-related laboratory values. Many of the indices of nutrition status are reliant upon understanding of preexisting conditions which may influence current values.

Review of a patient's past medical history is also an integral component of the nutrition care process. The RD must have a thorough understanding of the patient's current and previous health conditions in order to develop and deliver appropriate nutrition education.

### Skin Integrity

Patients who present for surgery with compromised skin integrity are at high nutrition risk postoperatively. Adequate nutrient intake is essential to the maintenance of proper skin integrity. The postoperative catabolic state coupled with prolonged decreased mobility and the perioperative period of inadequate nutrient intake combine to create a potentially high-risk situation for skin integrity. During the surgical recovery period, it may be particularly difficult for patients to meet their increased nutrient needs. However, it is crucial to ensure that patients maintain adequate nutrient intake to support postoperative healing and skin maintenance. In many instances, these patients will require oral protein-calorie supplements or specific amino acid modular formulas (i.e., arginine), which can be used to address the needs of patients with pressure ulcers. Additionally, maintaining proper hydration status is essential to promoting postoperative healing and improving skin integrity. Thus, patients who present at high nutrition risk, with compromised skin integrity or inadequate nutrient intake, should be closely monitored and followed by an RD postoperatively.

### Psychosocial Concerns

Nutrition assessment also allows the practitioner to identify psychosocial-related nutrition risk factors. A variety of psychological and social factors have been shown to significantly impact nutrition status. A comprehensive nutrition assessment conducted with patients who present at increased nutrition risk should include evaluation of living situations, social support systems, psychological conditions, access to food, and ability to purchase and prepare meals. Evaluation of such factors may assist in identifying the etiology of suboptimal nutrition status and will inform the development of an appropriate nutrition intervention and care plan.

## Consequences and Outcomes of the At-Risk Orthopedic Patient

### Underweight/Malnourished Patients

As previously described, patients presenting for surgery who are underweight or malnourished at baseline may be at an increased risk for postoperative complications. The catabolic response to surgery coupled with the perioperative fasting regimen may exacerbate the occurrence of suboptimal nutrient intake, further compromising the nutrition status of such patients. Problems associated with malnutrition are numerous, and include significantly increased rates of morbidity and mortality, medical costs, and length of hospitalization [14, 32].

As a result, malnourished patients risk prolonged hospitalization, which may be complicated by delayed wound healing [4], infection, delayed physical rehabilitation [14], development of pressure ulcers, weight loss, and lean muscle wasting. Malnourished patients undergoing major orthopedic surgery as a result of hip fracture, or need for total joint replacement or spinal surgery have been shown to have significantly higher rates of perioperative complications, including death, infections, and increased length of hospital stay [33]. Furthermore, several studies have evaluated the impact of malnutrition on fracture healing. Despite the fact that fractures do eventually heal in the malnourished patient, there is evidence to suggest that both the quality and strength are diminished [34]. Perioperative malnutrition has also been implicated in elevated rates of pneumonia, urinary tract infections, wound infections, and sepsis. These complications lead to overwhelming circumstances for the patients and their families, and add to the financial burden incurred by hospitals and insurance companies.

Prompt identification of malnourished or underweight patients and early initiation of nutrition intervention may help protect patients against the negative outcomes associated with undernourishment. The severity of malnutrition and related complications in the orthopedic patient may be minimized with early and adequate feeding or provision of specialized nutrition support.

### Unique Concerns of the Elderly Patient

Elderly patients are often determined to be at high nutrition risk for a multitude of reasons. Some elderly patients may be diagnosed with malnutrition due to inadequate food intake or

may present with physical and functional impairments. Conditions affecting patients' functional capacity to effectively chew and swallow food, prepare meals, and independently feed themselves can greatly impact nutrition status. As a result of declining physical and cognitive function, poor dentition, alterations in taste sensation, and reduced salivary flow, elderly patients may find it difficult to meet nutrient needs via oral intake. Often elderly patients presenting for surgery are found to have diminished lean body mass and visceral protein stores prior to admission, thus maintenance of muscle mass as well as skin integrity postoperatively is a primary nutrition-related concern.

Such patients should be identified as early as possible prior to surgery or immediately upon admission so that proper nutritional care can be initiated promptly. A protocol for identifying these high-risk patients and a pathway for initiating nutrition care (i.e., provision of protein/calorie supplements upon admission) may be a beneficial component of the nutrition screening process. An additional nutrition-related concern is that elderly patients may need assistive devices to overcome difficulty grasping utensils or cups, they may require assistance with meals, or their conditions may necessitate the use of altered food and beverage consistencies to reduce risk of aspiration in the hospital, thus prompt referral to an RD is essential for optimizing care.

## Trauma and Recent Surgery

As a result of the physiologic stress response brought about by physical trauma, the nutrient needs of a trauma patient presenting for orthopedic surgery may be greatly increased. Caloric needs postoperatively can be as high as two times the amount normally required for weight maintenance and the support of basic physical functioning. The greatly increased needs for protein and calories to support healing postoperatively and following trauma are often difficult for patients to achieve.

Furthermore, the perioperative fasting regimen as well as the side effects that are commonly experienced from medications may result in a negative net nutrient balance in the patient. Additionally, there has been considerable research to suggest that nutrition is closely linked with health outcomes of the trauma patient [35]. Malnutrition is not only frequently found among trauma patients, but has also been identified as an independent risk factor for morbidity, mortality, and length of hospitalization. Subsequently, trauma patients should be referred to an RD as early after admission as possible for a full nutrition assessment to evaluate adequacy of nutrient intake and identify specific dietary needs. The RD will assess the appropriateness and/or feasibility of specialized nutrition support, such as enteral tube feeding.

## Infections

Similar to the trauma patient, a patient who presents for orthopedic surgery with a current infection or history of recent infection is at increased nutrition risk. The inflammatory response and physiologic stress induced by infections significantly increase nutrient needs in such patients, well beyond the increases incurred by surgery alone. Surgical patients presenting with infection often require substantially greater amounts of protein and calories to support such elevated metabolic demands brought upon by infection, drainage, and the potential for multiple surgical procedures or debridement.

## Staged or Complex Surgeries

Due to the nature of staged or complex surgical procedures, patients are often intubated for prolonged periods of time. Patients who are intubated between surgeries are often candidates for enteral nutrition support (i.e., tube feeding) because of their inability to receive oral nutrition during this time. Additionally, for those patients with prolonged intubation, esophageal and oral irritation or swelling may result, thereby increasing the likelihood that the patient will experience difficult or painful swallowing. As a result of such swallowing discomfort patients are often unable to meet their nutrition needs orally. Thus, patients undergoing staged or complex surgeries should be followed by an RD and speech pathologist for proper assessment of alternative nutrition needs.

In addition to the increased likelihood of postoperative dysphagia, patients undergoing complex or staged surgery are at increased risk nutritionally, due to inadequate nutrient intake. Two of the commonly identified complications with staged surgery are infection and wound healing problems, both of which have been associated with poor nutrition status. Patients undergoing such surgeries are subjected to variable periods of fasting during the perioperative period. The preoperative fasting regimen, followed by the postoperative diet advancement (i.e., advancing from ice chips and clear liquids to solid foods over several days), combined with the catabolic state induced by surgery make it challenging for such patients to meet their increased metabolic needs nutritionally. Therefore, it is essential that patients undergoing complex or staged surgical procedures be seen and evaluated by an RD to optimize postoperative outcomes.

## Diabetes/Impaired Glucose Tolerance

Patients with a history of diabetes mellitus or impaired glucose tolerance often present a unique challenge during

**Table 21.5** Measures of glycemic control

| Glycemic control measures | Ideal values[a] |
|---|---|
| Preprandial (before meal) plasma glucose | 70–130 mg/dL |
| Peak (2 h after meal) postprandial plasma glucose | <180 mg/dL |
| Hemoglobin A1c | <7 % |

[a]Data from American Diabetes Association Recommendations

the perioperative period. Proper glycemic control is an important factor in promoting postoperative healing and supporting physiological functioning. It is well known that glycemic control has been associated with a variety of perioperative complications, resulting in increased morbidity and mortality. Thus, it is important to recognize that approximately 52 % of patients with arthritis have also been diagnosed with diabetes mellitus [36]. Because many patients with arthritis present for orthopedic surgery, understanding the impact of glycemic control is of high importance.

Research suggests that orthopedic surgical patients with uncontrolled diabetes mellitus may be at a significantly increased risk of having a cerebrovascular event, urinary tract infection, ileus, transfusion, wound infection, increased length of stay, and death [2]. The exact mechanism behind the relationship between glycemic control and perioperative outcomes is not clearly understood. However, it is well known that elevated blood sugar concentration can acutely influence the body's ability to heal wounds and maintain optimal physiological stability.

Preoperative evaluation of patients is essential to identify level of patient self-management, dietary compliance, and potential complications. Nutrition consultations should be included in a multidisciplinary evaluation in preparation for surgery. Assessment of a hemoglobin A1c level should be included as part of a medical clearance. Patients presenting for surgery with a history of diabetes mellitus or impaired glucose tolerance should be carefully evaluated for risk of elevated blood sugar during the postoperative period. Daily checks of blood glucose levels via fingersticks as well as a review of a patient's hemoglobin A1c (glycosylated or glycated hemoglobin) are recommended in order to properly manage blood glucose levels during the perioperative period (Table 21.5). Monitoring fingersticks allows the healthcare team to carefully monitor changes in blood glucose concentration on a daily basis, whereas the hemoglobin A1c is a serologic measure that provides information on the average glucose concentration in the bloodstream over the preceding 3 months. Since preoperative glycemic control is an important indicator of postoperative blood glucose trends, it is important to assess both daily and long-term measures. According to the Academy of Nutrition and Dietetics and the American Diabetes Association, a consistent carbohydrate diet is recommended in diabetic patients who are hospitalized.

## Perioperative Nutrition Therapy

### Preoperative Nutrition

Well-nourished patients who are seen preoperatively should be encouraged to consume a balanced diet and maintain adequate weight. Patients who indicate poor nutrient intake should be encouraged to consume oral nutritional supplements (ONS) leading up to the surgery. Current guidelines recommend the use of nutrition support in patients at severe nutrition risk for a period of 10–14 days prior to surgery [37]. This recommendation includes postponing surgery, if necessary to achieve this goal. Factors that are used to classify severe nutrition risk patients include occurrence of a 10–15 % weight loss within 6 months, a body mass index (BMI) of <18.5 kg/m$^2$, a Subjective Global Assessment Grade C, or a serum albumin <30 g/L (3 g/dL) without evidence of renal or hepatic dysfunction [37]. It is recommended to initiate nutrition support without delay by enteral route if possible, either with ONS or tube feeding (TF) in patients at severe nutrition risk [37]. Nutrition support via the enteral route is also recommended in those without evidence of nutrition risk, if it anticipated that the patient will be unable to eat for more than 7 days perioperatively or if the patient cannot maintain oral intake above 60 % for more than 10 days [37]. A combination of enteral and parenteral nutrition may be considered for patients in which energy needs cannot be met (<60 % of calorie requirement) via enteral nutrition alone [37].

Although not specific to the orthopedic patient, preoperative fasting from midnight may be unnecessary for most patients undergoing elective surgery [37, 38]. Additionally, patients who are considered to have no risk for aspiration may drink clear fluids until 2 h prior to anesthesia and solids 6 h prior to anesthesia [37, 38].

Preoperative carbohydrate loading has been used in patients undergoing hip replacement surgery to reduce postoperative insulin resistance, a factor in postoperative metabolism. A limited number of studies have shown that carbohydrate beverages given preoperatively decreased length of stay by up to 20 % [7, 14, 15, 39]. The authors suggest that since patients arrive at the hospital after fasting,

they are already facing metabolic stress. Thus, a carbohydrate supplement given before surgery can be quickly broken down to avoid interference with anesthesia. However, little research has been done in this area and further studies are needed to confirm that carbohydrate supplementation improves functional outcome after orthopedic surgery [40].

## Early Feeding/Postoperative Feeding

Periods of fasting following surgery have been a traditional practice, where oral feedings were held until bowel function (described as passing of flatus and return of bowel sounds) has resumed. Postoperative complications such as ileus, aspiration, abdominal distention, nausea, and vomiting have been the basis of this practice; however, this may not be the best practice for postoperative patients.

Since clinical guidelines have not been established for the orthopedic patient, we draw from the surgical and critical care literature that indicates benefit of early feeding and minimizing periods of fasting or inadequate nutrition. Avoidance of prolonged periods of preoperative fasting and reestablishing early enteral feeding after surgery have been a focus for the enhanced recovery of patients after surgery [37]. Recent nutrition support guidelines from the American Society of Parenteral and Enteral Nutrition (ASPEN) and the Society for Critical Care Medicine (SCCM) indicate several benefits of early enteral nutrition in medically and surgically critically ill patients [2]. Compared to delayed feedings, early enteral nutrition (described as enteral nutrition initiated within 24–48 h admission or onset of a hypermetabolic insult) is associated with decreased gut permeability, decreased activation and release of cytokines, decrease in systemic endotoxemia, reductions in infectious morbidity, reduced length of hospital stay, and increased tolerance to enteral nutrition [3]. These guidelines also indicate that it is safe and appropriate to feed through a mild-moderate ileus since enteral nutrition promotes GI motility [3]. Patients who can safely tolerate oral feedings should be provided with appropriate diets and ONS to meet their postoperative nutrient requirements. When oral intake is insufficient, enteral tube feedings should be used to provide nutrition support.

In literature regarding care for critically ill and surgical patients, it is recommended that if the gastrointestinal tract is functional, tube feeding should be initiated with a low flow rate within 24 h postoperatively [37]. Parenteral nutrition should be used for patients who are unable to be fed enterally, only as a last resort.

Shorter hospital stays, reduced time to adequate nutrient intake, and early mobilization are some benefits to early postoperative feeding, or reestablishing oral intake prior to clinical signs of bowel sounds and flatus [33, 41]. In abdominal surgery patients, early postoperative feeding as part of multimodal clinical pathways may also reduce ileus duration [33, 41]. Resuming early postoperative fluid intake after caesarian sections (abdominal) surgery was associated with reduced time to solid foods, shorter hospital stay, and reduced postoperative nausea [1].

## Perioperative Nutrition Care Planning

An optimal nutrition care plan in the orthopedic patient is one that provides adequate calories, protein, and micronutrients, supports wound healing and preservation of lean body mass, reduces the risk of postoperative complications associated with malnutrition, and improves function and capacity for rehabilitation. Inadequate oral intake for more than 14 days, regardless of preoperative nutrition status, is associated with higher mortality risk [37]. Among those presenting with malnutrition, adequate nutrient intake in the orthopedic patient results in improved nutrition status, improved wound healing [7], shorter hospital and rehabilitation length of stay, decreased mortality, and diminished undesired weight loss [42]. Thus it is important to carefully assess patients' nutrition status and to appropriately treat patients who are malnourished or at elevated nutrition risk to minimize the chance of developing complications.

In determining the nutrition intervention strategy for orthopedic patients, provision of energy and protein should be individualized and determined by comprehensive nutrition assessments conducted by the healthcare team. Typical energy requirements for orthopedic patients range from 25 to 35 kcal/kg/day and protein requirements range from 1.2 to 2.0 g/kg/day [43]; however, these values vary based on patients' weight status, surgery, and health history. Nutrition therapy for the orthopedic patient consists of early postoperative feedings by means of oral diets (with or without the use of ONS), enteral nutrition support via tube feedings (nasogastric or orogastric), gastrostomy or jejunostomy feedings, or parenteral routes. Micronutrient supplementation in the form of vitamins, minerals, and specific amino acids indicated for wound healing may also be required for nutrition therapy of the orthopedic patient. Additionally, fluid status should be optimized. Nutritional treatments will be discussed in detail later in this chapter. RDs have the necessary skills for determining nutrition status and nutrient requirements and can assist in the selection, administration, and monitoring of appropriate nutrition support.

Postoperative nutrition care should be initiated early in the postoperative period to ensure the best possible recovery. An important starting point in postoperative nutrition care is determining the route of nutrition intake (i.e., oral, enteral, and parenteral), followed by the assessment of the patient's

nutrition requirements. This includes determining the patient's energy and protein needs and establishing a nutrition care plan that will meet the patient's nutrient requirements. Nutrition care plans and interventions can be established with the support of an RD, who possesses the skills and knowledge necessary to conduct a nutrition assessment and determine the optimal nutrition care plan for the patient.

## Oral Nutritional Supplements

Oral nutritional supplementations (ONS) are commonly used in the preoperative or perioperative period to meet nutrient needs of patients. The use of ONS in elderly patients is often indicated to achieve favorable outcomes in hip fractures [44–46]. ONS are recommended in geriatric patients after hip fracture and orthopedic surgery to minimize complications and reduce risk of pressure ulcer development, which is prevalent in elderly orthopedic patients [45]. ONS are also indicated in patients who are well nourished if it is anticipated that the patients will be unable to meet nutrient requirements during the perioperative period. Most orthopedic patients face periods of fasting and liquid diets; therefore ONS have a role in supplementing nutrient intake to minimize nutrient depletion while oral intake is suspended (due to NPO status) or insufficient (during liquid diet phases).

ONS should be initiated early and should not be given only when malnutrition is apparent. The effectiveness of ONS is limited by patient compliance. Patient compliance to ONS has a significant impact on nutrition-related outcomes, and factors that affect ONS compliance may include support from hospital staff, providing supplements between meals as not to interfere with meal times, and provide patients with the desired flavors, temperature, and consistency.

ONS are recommended in orthopedic patients to augment nutrient intake. These commercial supplements provide approximately 250–360 cal and 8–14 g of intact protein in a 240 mL serving [47]. There are several types of ONS for different disease states, such as diabetes or renal disease; therefore ONS can be used for nutrition interventions in several patients. Furthermore, ONS are available in clear liquid form, which is appropriate for the clear liquid diet phase, and formulas are available in various flavors to meet patients' preferences and promote intake.

ONS have been shown to increase perioperative nutrient intake, and promote wound healing and favorable postoperative outcomes in hip fracture patients [44, 48–50], trauma patients, spine surgery patients, and patients recovering from amputations [51]. High protein ONS may assist in meeting the elevated protein requirements of orthopedic surgery [38]. Several studies indicate that the use of ONS in geriatric patients with hip fractures may lead to increased nutrient intake, decreased unfavorable outcomes, reduced proximal femur bone loss, enhanced recovery of plasma proteins, and shorter rehabilitation hospital stays [38, 48, 49]. It is important to note that several servings of ONS may be required daily to meet the nutrient needs of orthopedic patients and to be effective in achieving the desired outcomes.

## Nutrition Support Therapy

### Enteral Nutrition Support

Enteral nutrition support is a means of providing nutrients to patients who are unable to achieve the recommended nutrient intake orally. Among orthopedic patients, this may include patients who present with dysphagia (preexisting dysphagia or dysphagia that has occurred postoperatively), malnourished patients, trauma patients with elevated metabolic demands, patients suspected to require prolonged intubation periods, and patients who are scheduled for multiple surgeries. Additional factors that may determine enteral nutrition therapy in orthopedic patients include frail elderly patients, patients with early dementia who have insufficient oral intake, and patients with postoperative episodes of delirium or confusion that results in inadequate oral intake. Perioperative complications and dementia have been shown to contribute to low nutrient intake in hip fracture patients [38]; therefore these conditions may predispose patients to require intensive nutrition regimens, such as ONS, enteral tube feeding, or parenteral nutrition. Enteral nutrition therapy in elderly orthopedic patients has been shown to improve anthropometric parameters such as weight and BMI, in addition to increasing plasma protein stores and improved mobility after hip fracture surgery [45].

Compliance to enteral nutrition prescriptions can determine the effectiveness and expected outcomes of this type of nutrition support. Intolerances to enteral feedings have been a limiting factor in the compliance to tube feeding regimens and consequently have resulted in suboptimal nutrient provision. It is important that RDs have a role in the assessment and reassessment of patients who are receiving enteral feeding therapy to facilitate proper administration and compliance to the tube feeding prescription. Additionally, enteral feeding prescriptions should be implemented according to hospital safety standards and protocols for nutrition support.

Further research on the use of enteral feeding in orthopedic surgical patients is required to establish guidelines for orthopedic patients; however, the use of tube feeding has been shown to improve outcomes in patients who are critically ill. It is important to initiate enteral nutrition support early when there are signs of nutrition risk to promote

favorable postoperative outcomes [37]. Enteral nutrition support should be initiated early, even in patients who are not considered severely malnourished, if it is anticipated that patients will not be able to eat for more than 7 days perioperatively [37]. Additionally, nutrition support should be initiated in patients who are unable to maintain oral intake above 60 % of estimated nutrient needs for more than 10 days [37]. Thus, enteral nutrition support is indicated for patients who will be unable to eat for a period of >7 days perioperatively and/or for patients who are unable to maintain >60 % of their nutrient recommendations for more than 10 days.

Enteral nutrition is the preferred route over parenteral nutrition for critically ill patients who require nutrition support therapy. Enteral nutrition can help maintain integrity of gut-associated lymphoid tissue (GALT) and mucosal-associated lymphoid tissue (MALT) [52]. When compared to parenteral nutrition, enteral nutrition has been associated with lower incidence of infection and reduced costs in critically ill patients [3]. Enteral nutrition support is, however, contraindicated in patients with a dysfunctional gut, intestinal obstructions, severe ileus, severe shock, intestinal ischemia [37], or patients with terminal illnesses who decline nutrition support [45]. Patients with severe trauma, those who are malnourished, and those with anticipated inadequate oral intake (<60 % of estimated needs) for more than 10 days may benefit from early enteral nutrition support to minimize postoperative complications [37].

The route of enteral nutrition therapy via tube feedings depends on duration of nutrition support and available access. For long-term nutrition support (>4 weeks), percutaneous endoscopic gastrostomy (PEG) feedings are preferred over nasogastric tube (NGT) feedings [45]. PEG feedings may result in better nutrient administration than NGT feedings [53]. NGTs should be placed postpylorically in critically ill patients or patients with high aspiration risk, and feedings should be initiated at low rates. Proper safety precautions such as monitoring for aspiration, feeding intolerance, and administering feeds at appropriate rates should be carried out. RDs can provide valuable assistance in enteral tube feeding prescription and reassessment of the patient receiving this nutrition therapy.

## Parenteral Nutrition Support

The administration of total parenteral nutrition has been studied as a means to mitigate nutritional depletion in orthopedic patients, particularly in patients undergoing spinal surgery [31]. Protein and calorie malnutrition can develop in patients undergoing spinal reconstructive surgery, compromising wound healing and increasing infection risk [11]. Total parenteral nutrition has been used in patients undergoing either staged or same-day anterior/posterior (A/P) spinal surgery because of prolonged delays in postoperative diet progression, and inability to tolerate oral and/or enteral intake. One study found that TPN resulted in less postoperative nutritional depletion and expedited return to preoperative nutrition status in patients undergoing spine surgeries greater than ten levels (including A/P staged, A/P delayed more than 1 week, A/P same day, and posterior spine surgeries) [31]. This study, however, did not find differences in minor or major complications postoperatively.

Although total parenteral nutrition has historically been used to optimize nutrition status in patients undergoing complex spine surgery, use of this modality should be restricted due to the inherent risks associated with feeding via central venous access. Parenteral nutrition has been identified as a risk factor for catheter-related blood stream infections and hyperglycemia [54]. Furthermore, the benefits of enteral nutrition support over the use of parenteral nutrition support are well documented [3]. Several studies suggest reductions in infectious morbidity, length of hospital stay, and cost of nutrition therapy with regard to enteral nutrition compared to parenteral nutrition [3]. In the rare event that enteral nutrition is not feasible, parenteral nutrition should be initiated in patients who have been unable to receive adequate nutrition at least 5–7 days postoperatively.

## Micronutrient Supplementation

Micronutrient requirements are often met by means of oral, enteral, and parenteral routes; however, certain micronutrient and amino acid supplements may be of value to the orthopedic patient. In most cases, it is critical to first ensure that patients are receiving proper amounts of protein, energy, and fluids prior to providing micronutrient supplementations. The value of adequate protein and calories to support wound healing and prevent postoperative complications must not be overlooked. Many orthopedic patients suffer from specific micronutrient deficiencies, which should be corrected by supplementation. In addition to supplying orthopedic patients with adequate protein and calories to treat or prevent catabolism, certain micronutrients have a role in the perioperative nutrition care of orthopedic patients.

Calcium and vitamin D influence bone health and insufficient intake and levels of these micronutrients are linked to osteoporosis and bone fractures [55]. Vitamin D deficiency has been observed in elderly and hip fracture patients [55] as well as pediatric patients undergoing orthopedic surgery [56, 57]. Poor vitamin D status has been linked to cases of fracture nonunions, stress fractures, and slipped capital femoral epiphysis [53, 58–60]. All orthopedic patients should be screened for vitamin D deficiency and appropriate supplementation should be initiated. Calcium and vitamin D

supplementations have been indicated in elderly patients with hip fractures to reduce postoperative complications and minimize bone loss [55, 61].

Glutamine and arginine are amino acids that may promote wound healing potential and immune function. Hip fracture and elderly patients who are at high risk for developing pressure ulcers may benefit from arginine and glutamine supplementations. Low zinc levels may contribute to the development of pressure ulcers. Zinc and arginine supplementations have been used in patients with hip fractures to treat and reduce the incidence of pressure ulcers. In patients with zinc deficiency, the provision of 50 mg of elemental zinc for 2 weeks may be beneficial; however, zinc toxicity should be avoided and supplementation should be carefully monitored since zinc can interfere with copper absorption [15].

## Nutrition Management of Postoperative Ileus

Postoperative ileus (POI), described as a temporary impairment of bowel and gastric motility after surgery, has been identified as a complication after total hip and knee arthroplasty, hip fracture repair, and spine surgery [19, 62]. The occurrence of POI contributes to increased hospital stay, elevated healthcare costs, and can contribute to unfavorable surgical outcomes such as delayed wound healing, deep vein thrombosis, and pneumonia [62]. After the diagnosis of a POI, patients' diets are often held or downgraded to clear liquids, which presents a challenge in overcoming the catabolic demands of the postoperative patient. This change in diet leads to inadequate nutrient intake, and can affect wound healing potential, immunity, and gastrointestinal physiology.

Until recently, physicians have relied on the presence of bowel sounds and flatus in order to resume oral nutrition and hydration in a patient who has had a POI. Recent literature has indicated that the presence of bowel sounds and/or flatus should not be the factors used to initiate oral nutrition and early feeding may reduce duration of POI [19]. When patients are not allowed to eat, intravenous (IV) maintenance fluids should contain carbohydrates (e.g., 10 % dextrose solutions) in order to provide a source of calories in a patient who risks catabolism and a worsening malnutrition status. Perioperative fluid management is imperative and hydration status should be closely monitored since overhydration from intravenous fluid therapy may contribute to gut edema which can worsen POI [19].

In addition to affecting wound healing, delayed oral intake can impact the resolution of an ileus. Periods of restricted oral hydration and nutrition (NPO status) should be limited perioperatively to prevent or lessen the duration of POI [19] and minimize duration of inadequate nutrient intake.

Research has studied the use of probiotics and carbohydrate loading preoperatively for the prevention of POI; however, these practices have not been adopted in the orthopedic patient [63]. Probiotics given in the pre- and postoperative period are hypothesized to maintain gastric motility, and carbohydrate loading in the form of carbohydrate-rich liquids within hours of surgery has been found in some studies to shorten bowel recovery time [40]. However, the avoidance of prolonged preoperative fasting has been indicated to prevent the occurrence of POI [19].

Studies investigating early enteral feedings in postoperative patients have shown reduced occurrences and durations of POI, including early enteral feeding as a strategy to prevent POI [19].

Gum chewing has been recently indicated as a treatment for POI because it serves as a "sham feeding," stimulating the cephalic-vagal complex and stimulating gastric function and bowel motility [19]. Several studies have found that in patients with POI following abdominal surgery, chewing gum reduced the time to passage of flatus and stool, thus reducing the duration of POI [64]. Patients' mental status, aspiration risk, and dentition should be assessed before providing chewing gum as a POI treatment.

## Summary

Recognizing nutrition-related factors that impact the health outcomes of patients is critical. Insufficient nutrient intake in orthopedic surgical patients leads to increased complications and delayed recovery. Optimizing nutrition in the orthopedic patient may lead to fewer infections, reduced risk of pressure ulcer development, improved wound healing, and enhanced physical function. Optimization of nutrient intake should include preoperative nutrition assessment, establishment of an appropriate nutrition care plan, and continuous monitoring of nutrient intake.

In an effort to maximize patient outcomes and minimize risk of morbidity and mortality, clinicians should carefully consider patients' preoperative nutrition status. When feasible, clinicians should refer patients who appear to be at increased nutrition risk to an RD early in the preoperative planning stage. Postoperative provision of nutrition care and effort to ensure adequate intake of macro- and micronutrients should be a priority of the orthopedic healthcare team.

The overall benefits of optimal nutrition are supported in the literature; however, future research regarding perioperative nutrition care of the orthopedic patient is needed to establish and identify specific guidelines, risks, and benefits for the

optimal methods of nutrition support when oral nutrition is not possible.

**Summary Bullet Points**

- Orthopedic patients who are malnourished are at a higher risk for postoperative complications, such as infection, poor wound healing, increased hospital length of stay, and mortality.
- Nutritional status of orthopedic patients should be evaluated preoperatively. If orthopedic patients are at nutritional risk, an intervention should be initiated as early as possible.
- Anthropometric data, laboratory values, recent changes in weight and nutrient intake, and medical history are used to determine orthopedic patients' nutritional risk. The NRS 2002 and the SGA are examples of nutritional screening tools for orthopedic patients.
- Perioperative nutrition management of orthopedic patients may include specialized nutrition support. If nutrition support is required, enteral nutrition is preferred over parenteral nutrition. Oral nutrition supplements may benefit patients who have sustained hip fractures and amputations.
- Minimizing periods of fasting postoperatively and initiating early feedings may result in reduced time to adequate nutrient intake, early mobilization, and shorter hospital stays.

## Appendix 1. Nutritional Risk Screening (NRS 2002)

(Used with permission from Kondrup J, Allison SP, Elia M, Vellas B, Plauth M. ESPEN Guidelines for Nutrition Screening 2002. Clinical Nutrition (2003) 22(4): 415–421.)

## Appendix 2. Subjective Global Assessment (SGA)

(Used with permission from Sacks GS, Dearman K, Replogle W H, Cora V L, Meeks M, Canada T. Use of Subjective Global Assessment to Identify Nutrition-Associated Complications and Death in Geriatric Long-Term Care Facility Residents. Journal of the American College of Nutrition 2000; 19(5), 570–577.)

*Nutritional Risk Screening (NRS 2002)*

**Table 1** Initial screening

| | | Yes | No |
|---|---|---|---|
| 1 | Is BMI <20.5? | | |
| 2 | Has the patient lost weight within the last 3 months? | | |
| 3 | Has the patient had a reduced dietary intake in the last week? | | |
| 4 | Is the patient severely ill ? (e.g. in intensive therapy) | | |

**Yes**: If the answer is 'Yes' to any question, the screening in Table 2 is performed.
**No**: If the answer is 'No' to all questions, the patient is re-screened at weekly intervals. If the patient e.g. is scheduled for a major operation, a preventive nutritional care plan is considered to avoid the associated risk status.

**Table 2** Final screening

| **Impaired nutritional status** | | **Severity of disease (≈ increase in requirements)** | |
|---|---|---|---|
| Absent **Score 0** | Normal nutritional status | Absent **Score 0** | Normal nutritional requirements |
| Mild **Score 1** | Wt loss >5% in 3 mths or Food intake below 50–75% of normal requirement in preceding week | Mild **Score 1** | Hip fracture* Chronic patients, in particular with acute complications: cirrhosis*, COPD*. *Chronic hemodialysis, diabetes, oncology* |
| Moderate **Score 2** | Wt loss >5% in 2 mths or BMI 18.5 – 20.5 + impaired general condition or Food intake 25–60% of normal requirement in preceding week | Moderate **Score 2** | Major abdominal surgery* Stroke* *Severe pneumonia, hematologic malignancy* |
| Severe **Score 3** | Wt loss >5% in 1 mth (>15% in 3 mths) or BMI <18.5 + impaired general condition or Food intake 0-25% of normal requirement in preceding week in preceding week. | Severe **Score 3** | Head injury* Bone marrow transplantation* *Intensive care patients (APACHE>10).* |
| **Score:** | + | **Score:** | **=Total score** |
| **Age** | if ≥70 years: add 1 to total score above | **=age-adjusted total score** | |

**Score ≥3**: the patient is nutritionally at-risk and a nutritional care plan is initiated
**Score <3**: weekly rescreening of the patient. If the patient e.g. is scheduled for a major operation, a preventive nutritional care plan is considered to avoid the associated risk status.

**NRS-2002** is based on an interpre-tation of available randomized clinical trials.
*indicates that a trial directly supports the categorization of patients with that diagnosis. Diagnoses shown in *italics* are based on the prototypes given below.
**Nutritional risk** is defined by the present **nutritional status** and risk of impairment of present status, due to **increased requirements** caused by stress metabolism of the clinical condition.

**A nutritional care plan** is indicated in all patients who are

(1) severely undernourished (score = 3), or (2) severely ill (score = 3), or (3) moderately undernourished + mildly ill (score 2 + 1), or (4) mildly undernourished + moderately ill (score 1 + 2).

**Prototypes for severity of disease**
**Score = 1**: a patient with chronic disease, admitted to hospital due to complications. The patient is weak but out of bed regularly. Protein requirement is increased, but can be covered by oral diet or supplements in most cases.

**Score = 2**: a patient confined to bed due to illness, e.g. following major abdominal surgery. Protein requirement is substantially increased, but can be covered, although artificial feeding is required in many cases.

**Score = 3**: a patient in intensive care with assisted ventilation etc. Protein requirement is increased and cannot be covered even by artificial feeding. Protein breakdown and nitrogen loss can be significantly attenuated.

| MEDICAL HISTORY | SGA Rating A | B | C |
|---|---|---|---|
| 1. **Weight Change** Clothing Size _____ No Change _____ Change<br>Overall loss in past month: _____ _____ 6 months _____ 1 year | | | |
| % Loss of usual weight _____ < 5%<br>_____ 5-10%<br>_____ > 10% | | | |
| Change in past 2 weeks _____ Increase (*gain*)<br>_____ No change (*stabilization*)<br>_____ Decrease (*continued loss*) | | | |
| 2. **Dietary Intake** Reduction _____ Unintentional _____ Intentional<br>Overall Change _____ No Change<br>_____ Change Increase or Decrease | | | |
| Duration _____ Weeks _____ Months | | | |
| Diet Change _____ Suboptimal solids (i.e., 75%, 50%, 25% intake)<br>_____ Full liquid diet<br>_____ Hypocaloric fluids<br>_____ NPO (*starvation*) | | | |
| 3. **Gastrointestinal Symptoms** (*persisting daily for > 2 weeks)*<br>_____ None _____ Diarrhea _____ Dysphagia/Odynaphagia<br>_____ Nausea _____ Vomiting _____ Anorexia | | | |
| 4. **Functional Impairment**<br>Overall impairment _____ None _____ Mild _____ Severe | | | |
| Duration _____ Days _____ Weeks _____ Months | | | |
| Type _____ Ambulatory (Walking or Wheelchair)<br>Bedridden | | | |

| PHYSICAL EXAMINATION | SGA Rating Well (A) | Mild/Mod (B) | Severe (C) |
|---|---|---|---|
| 5. **Muscle Wasting** _____ Bicep _____ Tricep | | | |
| _____ Quadricep _____ Deltoid _____ Temple | | | |
| 6. **Subcutaneous Fat Loss** _____ Tricep _____ Chest<br>_____ Eyes _____ Perioral _____ Interosseous _____ Palmar | | | |
| 7. **Edema** _____ Hands _____ Sacral _____ Lower extremity | | | |

**(A) Well Nourished ____ (B) Mild/Moderate Undernutrition ____ (C) Severe Undernutrition ____**

## References


1. Mangesi L, Hofmeyr GJ. Early compared with delayed oral fluids and food after caesarean section. Cochrane Database Syst Rev 2002;(3): CD003516.
2. Marchant MH, Viens NA, Cook C, Vail TP, Bolognesi MP. The impact of glycemic control and diabetes mellitus on perioperative outcomes after total joint arthroscopy. J Bone Joint Surg. 2009; 91(7):1621–9.
3. McClave SA, Martindale RG, Vanek VW, McCarthy M, Roberts P, Taylor B, Ochoa J, Napolitano L, Cresci G. Guidelines for provision and assessment of nutrition support therapy in the adult critically ill patient: society for critical care medicine (SCCM) and American society of parenteral and enteral nutrition (ASPEN). J Parenter Enteral Nutr. 2009;33:277–316.
4. Guo JJ, Yang H, Qian H, Huang L, Guo Z, Tang T. The effects of different nutritional measurements on delayed wound healing after hip fracture in the elderly. J Surg Res. 2010;159(1):503–8.
5. Patel D, Roth M, Kapil N. Stress fractures: diagnosis, treatment, and prevention. Am Fam Physician. 2011;83(1):39–46.
6. Martindale R, Maerz L. Management of perioperative nutrition support. Curr Opin Crit Care. 2006;12:290–4.
7. Dwyer AJ, John B, Mam MK, Antony P, Abraham R, Joshi M. Nutritional status and wound healing in open fractures of the lower limb. Int Orthop. 2005;29:251–4.
8. White JV, Guenter P, Jensen G, Malone A, Schofield M, Academy Malnutrition Work Group, A.S.P.E.N. Malnutrition Task Force, A. S.P.E.N. Board of Directors. Consensus statement of the Academy of Nutrition and Dietetics/American Society for Parenteral and enteral nutrition: characteristics recommended for the identification and documentation of adult malnutrition (undernutrition). J Acad Nutr Diet. 2012;112(5):730–8.
9. National Institutes of Health. Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults (NIH Publication No. 98-4083). Washington, DC: US Dept of Health and Human Services, Public Health Service, National Institutes of Health, National Heart, Lung, and Blood Institute; 1998.
10. Sacks GS, Dearman K, Replogle WH, Cora VL, Meeks M, Canada T. Use of subjective global assessment to identify nutrition-associated complications and death in geriatric long-term care facility residents. J Am Coll Nutr. 2000;19(5):570–7.
11. Dick J, Boachie-Adjei O, Wilson M. One-stage versus two-stage anterior and posterior spinal reconstruction in adults. Comparison of outcomes including nutritional status, complications rates, hospital costs, and other factors. Spine. 1992;17(8 Supplement):S310–6.
12. Ozkalkanli M, Ozkalkanli DT, Katircioglu K, Savaci S. Comparison of tools for nutrition assessment and screening for predicting the development of complications in orthopedic surgery. Nutr Clin Pract. 2009;24:274–80.
13. Gramlich L, Kichian K, Pinilla J, Rodych NJ, Dhaliwal R, Heyland DK. Does enteral nutrition compared to parenteral nutrition result in better outcomes in critically ill adult patients. A systematic review of the literature. Nutrition. 2004;20(10):843–8.
14. Jensen JE, Jensen TG, Smith TK, Johnston A, Dudrick SJ. Nutrition in orthopaedic surgery. J Bone Surg. 1982;64(9):1263–72.
15. Academy of Nutrition and Dietetics. Nutrition Care Manual® (NCM®). http://nutritioncaremanual.org/content/cfm?ncm_content. Accessed January 3, 2012.
16. Lenke LG, Bridwell KH, Blanke K, Baldus C. Prospective analysis of nutritional status normalization after spinal reconstructive surgery. Spine. 1995;20:1359–67.
17. National Kidney Foundation (NKF)/KDOQI Guidelines 2000. http://www.kidney.org/professionals/kdoqi/guidelines_updates/nut_a03.html
18. Patterson BM, Cornell CN, Carbone B, Levine B, Chapman D. Protein depletion and metabolic stress in elderly patients who have a fracture of the hip. J Bone Joint Surg Am. 1992; 74(2):251–60.
19. Story SK, Chamberlain RS. A comprehensive review of evidence-based strategies to prevent and treat postoperative ileus. Dig Surg. 2009;26:265–75.
20. Sutipornpalangkul W, Harnroongroj T. Protein depletion in Thai patients with hip fractures. J Med Assoc Thai. 2007;90(11):2332–7.
21. Ozturk A, Ozkan Y, Akgoz S, Yalcin N, Aykut S, Ozdemir MR. The effect of blood albumin and total lymphocyte count on short-term results in elderly patients with hip fractures. Ulus Travma Acil Cerrahi. 2009;15(6):546–52.
22. Robinson TN, Eiseman B, Wallace JI, Church SD, McFann KK, Pfister SM, Sharp TJ, Moss M. Redefining geriatric preoperative assessment using frailty, disability and co-morbidity. Ann Surg. 2009;250(3):449–55.
23. Sakuma M, Endo N, Oinuma T, Hayami T, Endo E, Yazawa T, Watanabe K, Watanabe S. Vitamin D and intact PTH status in patients with hip fracture. Osteoporos Int. 2006;17(11):1608–14.
24. Symeonidis PD, Clark D. Assessment of malnutrition in hip fracture patients: effects on surgical delay, hospital stay and mortality. Acta Orthop Belg. 2006;72(4):420–7.
25. Koval KJ, Maurer SG, Su ET, Aharonoff GB, Zuckerman JD. The effects of nutritional status on outcome after hip fracture. J Orthop Trauma. 1999;13(3):164–9.
26. Mandelbaum BR, Tolo VT, McAfee PC, Burest P. Nutritional deficiencies after staged anterior and posterior spinal reconstructive surgery. Clin Orthop Relat Res. 1988;234:5–11.
27. Mizrahi EH, Fleissig Y, Arad M, Blumstein T, Adunsky A. Rehabilitation outcome of hip fracture patients: the importance of positive albumin gain. Arch Gerontol Geriatr. 2008;47(3):318–26.
28. Gruson KI, Aharonoff GB, Egol KA, Zuckerman JD, Koval KJ. The relationship between admission hemoglobin level and outcome after hip fracture. J Orthop Trauma. 2002;16(1):39–44.
29. Ecker ML, Lotke PA. Postoperative care of the total knee patient. Orthop Clin N Am. 1989;20(1):55–62.
30. Ozturk A, Ozkan Y, Akgoz S, Yalcyn N, Ozdemir RM, Aykut S. The risk factors for mortality in elderly patients with hip fractures: postoperative one-year results. Singapore Med J. 2010;51(2): 137–43.
31. Lapp MA, Bridwell KH, Lenke LG, Baldus C, Blanke K, Iffrig TM. Prospective randomization of parenteral hyperalimentation for long fusions with spinal deformity: its effect on complications and recovery from postoperative malnutrition. Spine. 2001;26(7): 809–17. discussion 817.
32. Correia MI, Waitzberg DL. The impact of malnutrition on morbidity, mortality, length of hospital stay and costs evaluated through a multivariate model analysis. Clin Nutr. 2003;22:235–9.
33. Molinari R, Lenke L. Nutrition in spinal surgery. Curr Opin Orthop. 1998;9(II):39–42.
34. Smith TK. Prevention of complications in orthopedic surgery secondary to nutritional depletion. Clin Orthop Relat Res. 1987; 222:91–7.
35. Goiburu ME, Jure Goiburu MM, Bianco H, Diaz JR, Alderete F, Palacios MC, Cabral V, Escobar D, Lopez R, Waitzberg DL. The impact of malnutrition on morbidity, mortality and length of hospital stay in trauma patients. Nutr Hospital. 2006;21(5):604–10.
36. Centers for Disease Control and Prevention. Arthritis: meeting the challenge. At a glance 2009. http://www.cdc.gov.nccdphp/publications/aag/arthritis.htm. Accessed May 9, 2009.
37. Weinman A, Braga M, Harsanyi L, Laviano A, Ljungqvist O, Soeters P, DGEM (German Society for Nutritional Medicine), Jauch KW, Kemen M, Hiesmayr JM, Horbach T, Kuse ER, Vestweber KH, ESPEN (European Society for Parenteral and

Enteral Nutrition). ESPEN guidelines on enteral nutrition: surgery including organ transplantation. Clin Nutr. 2006;25:224–44.
38. Foss NB, Jensen PS, Kehlet H. Risk factors for insufficient perioperative oral nutrition after hip fracture surgery within a multimodal rehabilitation programme. Age Ageing. 2007;36(6):538–43.
39. O'Daly B, Walsh JC, Quinlan JF, Falk GA, Stapleton R, Quinlan WR, O'Rourke SK. Serum albumin and total lymphocyte count as predictors of outcome in hip fractures. J Clin Nutr. 2009;29:89–93.
40. Noblett S, Watson D, Huong H, Davison B, Hainsworth A. A preoperative oral carbohydrate loading in colorectal surgery: a randomized controlled trial. Colorectal Dis. 2006;8:563–9.
41. Ng WQ, Neill J. Evidence for early oral feeding of patients after elective open colorectal surgery: a literature review. J Clin Nurs. 2004;15(6):696–709.
42. Gunnarson AK, Lonn K, Gunningberg L. Does nutritional intervention for patients with hip fractures reduce postoperative complications and improve rehabilitation? J Nurs. 2009;18:1325–33.
43. Mechanick J. Practical aspects of nutritional support for wound-healing patients. Am J Surg. 2004;188(1A):52–6.
44. Delmi M, Rapin CH, Bengoa JM, Delmas PD, Vasey H, Bonjour JP. Dietary supplementation in elderly patients with fractured neck of the femur. Lancet. 1990;335(8696):1013–6.
45. Volkert D. European Society for Parenteral and Enteral Nutrition guidelines on enteral nutrition: geriatrics. Z Gerontol Geriatr. 2011; 44(2):91–6. 99.
46. Schurch MA, Rizzoli R, Slosman D, Vadas L, Vergnaud P, Bonjour JP. Protein supplements increase serum insulin-like growth factors-I levels and attenuate proximal femur bone loss in patients with recent hip fractures. Ann Intern Med. 1998;128:801–9.
47. Mahan LK, Escott-Stump S. Krause's food & nutrition therapy. 12th ed. St Louis, MO: Elsevier Health Sciences; 2007.
48. Avenell A, Handoll HH. Nutritional supplementation for hip fracture aftercare in older people. Cochrane Database Sys Rev 2010;(1): CD001880.
49. Botella-Carretero JJ, Iglesias B, Balsa JA, Arrieta F, Zamarrón L, Vázquez C. Perioperative oral nutritional supplements in normally or mildly undernourished geriatric patients submitted to surgery for hip fracture: a randomized clinical trial. Clin Nutr. 2010;29:574–9.
50. Volkert D, Berner YN, Berry E, Cederholm T, Coti Bertrand P, Milne A, Palmblad J, Schneider S, Sobotka L, Stanga Z, DGEM (German Society for Nutritional Medicine), Lenzen-Grossimlinghaus R, Krys U, Pirlich M, Herbst B, Schütz T, Schröer W, Weinrebe W, Ockenga J, Lochs H. European Society for Parenteral and Enteral Nutrition guidelines on enteral nutrition: geriatrics. Clin Nutr. 2006; 25(2):330–60.
51. Eneroth M, Apelqvist J, Larsson J, Persson BM. Improved wound healing in transtibial amputees receiving supplementary nutrition. Int Orthop. 1997;21:104–8.
52. Kang W, Kudsk KA. Is there evidence that the gut contributes to mucosal immunity in humans? J Parenter Enteral Nutr. 2007;31(3): 246–58.
53. Van Demark 3rd RE, Allard B, Van Demark Jr RE. Nonunion of distal tibia stress fracture associated with vitamin D deficiency: a case report. S D Med. 2010;63(3):87–91. 93.
54. Opilla M. Epidemiology of infection associated with parenteral nutrition. Am J Infect Control. 2008;36(10):S173e5–8.
55. Bonjour JP, Schurch MA, Rizzoli R. Nutritional aspects of hip fractures. Bone. 1996;18(3):139S–44.
56. Davies J, Reed J, Blake E, Priesemann M, Jackson AA, Clarke NM. Epidemiology of Vitamin D deficiency in children presenting to a pediatric orthopedic service in the UK. J Pediatr Orthop. 2011; 31(7):798–802.
57. Parry J, Elory S, Scott AC. Vitamin d sufficiency screening in preoperative pediatric orthopedic patients. J Pediatr Orthop. 2011; 31(3):331–3.
58. Brinker M, O'Connor D, Monla Y, Earthman T. Metabolic and endocrine abnormalities in patients with nonunions. J Orthop Trauma. 2007;2:557–70.
59. Patel N, Bagan B, Vadera S, Maltenfort MG, Deutsch H, Vaccaro A, Harrop J, Sharan A, Ratliff J. Obesity and spine surgery: relation to perioperative complications. J Neurosurg Spine. 2007;6(4):291–7.
60. Skelley NW, Papp DF, Lee RJ, Sargent MC. Slipped capital femoral epiphysis with severe vitamin d deficiency. Orthopedics. 2010; 33(12):921.
61. Espaulella J, Guyer H, Diaz-Escriu F, Mellado-Navas JA, Castells M, Pladevall M. Nutritional supplementation of elderly hip fracture patients. A randomized, double-blind, placebo-controlled trial. Age Ageing. 2000;29(5):425–31.
62. Berend KR, Lombardi AV, Mallory TH, Dodds KL, Adams JB. Ileus following total hip or knee arthroplasty is associated with increased risk of deep venous thrombosis and pulmonary embolism. J Arthroplasty. 2004;19:82–6.
63. Bengmark S, Gil A. Bioecological and nutritional control of disease: prebiotics, probiotics, and synbiotics. Nutr Hospital. 2006; 21: 72–84.
64. Hocevar B, Robinson B, Gray B. Does chewing gum shorten the duration of postoperative ileus in patients undergoing abdominal surgery and creation of stoma? J Wound Ostomy Continence Nurs. 2010;37(2):140–6.
65. Hamwi GJ. Therapy: changing dietary concepts. In: Danowski TS, editor. Diabetes mellitus: diagnosis & treatment. New York, NY: American Diabetes Association; 1964. p. 73–8.

## Further Reading

Bederman SS, Betsy M, Winiarsky R, Seldes RM, Sharrock NE, Sculco TP. Postoperative Ileus in the lower extremity arthroplasty patient. J Arthroplasty. 2001;16:1066–70.
Beiner JM, Grauer J, Kwon BK, Vaccaro AR. Postoperative wound infections of the spine. Neurosurg Focus. 2003;15(3):E14.
Del Savio GC, Zelicof SB, Wexler LM, Byrne DW, Reddy PD, Fish D, Ende KA. Preoperative nutritional status and outcome of elective total hip replacement. Clin Orthop Relat Res. 1996;326:153–61.
Detsky AS, McLaughlin J, Baker JP, Johnston N, Whittaker S, Mendelson RA, et al. What is subjective global assessment? J Parenter Enteral Nutr. 1987;11(1):8–13.
Gallagher D, Visser M, Sepulveda D, Pierson RN, Harris T, Heymsfield SB. How useful is body mass index for comparison of body fatness across age, sex, and ethnic groups? Am J Epidemiol. 1996;143:228–39.
Houwing RH, Rozendaal M, Wouters-Wesseling W, Beulens JWJ, Buskens E, Haalboom JR. A randomized, double-blind assessment of the effect of nutrition supplementation on the prevention of pressure ulcers in hip fracture patients. Clin Nutr. 2003;22(4): 401–5.
Huddleston J, Want Y, Uquillas C, Herndon J, Maloney W. Age and obesity are risk factors for adverse events after total hip arthroplasty. Clin Orthop Relat Res. 2012;470(2):490–6.
Robinson TN, Wallace JI, Wu DS, Wiktor A, Pointer LF, Pfister SM, Sharp TJ, Buckley MJ, Moss M. Accumulated frailty characteristics predict postoperative discharge institutionalization in the geriatric patient. J Am Coll Surg. 2011;213(1):37–42.
Shapiro G, Green DW, Fatica NS, Boachie-Adjei O. Medical complications in scoliosis surgery. Curr Opin Pediatr. 2001; 13: 36–41.
Skipper A. Malnutrition coding. In: Skipper A, editor. Nutrition care manual. 2011. http://nutritioncaremanual.org/category.cfm?ncm_category_id=11. Accessed on December 22, 2011.

# Infection and Perioperative Orthopedic Care

# 22

Andy O. Miller and Barry D. Brause

**Objectives**

To outline primary considerations in:

- Preoperative risk assessment for infection
- Perioperative surgical prophylaxis
- Fever in the immediate postoperative period
- Preoperative management of the infected patient

**Key Points**

- The preoperative medical assessment should include an evaluation for the presence of active infection and risk factors for surgical infection. The issues surrounding the preoperative evaluation for *Staphylococcus aureus* colonization of the skin, routine testing for subclinical urinary infections, and dental clearance will be discussed.
- Perioperative skin preparation and antibiotic prophylaxis decrease surgical site infections, when used appropriately.
- Fever in the immediate postoperative period is rarely due to surgical infection; the need for a complete workup depends on specific medical and surgical concerns.
- Orthopedic surgery in the patient with known infection requires strategic thinking and careful analysis of risk and benefit.

A.O. Miller (✉)
Division of Infectious Diseases, Department of Medicine, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA
e-mail: milleran@hss.edu

B.D. Brause
Division of Infectious Diseases, Department of Medicine, Hospital for Special Surgery, New York, NY, USA
e-mail: brauseb@hss.edu

## Introduction

Infection is among the most common and serious complications of orthopedic surgery. More than 500,000 arthroplasties and more than six million ambulatory orthopedic procedures are performed annually in the United States [1, 2]. Surgical infection rates and volumes differ by center and by procedure type ranging from nil to above 5 %. The importance of prevention, early recognition, and appropriate therapy of orthopedic surgical infections cannot be overstated.

While representing a substantial burden to patients and physicians [3], they are also quantifiable units of quality of care and are of interest to financial (i.e., Medicare) and quality (i.e., CDC/SCIP, NHSN, and the Joint Commission) constituencies. Decreasing the rate of surgical infection is a major component of the quality and safety initiatives spearheaded by various agencies at the federal, state, and professional society level. While there may be a baseline, nonzero minimum rate of infection in orthopedic surgery, there is little to suggest that the nadir rate has been achieved in this era.

Risk factors for infection in orthopedic surgery can be considered modifiable, or not. *Modifiable* risk factors include the presence of active infection (including dental disease), smoking, control of hyperglycemia, and colonization with *Staphylococcus aureus* (although risk modification by decolonization is controversial, as discussed later in this chapter). In addition, dermatitis of peri-incisional skin and urinary infections are frequently encountered modifiable risks in the perioperative patient. *Nonmodifiable* factors that increase infection risk include previous same-site surgery, the presence of foreign material (i.e., prosthesis, graft) at the operative site, and age. Underlying medical illnesses (obesity, diabetes, vasculopathy, autoimmune disorders and their related treatment-induced immunodeficiencies) often fall in a middle ground, where not all of the risk is easily modified.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_22, 

The preoperative medical assessment, which has traditionally focused on evaluation of cardiopulmonary risk, offers an opportunity to stratify patients' risk of infection and to address important modifiable risk factors.

Antimicrobial prophylaxis (AMP), when properly administered, is effective at decreasing surgical infections in almost every field of surgery. AMP is indicated "for all operations or classes of operations in which its use has been shown to reduce SSI (Surgical Site Infection) rates based on evidence from clinical trials or for those operations after which incisional or organ/space SSI would represent a catastrophe [4]."

Multiple publications in orthopedic surgery have documented the decreasing infection rate, particularly when prosthetic hardware is being placed into an uninfected joint. Considerations in the proper administration of AMP include the local ecology of nosocomial pathogens (particularly MRSA); the class, timing, and dosing of the antibiotic; the proposed surgery; patient factors (like BMI, renal function, and allergy history); and the preoperative concern for the presence of infection.

Fever in the immediate postoperative period is rarely due to SSI, is usually self-limited, and can lead to unnecessary and expensive testing. Although careful assessment of the surgical wound and careful consideration and management of treatable nosocomial infections (IV line sepsis, *C. difficile* colitis, hospital-acquired pneumonia) are always required, it is equally important to consider noninfectious causes (hematoma, atalectasis, ileus). Multiple studies have underlined the low yield and high cost of a "fever workup" in the postoperative patient without focal symptoms.

Orthopedic infections, whether iatrogenic or not, are diverse in presentation and management. Bacteria, in particular Gram-positive cocci, predominate, but there is a wide microbiologic diversity of pathogens in orthopedic infections. Microbiologic diagnosis is a key to management. In the absence of sepsis, empiric systemic antibiotic therapy is often not indicated in suspected orthopedic infection, because it can interfere with the diagnostic workup, and because it is frequently noncurative. Strategic thinking and early involvement of experienced infectious disease consultative services can be helpful for optimal management of perioperative care of infected patients.

## Preoperative Evaluation and Risk Reduction

The preoperative medical assessment should include evaluation for the presence of active infections, for the presence of risk factors for surgical infection. Involving the patient and relevant specialists in this assessment is critical to setting realistic expectations and open dialogue [5]. Active infections are a contraindication to elective orthopedic surgery, and the prevalence of untreated dental pathology in the preoperative arthroplasty population may be high [6]. Ultimately, no surgery is risk free, and deferring elective surgery is not always a simple decision. The discussion of risks and benefits quickly becomes highly individualized.

Eczematous skin has a marked propensity to be colonized with *S. aureus*. The presence of eczema at sites local and remote from the incision site may increase the risk of infection [7, 8]. Local skin disease may impair wound healing, enhance the likelihood and burden of local colonization with potential pathogens, and decrease host defense. In our practice, dermatitis should be evaluated and treated (by a dermatologist, preferably) prior to elective orthopedic surgery.

The role of asymptomatic bacteriuria in the risk of perioperative infection is unclear, but active urinary infection should be identified and treated prior to surgery. If this is not feasible (e.g., in emergent cases), perioperative antibiotic prophylaxis should include coverage of likely uropathogens, and adequate treatment of the urinary infection is indicated. Catheterization of the bladder is routine in most anesthesiology protocols in major orthopedic surgery, and is associated with transient bacteremia [9]. Reassuringly, data suggest that uropathogens are not a common cause of deep orthopedic infections in the immediate postoperative period [10].

Comorbid illnesses may represent modifiable risk factors, even if the risk is not entirely eliminated. Diabetes, obesity, liver disease, rheumatologic disease, sickle-cell disease, and severe vascular disease all raise the risk of infection, and this risk can often be reduced substantially prior to surgery [5, 11]. Dermatitis, predispositions to urinary tract infections (including prostatic hypertrophy in need of transurethral prostate procedures), and active dentogingival pathology are all reasons to consider postponing surgery. Referral to relevant specialists can be critical in the preoperative period in patients with such modifiable risk factors.

Smoking is a modifiable factor that increases the risk of surgical site infection as well as arthroplasty failure and death [12–14]. Limited evidence suggests that interventions, including nicotine replacement therapy, that occur 1–2 months prior to surgery decrease perioperative morbidity and aid in long-term smoking cessation [15]. The preoperative period is an opportunity to help patients quit smoking.

Obesity is less modifiable over the period typically available in the preoperative period. Although not every study has shown that obesity results in worse orthopedic outcomes and increased infection rates [16], most studies have supported this association [17–19]. Obese patients should be provided with adequate dosing of perioperative antibiotics (rather than a "one-size-fits-all approach") based on body weight/BMI.

The role of *Staphylococcus aureus* skin carriage and the effect of decolonization on perioperative infection risk are complex and subject to controversy. Methicillin-sensitive *S. aureus* colonizes the nasal mucosa of about 30 % of Americans; 1.5 % or more are colonized with MRSA at any given time [20, 21]. The positive association between *S. aureus* carriage and surgical site infection has been well documented [22, 23]. However, it is not clear that decolonizing the skin and nasal mucosa reduces this risk significantly; as such it is not certain that such approaches are cost-effective [22, 24, 25]. The efficacy of standard decolonization protocols, such as chlorhexidine bathing plus intranasal mupirocin ointment, is not 100 %. Furthermore, development of high rates of resistance to chlorhexidine and mupirocin has been demonstrated in health care settings where their use has become widespread [26].

At present, we believe that there are questionable data supporting the routine screening of all preoperative patients for *S. aureus*, on a basis of both clinical efficacy and cost/practicality. At our institution, we do screen those patients with a history of furunculosis, eczema, or other high-risk skin condition, a history of other *S. aureus* infection, prior SSI, and in situations where the exposure burden or likelihood of persistent colonization is felt to be increased.

Nonmodifiable general risk factors, such as history of previous surgery and/or infection at the same site, well-controlled HIV infection, diabetes, or renal insufficiency, must be added into the discussion of risks and benefit, especially in cases of elective procedures, but rarely represent absolute contraindications.

## Optimization of the Patient for Surgery

### Skin Preparation

The health of skin and subcutaneous tissue is an important concern, and a variety of techniques have evolved to prepare surgical sites for surgery. There is little evidence suggesting a benefit to preoperative bathing with anything more than soap for routine orthopedic surgery [27]. Shaving has largely been replaced by electric clipping on the day of surgery [28] and should no longer be used due to the production of skin abrasions.

Preparation of the skin at the site of surgical incision at the time of surgery is controversial. Iodine-based preparations have largely been supplanted by chlorhexidine gluconate-containing (CHG) preparations in orthopedics. The largest well-conducted study demonstrated superiority of a CHG-alcohol preparation over povidone-iodine in prevention of SSI [29]. Chlorhexidine without alcohol and iodine with alcohol represent two preparations which have not been adequately studied: in our view, the superiority of CHG over iodine has not been demonstrated. CHG is less costly. Alcohol-containing solutions have been reported to cause operating room fires [30].

### Antibiotic Prophylaxis

Perioperative antibiotics have been known for decades to markedly increase the sterility of operative beds and to decrease the incidence of SSI [31]. Direct and indirect evidence, in animal and human clinical studies, strongly suggests that the timing of antibiotic administration is critical: almost all of the benefit is lost when antibiotics are administered too early or after initial incision [32, 33]. We now understand that the majority of clinical benefit comes from the first, pre-incision dose of antibiotic, but 24 h of post-incisional antibiotic has become the present standard of care. Evidence for the benefit of prophylactic perioperative antibiotics in orthopedic surgery is strongest for spine [34] and arthroplasty [35] procedures. Prophylaxis for low-risk patients undergoing arthroscopy is not clearly of benefit [36, 37] but commonly administered nonetheless. A detailed discussion of antibiotic prophylaxis in orthopedic surgery following open fractures and other traumatic injuries is outside the scope of our chapter, but guidelines typically suggest 3–5 days of prophylaxis, with duration based on the severity of injury and antibiotic selection guided by local resistance patterns of likely pathogens. Dosing of antibiotics should ideally be completed before application of surgical tourniquets.

In cases of suspected orthopedic infection, where intraoperative cultures are of high value, we believe that the benefit of obtaining deep operative cultures prior to administration of peri-incisional antibiotics outweighs the risk of delayed administration. Making a firm microbiological diagnosis is key in orthopedic infections, and as long as there is no hardware being placed, guidelines do not mandate perioperative antibiotics in most of these procedures (hardware removal and/or I&D of potentially infected orthopedic sites).

Choosing an antibiotic for surgical prophylaxis depends on local microbial ecology, particularly as it pertains to the prevalence of cephalosporin-resistant Gram-positive organisms. First-generation cephalosporins (especially cefazolin) are typical routine choices because of their low risk of immediate-type hypersensitivity reactions, potency against most Gram-positive skin flora (as well as against some Gram-negative and anaerobic organisms), low cost, ready availability, and familiarity. In cases where beta lactams are not advisable, vancomycin is recommended. Infusion of vancomycin is to be started within 2 h of incision, in part in order to compensate for the slower infusion rate of the drug.

Dosing should be based on weight and renal function. Additional doses should be given when (a) there is significant intraoperative blood loss or (b) the procedure time exceeds twice the half-life of the antibiotic (e.g., after 4 h and 10 h for cefazolin and vancomycin, respectively) [38].

### Other Considerations

Advances in processing of sterile equipment, operating room design, airflow, traffic of personnel, and other important engineering concerns are not discussed in this chapter, despite their importance [39].

## Postoperative Management

### The Postoperative Fever

Body temperature in the surgical patient can be altered via multiple pathways. Evaluation of fever in the immediate postoperative period is costly, and rarely results in a diagnosed infection or a change in therapy. Postoperative fevers are rarely due to surgical infection; the need for a complete workup depends on specific medical and surgical concerns.

A representative study evaluated fever (temperature greater than 38.5 °C) in 1,100 arthroplasty patients at a single institution over a 2-year period [40]. In this study, chest X-ray and blood cultures were positive in 2 and 6 % of cases of fever in the first 72 h. Fever after postoperative day 3 (OR 23; $p < 0.001$) and multiple days of fever (OR 8.6; $p < 0.05$) independently predicted the likelihood of a positive workup. Temperature > 39.0 °C was associated with diagnostic findings 25 % of the time, whereas patients with fevers less than 39.0 °C were less than 7 % likely to have a positive fever workup. These findings have been validated in other recent data [41, 42].

In our practice, fever in the immediate postoperative period is best evaluated by interview and physical examination. Since there is a low likelihood that a routine "fever workup" is useful in the initial 72 h, a brief visit can be a very low cost way to occasionally detect critical focal problems (peripheral intravenous line infections or obvious wound problems, for example), and provide reassurance to the patient and treatment team that the postoperative febrile state is within expected limits. It is likely that limiting fever workups in the immediate postoperative period limits cost.

### Orthopedic Surgery in the Patient with Known Orthopedic Infection

Perioperative management of the patient with known or suspected orthopedic infection requires thought and expertise.

The decision to operate on a patient with infection requires consideration of multiple factors including acuity, risks of morbidity and mortality with and without the surgical procedure, the likelihood of obtaining a meaningful diagnosis, the likelihood of controlling or curing the infection, the possibility of other foci of the same infection, and the underlying medical and social factors that often play major roles in the decision-making process.

Elective orthopedic surgery is typically not recommended in patients with any active bacterial infection. Considering the possibility of infection is always necessary in cases of revision surgery for painful or loose prostheses, nonunions of fractures and arthodeses, and spontaneous loosening of internal hardware. Indolent infection can present without gross visual cues and frequently without histopathological correlates, making microbiologic diagnosis key.

Microbiologic diagnosis of orthopedic infection is critical to proper management. Molecular methods may someday become routine, but today, microbiologic culture remains the mainstay of pathogen detection. Obtaining specimens of optimal quality is the clinicians' job. Cultures taken from an infected patient while the patient is on effective antibiotics are frequently negative. A sufficient antibiotic-free interval (2 weeks or more) can increase the yield of cultures tremendously, and minimizes the potential of false-negative misdiagnosis [43]. Sonication of infected prostheses is more sensitive than traditional culture when the patient has taken antibiotics in the past 14 days [43].

Orthopedic infections present in varied ways. The microbiologically astute clinician needs to consider the advantages and disadvantages of every culture taken. The site and type of culture are critical.

#### Surface Cultures

The surface of human skin, including the exterior of surgical wounds, is colonized by a diverse group of culturable bacteria which are also frequently implicated in orthopedic infection. For this reason surface cultures are rarely a useful part of the workup of most deep orthopedic infections. Cultures from sinus tracts draining sites of chronic osteomyelitis can occasionally be helpful (but never definitive); they are more likely to be correct when they detect *S. aureus* than when they detect other pathogens; they can also detect bacteria (not necessarily the pathogen) that are important in terms of

hospital infection control (i.e., vancomycin-resistant *Enterococci* and MRSA) [38, 44, 45]. However, limited correlation is seen between cultures of the superficial wound/fistula and deeper surgical cultures. Surface cultures cannot be relied upon for diagnosis of deep orthopedic infection.

### Synovial Fluid

Cultures of synovial fluid are critical specimens in the evaluation of the potentially infected joint. Cultures must be interpreted in the context of arthrography, cell count and differential, cytopathology (for crystal arthropathy), and gross appearance. As always, there is a distinct decrease in sensitivity when the patient is on antibiotics. In our view, there is no need to divide a single sample of synovial fluid into aliquots for serial culture (unless there is concern for a loculated process). The constant possibility of inadvertent contamination of cultures, and the rare but serious risk of inoculating pathogens into an uninfected space, must be considered before deciding to aspirate any fluid collection in settings where the pretest likelihood of infection is low.

### Other Collections

Cultures of other fluid collections (for instance, in the postoperative spine patient with a potentially infected seroma/hematoma) are frequently performed although operator characteristics for such evaluations are poorly described. At our institution, the use of radiographic imaging and guided drainage of fluid collections (roentgenographic abscessogram/fistulogram, CT, ultrasound, and MRI) are commonly utilized.

### Wound Cultures

Intraoperative wound cultures should be performed without the use of culturette swabs which have suboptimal sensitivity. Ideally, multiple specimens (tissue, fluid) from multiple sites within the operative field, obtained with single-use sterile instruments, should be obtained. We routinely culture for aerobic (5 days) and anaerobic (10–21 days) bacteria; fungal and mycobacterial cultures are sent when clinically indicated. The importance of obtaining multiple specimens cannot be overestimated, although excessive cultures increase cost and labor, and increase the likelihood of contaminated cultures. We use 5–6 cultures as a standard optimum target based on institutional experience and published literature [46].

### Blood Cultures

Blood cultures have a limited but important role in orthopedic infectious diseases; bacteremia is commonly implicated, but only occasionally detected, in late hematogenous prosthetic joint infections. As such positive blood cultures are specific but insensitive as a method of pathogen detection in orthopedic infections. Orthopedic infections are occasional but important initial presentations of bacterial endocarditis. One out of three patients with an arthroplasty and documented *S. aureus* bacteremia seeds the prosthetic joint [47].

## Summary

The detection and treatment of infections are integral to orthopedic surgical and perioperative practice. Prevention, prompt diagnosis, and appropriate therapy are key. Patients and families, medical professionals, payors, and government agencies share a strong interest in minimizing the impact of these devastating complications.

Risk factors for infections can be identified, and often decreased, preoperatively. Dental, skin, and genitourinary disease, tobacco use, uncontrolled hyperglycemia, unstable cardiovascular disease, and immunosuppressive diseases and medications are examples of conditions that raise the infection risk and can often be decreased in the preoperative period. *S. aureus* colonization, as discussed previously, may be a modifiable risk factor. Nonmodifiable risk factors, such as age, number of prior same-site surgeries, and presence of indwelling hardware, still are important factors in the risk-benefit analysis of proposed surgeries.

AMP is of known benefit in spine and arthroplasty procedures, and is commonplace in arthroscopy. Its benefit is dependent on peri-incisional timing and intelligent thinking. Attention to local ecology of pathogens, body size and renal function, allergy history, and operative time is important.

Fever following orthopedic surgery is rarely from an infection, and even more rarely from a surgical site infection. Data suggest that, within the first 72 h, most patients do not benefit from the traditional fever workup of labs, urine and blood cultures, and a chest X-ray. However, focal complaints or exam findings, high or persistent fever, and other clinical considerations must be taken into account when dealing with this entity. Nosocomial infections can and do occur in the postsurgical patient, and clinical vigilance is never inappropriate.

Management of the infected patient is rarely routine; patients present with varied acuity and symptoms, and standard protocols for orthopedic infections need to be kept flexible. There is microbiologic diversity of pathogens in orthopedic infections. Empiric antibiotics in the absence of deep cultures frequently prevent microbiologic diagnosis, rarely cure the infection at hand, and are rarely indicated (unless there are life-threatening reasons to employ them). Strategic thinking and early involvement of experienced personnel can optimize care of these challenging patients.

**Summary Bullet Points**

- Risk factors for infection can be modifiable or not, and surgery can be elective or not. Optimizing patients' modifiable risk factors for infection prior to surgery is an important part of the preoperative evaluation.
- Postoperative fever is rarely infectious, and routine cultures and chest X-ray are almost never helpful.
- Perioperative patients with known or suspected orthopedic infection require careful evaluation and thought, with strategic use of the array of diagnostic tests.
- Making a microbiologic diagnosis of infection—identifying the offending microorganism—is primary in the patient presenting with possible orthopedic infection.

## Case Study

A case study for this chapter is included in Appendix L at the end of this book.

## References


1. Kim S. Changes in surgical loads and economic burden of hip and knee replacements in the US: 1997-2004. Arthritis Rheum. 2008;59 (4):481–8.
2. Kim S, Bosque J, Meehan JP, Jamali A, Marder R. Increase in outpatient knee arthroscopy in the United States: a comparison of National Surveys of Ambulatory Surgery, 1996 and 2006. J Bone Joint Surg Am. 2011;93(11):994–1000.
3. Whitehouse JD, Friedman ND, Kirkland KB, Richardson WJ, Sexton DJ. The impact of surgical-site infections following orthopedic surgery at a community hospital and a university hospital: adverse quality of life, excess length of stay, and extra cost. Infect Control Hosp Epidemiol. 2002;23(4):183–9.
4. Mangram AJ, Horan TC, Pearson ML, Silver LC, Jarvis WR. Guideline for prevention of surgical site infection, 1999. Hospital Infection Control Practices Advisory Committee. Infect Control Hosp Epidemiol. 1999;20(4):250–78. quiz 279–80.
5. Bosco 3rd JA, Slover JD, Haas JP. Perioperative strategies for decreasing infection: a comprehensive evidence-based approach. J Bone Joint Surg Am. 2010;92(1):232–9.
6. Barrington JW, Barrington TA. What is the true incidence of dental pathology in the total joint arthroplasty population? J Arthroplasty. 2011;26(6 Suppl):88–91.
7. Boguniewicz M, Leung DY. Atopic dermatitis: a disease of altered skin barrier and immune dysregulation. Immunol Rev. 2011;242 (1):233–46.
8. Lim CT, Tan KJ, Kagda F, Ang KC. Implant infection caused by dermatitis: a report of two cases. J Orthop Surg (Hong Kong). 2007;15(3):365–7.
9. Sullivan NM, Sutter VL, Mims MM, Marsh VH, Finegold SM. Clinical aspects of bacteremia after manipulation of the genitourinary tract. J Infect Dis. 1973;127(1):49–55.
10. Koulouvaris P, Sculco P, Finerty E, Sculco T, Sharrock NE. Relationship between perioperative urinary tract infection and deep infection after joint arthroplasty. Clin Orthop Relat Res. 2009;467(7):1859–67.
11. Hsieh PH, Chen LH, Lee MS, Chen CH, Yang WE, Shih CH. Hip arthroplasty in patients with cirrhosis of the liver. J Bone Joint Surg Br. 2003;85(6):818–21.
12. Hawn MT, Houston TK, Campagna EJ, Graham LA, Singh J, Bishop M, Henderson WG. The attributable risk of smoking on surgical complications. Ann Surg. 2011;254(6):914–20.
13. Thomsen T, Villebro N, Moller AM. Interventions for preoperative smoking cessation. Cochrane Database Syst Rev 2010;CD002294
14. Turan A, Mascha EJ, Roberman D, Turner PL, You J, Kurz A, Sessler DI, Saager L. Smoking and perioperative outcomes. Anesthesiology. 2011;114(4):837–46.
15. Lindström D, Sadr Azodi O, Wladis A, Tønnesen H, Linder S, Nåsell H, Ponzer S, Adami J. Effects of a perioperative smoking cessation intervention on postoperative complications: a randomized trial. Ann Surg. 2008;248(5):739–45.
16. Suleiman LI, Ortega G, Ong'uti SK, Gonzalez DO, Tran DD, Onyike A, Turner PL, Fullum TM. Does BMI affect perioperative complications following total knee and hip arthroplasty? J Surg Res. 2012;174(1):7–11.
17. Bozic KJ, Lau E, Kurtz S, Ong K, Rubash H, Vail TP, Berry DJ. Patient-related risk factors for periprosthetic joint infection and postoperative mortality following total hip arthroplasty in medicare patients. J Bone Joint Surg Am. 2012;94(9):794–800.
18. Font-Vizcarra L, Tornero E, Bori G, Bosch J, Mensa J, Soriano A. Relationship between intraoperative cultures during hip arthroplasty, obesity, and the risk of early prosthetic joint infection: a prospective study of 428 patients. Int J Artif Organs. 2011;34 (9):870–5.
19. Haverkamp D, Klinkenbijl MN, Somford MP, Albers GH, van der Vis HM. Obesity in total hip arthroplasty – does it really matter? A meta-analysis. Acta Orthop. 2011;82(4):417–22.
20. Gorwitz RJ, Kruszon-Moran D, McAllister SK, McQuillan G, McDougal LK, Fosheim GE, Jensen BJ, Killgore G, Tenover FC, Kuehnert MJ. Changes in the prevalence of nasal colonization with Staphylococcus aureus in the United States, 2001-2004. J Infect Dis. 2008;197(9):1226–34.
21. Kim DH, Spencer M, Davidson SM, Li L, Shaw JD, Gulczynski D, Hunter DJ, Martha JF, Miley GB, Parazin SJ, Dejoie P, Richmond JC. Institutional prescreening for detection and eradication of methicillin-resistant Staphylococcus aureus in patients undergoing elective orthopaedic surgery. J Bone Joint Surg Am. 2010;92(9):1820–6.
22. Kalmeijer MD, Coertjens H, van Nieuwland-Bollen PM, Bogaers-Hofman D, de Baere GA, Stuurman A, van Belkum A, Kluytmans JA. Surgical site infections in orthopedic surgery: the effect of mupirocin nasal ointment in a double-blind, randomized, placebo-controlled study. Clin Infect Dis. 2002;35(4):353–8.
23. Kluytmans JA, Mouton JW, Ijzerman EP, Vandenbroucke-Grauls CM, Maat AW, Wagenvoort JH, Verbrugh HA. Nasal carriage of Staphylococcus aureus as a major risk factor for wound infections after cardiac surgery. J Infect Dis. 1995;171(1):216–9.
24. Perl TM, Cullen JJ, Wenzel RP, Zimmerman MB, Pfaller MA, Sheppard D, Twombley J, French PP, Herwaldt LA, Mupirocin and the Risk of Staphylococcus Aureus Study Team. Intranasal mupirocin to prevent postoperative Staphylococcus aureus infections. N Engl J Med. 2002;346(24):1871–7.
25. Bode LG, Kluytmans JA, Wertheim HF, Bogaers D, Vandenbroucke-Grauls CM, Roosendaal R, Troelstra A, Box AT, Voss A, van der Tweel I, van Belkum A, Verbrugh HA, Vos MC. Preventing surgical-site infections in nasal carriers of Staphylococcus aureus. N Engl J Med. 2010;362(1):9–17.
26. Lee AS, Macedo-Vinas M, François P, Renzi G, Schrenzel J, Vernaz N, Pittet D, Harbarth S. Impact of combined low-level

mupirocin and genotypic chlorhexidine resistance on persistent methicillin-resistant Staphylococcus aureus carriage after decolonization therapy: a case-control study. Clin Infect Dis. 2011;52 (12):1422–30.
27. Webster J, Osborne S. Preoperative bathing or showering with skin antiseptics to prevent surgical site infection. Cochrane Database Syst Rev 2007;(2):CD004985.
28. Bratzler DW, Hunt DR. The surgical infection prevention and surgical care improvement projects: national initiatives to improve outcomes for patients having surgery. Clin Infect Dis. 2006;43(3): 322–30.
29. Darouiche RO, Wall Jr MJ, Itani KM, Otterson MF, Webb AL, Carrick MM, Miller HJ, Awad SS, Crosby CT, Mosier MC, Alsharif A, Berger DH. Chlorhexidine-alcohol versus povidone-iodine for surgical-site antisepsis. N Engl J Med. 2010;362(1):18–26.
30. Rocos B, Donaldson LJ. Alcohol skin preparation causes surgical fires. Ann R Coll Surg Engl. 2012;94(2):87–9.
31. Howes EL. Prevention of wound infection by the injection of nontoxic antibacterial substances. Ann Surg. 1946;124(2):268–76.
32. Classen DC, Evans RS, Pestotnik SL, Horn SD, Menlove RL, Burke JP. The timing of prophylactic administration of antibiotics and the risk of surgical-wound infection. N Engl J Med. 1992;326 (5):281–6.
33. Burke JF. The effective period of preventive antibiotic action in experimental incisions and dermal lesions. Surgery. 1961; 50: 161–8.
34. Watters 3rd WC, Baisden J, Bono CM, Heggeness MH, Resnick DK, Shaffer WO, Toton JF, North American Spine Society. Antibiotic prophylaxis in spine surgery: an evidence-based clinical guideline for the use of prophylactic antibiotics in spine surgery. Spine J. 2009;9(2):142–6.
35. AlBuhairan B, Hind D, Hutchinson A. Antibiotic prophylaxis for wound infections in total joint arthroplasty: a systematic review. J Bone Joint Surg Br. 2008;90(7):915–9.
36. Wieck JA, Jackson JK, O'Brien TJ, Lurate RB, Russell JM, Dorchak JD. Efficacy of prophylactic antibiotics in arthroscopic surgery. Orthopedics. 1997;20(2):133–4.
37. Bert JM, Giannini D, Nace L. Antibiotic prophylaxis for arthroscopy of the knee: is it necessary? Arthroscopy. 2007;23(1):4–6.
38. Bratzler DW, Houck PM, Surgical Infection Prevention Guideline Writers Workgroup. Antimicrobial prophylaxis for surgery: an advisory statement from the National Surgical Infection Prevention Project. Am J Surg. 2005;189(4):395–404.
39. Allo MD, Tedesco M. Operating room management: operative suite considerations, infection control. Surg Clin North Am. 2005;85(6): 1291–7. xii.
40. Ward DT, Hansen EN, Takemoto SK, Bozic KJ. Cost and effectiveness of postoperative fever diagnostic evaluation in total joint arthroplasty patients. J Arthroplasty. 2010;25(6 Suppl):43–8.
41. Athanassious C, Samad A, Avery A, Cohen J, Chalnick D. Evaluation of fever in the immediate postoperative period in patients who underwent total joint arthroplasty. J Arthroplasty. 2011;26(8): 1404–8.
42. Czaplicki AP, Borger JE, Politi JR, Chambers BT, Taylor BC. Evaluation of postoperative fever and leukocytosis in patients after total hip and knee arthroplasty. J Arthroplasty. 2011;26(8): 1387–9.
43. Trampuz A, Piper KE, Jacobson MJ, Hanssen AD, Unni KK, Osmon DR, Mandrekar JN, Cockerill FR, Steckelberg JM, Greenleaf JF, Patel R. Sonication of removed hip and knee prostheses for diagnosis of infection. N Engl J Med. 2007;357(7): 654–63.
44. Bernard L, Uçkay I, Vuagnat A, Assal M, Stern R, Rohner P, Hoffmeyer P. Two consecutive deep sinus tract cultures predict the pathogen of osteomyelitis. Int J Infect Dis. 2010;14(5):e390–3.
45. Zuluaga AF, Galvis W, Saldarriaga JG, Agudelo M, Salazar BE, Vesga O. Etiologic diagnosis of chronic osteomyelitis: a prospective study. Arch Intern Med. 2006;166(1):95–100.
46. Atkins BL, Athanasou N, Deeks JJ, Crook DW, Simpson H, Peto TE, McLardy-Smith P, Berendt AR. Prospective evaluation of criteria for microbiological diagnosis of prosthetic-joint infection at revision arthroplasty. The OSIRIS Collaborative Study Group. J Clin Microbiol. 1998;36(10):2932–9.
47. Murdoch DR, Roberts SA, Fowler Jr VGJ, Shah MA, Taylor SL, Morris AJ, Corey GR. Infection of orthopedic prostheses after Staphylococcus aureus bacteremia. Clin Infect Dis. 2001;32(4): 647–9.

# Risk and Benefits of Bilateral Total Knee Replacement Surgery

23

Ettore Vulcano, Alejandro González Della Valle, and Stavros G. Memtsoudis

**Objectives**

- To describe the different options for the surgical treatment of patients presenting with bilateral knee osteoarthritis.
- To describe the advantages of undergoing bilateral total knee arthroplasty under the same anaesthesia (single-stage).
- To describe the drawbacks and complications of single-stage bilateral total knee replacement surgery.
- To provide guidelines for the selection of candidates for single-stage bilateral total knee replacement surgery based on risk stratification.

**Key Points**

- Bilateral total knee replacements can be performed under the same anaesthetic or so-called "single-stage" (simultaneously or sequentially), or under different anaesthetics or so-called "staged" (during the same or different hospitalizations).
- The main advantages of single-stage bilateral total knee replacement surgery include good clinical results, the need for a single anaesthetic, lower total amount of pain medication used, shorter overall surgical and rehabilitation time, high patient satisfaction, and possibly lower total cost.
- The drawbacks of single-stage bilateral total knee replacement surgery include increased risk of perioperative complications.
- Published guidelines for the selection of patients being considered for single-stage bilateral knee arthroplasty contemplate the exclusion of patients of extreme age—patients with significant end organ dysfunction (i.e. ASA physical status of 3 or greater).

E. Vulcano • A. González Della Valle (✉)
Department of Orthopaedic Surgery, Hospital for Special Surgery, Weill Medical College of Cornell University, 535 E70th Street, New York, NY 10021, USA
e-mail: gonzaleza@hss.edu

S.G. Memtsoudis
Department of Anesthesiology, Hospital for Special Surgery, Weill Medical College of Cornell University, 525 East 70th Street, New York, NY 10021, USA

## Introduction

Knee osteoarthritis affects approximately 80 % of the population above the age of 65 [1]. Thus, it is not surprising that the number of total knee arthroplasties (TKA) performed in the USA has been steadily increasing over the last decades [2–5].

Approximately 20 % of patients undergoing primary unilateral TKA complain of severe pain in the contralateral knee [6], and about 10 % of patients who have a primary TKA will undergo contralateral TKA surgery within 1 year [7].

Patients with debilitating bilateral joint disease represent a unique challenge. While proponents of performing single-stage bilateral total knee arthroplasties (BTKA) point out its low complication rates, high patient satisfaction, and cost-effectiveness [8–15] concerns persist that BTKA performed during the same anesthetic session is associated with increased morbidity and mortality [14–21]. Despite extensive research into risks and benefits of single-stage BTKA, many important questions related to the safety of the procedure remain unanswered [22–27]. Moreover, there are no scientifically based consensus guidelines to aid in appropriate patient selection.

In order to clarify terms to describe the chronologic relationship of the first and second joint arthroplasty in this chapter, the following definitions have been chosen:

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_23, 

1. *Single-stage BTKA*: Both TKAs are performed during the same anesthetic session. Single-stage BTKA can be performed (a) *simultaneously*, when both TKAs are performed at the same time by different surgical teams or (b) *sequentially*, when TKAs are performed consecutively by the same surgical team.
2. *Staged BTKA*: Each TKA is performed in a separate anesthetic sessions. Staged procedures can be done *during the same hospitalization* (generally a few days apart) or *during different hospitalizations* separated by weeks to months.

The objective of single-stage BTKA surgery is to reduce the risk of repeated anesthetic procedures, total hospitalization and recovery time, and cost. The goal is to perform single-stage BTKA while maintaining patient safety, and the clinical and functional outcomes observed in patients undergoing unilateral TKA or staged BTKA [10, 11, 27–41]. In view of the divided opinions on the use of single-stage BTKA surgery, careful patient selection appears to be the safest clinical approach, as proponents point to good outcomes in selected patients at their institution [8, 16, 42–44]. In an attempt to reconcile competing factors in the decision making process to perform single-stage BTKA procedures, many institutions, including ours, have developed guidelines for the selection of patients considered to be at a low perioperative risk.

In this chapter we will discuss the published evidence in regard to multiple aspects surrounding BTKA procedures, including the epidemiology and trends, benefits and risks, and the approach taken at our institution as an example of how consensus can be reached to reconcile the benefits with concerns for patient safety.

## Epidemiology and Trends

The performance of unilateral and bilateral TKA has increased dramatically over time [5, 24]. The proportion of BTKA to unilateral TKA in the USA was approximately 4 % between 1990 and 1994. The proportion rose to 6.5 % in the period between 1998 and 2006, indicating an increased popularity for this approach [45]. The absolute number and use of BTKAs also increased from 1990 to 2004. Of an estimated total of 153,259 discharges after BTKAs, 20.18 % were performed between 1990 and 1994, 28.73 % between 1995 and 1999, and 51.08 % between 2000 and 2004. From 1990 to 2004, the use of BTKAs more than doubled for the entire civilian population and almost tripled among the female population (Fig. 23.1), with the steepest increase seen between 1995 and 2004 [24].

Patients undergoing BTKA are on average younger and healthier compared with their counterparts undergoing unilateral TKA [25, 45, 46]. Trends toward decreasing average age have paralleled those of unilateral TKA recipients [24]. However, while a shift toward increasing comorbidity burden was seen over time in the latter group, decreased rates of cardiac and pulmonary disease and utilization among the elderly (i.e.>85 years) have been noted in the BTKA group starting in the mid 1990s (Fig. 23.2). These trends may be explained by the desire of clinicians to perform BTKA, especially single-stage, in a healthier and younger group of patients, presumably in order to decrease the risk of perioperative complications.

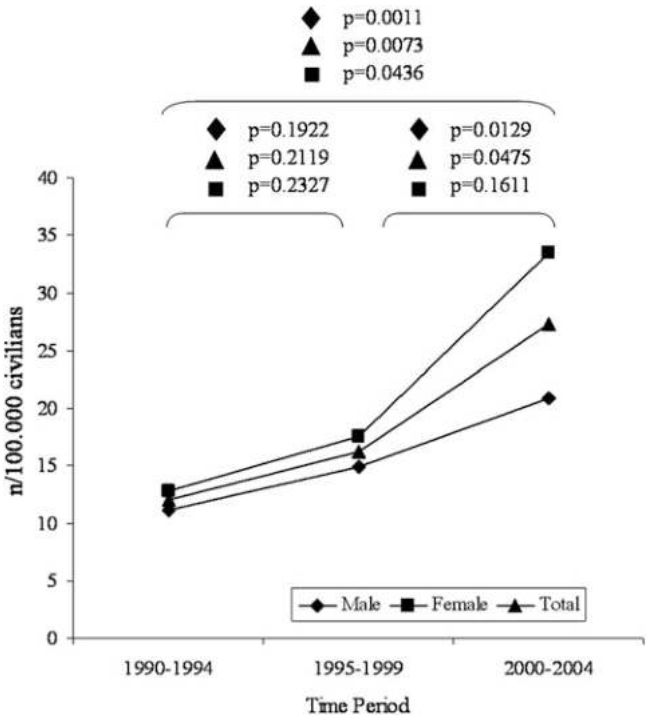


**Fig. 23.1** Temporal changes in gender-adjusted and unadjusted use of BTKAs by time. The use of BTKAs more than doubled for the entire population and almost tripled among the female population, with the steepest increase seen during the last two study periods. The values are expressed as number per 100,000 US civilians per time (Used with permission from Memtsoudis SG, Besculides MC, Reid S, Gaber-Baylis LK, Gonzalez Della Valle A: Trends in bilateral total knee arthroplasties: 153,259 discharges between 1990 and 2004. Clin Orthop Relat Res 2009; 467:1568–76)

Although male patients make up approximately 36 % of patients undergoing unilateral TKA, they are over proportionately represented in the BTKA group (41 %) [25].

These trends may be driven by the expansion of indications for TKA to younger, more active patients, the epidemic of obesity and its consequences in the progression of osteoarthritis [47], all factors resulting in a higher demand for the procedure. Advances in anaesthesia, surgery and perioperative care may further contribute to the increase in utilization of BTKA [24], as physician and patient confidence increase.

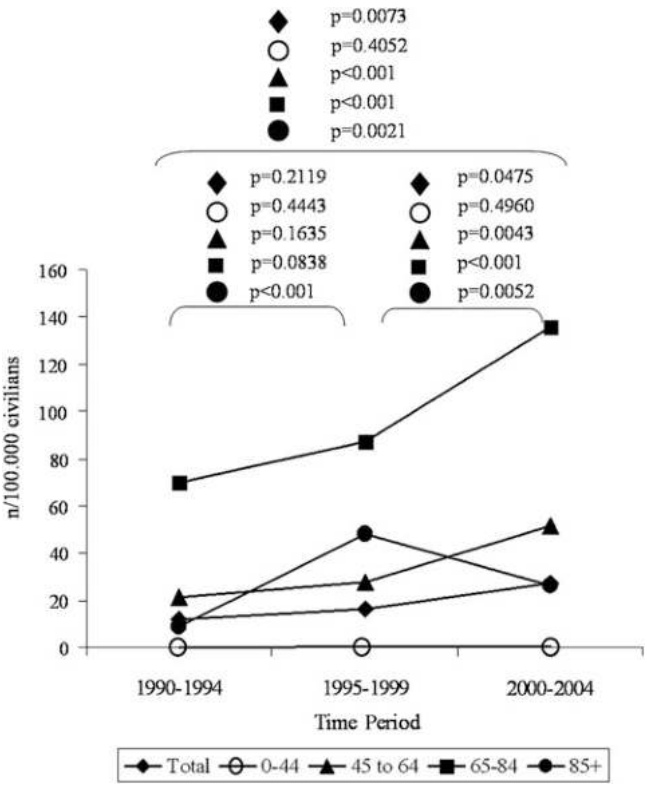


**Fig. 23.2** Changes in age group-adjusted and unadjusted use of BTKAs by time. All age groups experienced an increase in use of BTKAs throughout the study period, except the group 85 years and older. Between the second and third periods of study, a decline of nearly 50 % was seen. The values are expressed as number per 100,000 US civilians per time (Used with permission from Memtsoudis SG, Besculides MC, Reid S, Gaber-Baylis LK, Gonzalez Della Valle A: Trends in bilateral total knee arthroplasties: 153,259 discharges between 1990 and 2004. Clin Orthop Relat Res 2009; 467:1568–76)

## Benefits of Single-Stage Bilateral Total Knee Arthroplasty

The use of single-stage BTKA has advantages that include: good clinical results, the exposure to only one anesthetic, lower total amount of pain medication used, shorter overall surgical and rehabilitation time, high patient satisfaction, and possibly lower cost. See Table 23.1.

### Clinical Results of Bilateral Total Knee Arthroplasty

Five studies [12, 14, 17, 48, 49] reporting on the clinical results of a combined number of 2,641 BTKA patients support that single-stage BTKA is a very successful operation, with results that are comparable to those of unilateral TKA. BTKA patients demonstrated similar or better results in terms of range of motion [17], Oxford Knee Score [17], WOMAC [48], SF-36 [48], SF-12 [49], Knee Society Score [49], and survivorship at 7 years [14] and 10 years [12].

### Number of Anesthetic Sessions

Although major anaesthesia related complications are rare, the risks associated with potential procedures, such as endotracheal intubation in the case of general anesthetic, neuraxial complications with a regional technique and those associated with the administration of drugs and insertions of invasive lines cannot be discounted completely. Thus, it is obvious that strictly from an anesthetic procedural aspect the avoidance of a second exposure may be of benefit.

### Surgical Time

Predictably, surgical time varies with the type of BTKA performed. In 1998, Liu et al. compared operative time between 64 patients undergoing sequential BTKA, and 24 patients undergoing staged BTKA 7 days apart [50]. The mean operative and tourniquet time for patients undergoing sequential procedures was 19 min and 26 min shorter than for those undergoing staged BTKA, respectively. This is reflected not only in lower operating room costs but also in the reduction of potential risks associated with tourniquet application, such as nerve palsy, vascular injury, muscle damage, post-operative swelling and stiffness [51–57]. Other less frequent complications have also been reported with tourniquet use, such as intraoperative cardiac arrest at the time of deflation, reactive hyperaemia, early infection, and wound healing disorders due to perioperative hypoxia and reduced post-operative tissue perfusion [58–63].

### Use of Pain Medication

The general belief is that patients undergoing single-stage BTKA will experience worse pain and will have a higher requirement for narcotics than those undergoing unilateral TKA. Three studies have challenged this belief: Powell et al. [64] observed that narcotic requirements were slightly greater but not significantly different for the simultaneous BTKA group compared with a unilateral TKA group during the first 72 h after surgery. They reported less pain in unilateral TKA recipients (mean 4.53 on a 0 (no pain) to 10 (maximum pain) visual analog scale (VAS)) than in BTKA patients (mean 5.83) in the early post-operative period. However, there was no statistically significant difference in pain scores after the first post-operative day. Surprisingly, patients who underwent simultaneous BTKA reported slightly less pain than those undergoing unilateral TKA after the first

**Table 23.1** Studies reporting on series of consecutive BTKA patients

| Author (year) [Type of study] | Number of patients | Modality (SA/DA) | Mean age (range) | Gender (M:F) | Follow-up | Life-threatening complications | Mortality |
|---|---|---|---|---|---|---|---|
| Alemparte et al. [8] (2002) [Re] | 604 | SA | 70 (30–92) | 35:65 | 1 year | 3.1 % | 0.7 % |
| Pavone et al. [42] (2004) [Re] | 501 | SA | 66 (18–88) | 43:57 | N/A | 10 % | 0 |
| Williams-Russo et al. [99] (1992) [Pr] | 51 | SA | 68 (48–84) | 45:55 | 7 days | 2 % | 0 |

*Re* retrospective, *Pr* prospective, *SA* single anesthetic, *DA* different anesthetic, *N/A* not available

post-operative day. Similarly, Shetty et al. [65]. prospectively studied 50 patients undergoing sequential BTKA, and 50 undergoing unilateral TKA. The mean difference in post-operative VAS scores was significant only on the first post-operative day, becoming non-significant during the remainder of the hospitalization and at discharge. Moreover, Fick et al. [17], despite differences in the analgesic protocol, reported that opioid consumption was not statistically different between the BTKA and unilateral TKA groups.

## Patient Satisfaction

Along with functional outcome, health status and perception of well-being are becoming increasingly important markers when evaluating TKA results [66]. In terms of functional results and implant survivorship, there is strong evidence suggesting that single-stage BTKA patients do as well as unilateral TKA recipients [10, 12–14, 18, 29, 31, 67, 68]. Furthermore, a large survival analysis conducted by Ritter et al. [10] on 2,050 simultaneous BTKA patients, 152 staged BTKA patients (performed within 1 year) and 1,796 unilateral TKA patients at 5, 10 and 15 years post-operatively concluded that patients who had undergone unilateral TKA had significantly lower Knee Society Scores compared with patients with simultaneous BTKA.

Patient satisfaction and health perception are also advantages of single-stage BTKA. It has been reported that the majority (94.7 %) of patients who had experienced BTKA would opt for the same procedure again [14]. Similar results were presented by other authors, reporting that patients undergoing simultaneous BTKA have improved physical and social function, less pain and better general and mental health than patients undergoing unilateral TKA [48].

## Cost

If the combined cost of two unilateral TKAs exceeds the total cost of a single-stage BTKA, then the latter can be considered to be more economical. Cost analysis performed by numerous authors [9, 28, 31, 35] showed that single-stage BTKA results in overall savings in the range of 18–58 % compared with the cost of staged procedures. The economical advantage of single-stage BTKA surgery is driven by numerous factors that include: a reduced hospital stay [30, 69], lower charges for laboratory tests, medical consultations, operating room fees, anesthesia and surgical fees, recovery room time, antibiotics, and physical therapy [14]. The cost in surgical fees for the insurance company are also lower as in the USA most insurers including Medicare reimburse the second joint replacement performed during the same anesthetic at 50 %.

When calculating the overall cost of care, both transfer to a rehabilitation centre and re-admission should be taken into consideration. One study [48] compared the 12-month clinical outcome of 198 unilateral TKA and 139 simultaneous BTKA patients. The proportion of patients being discharged to a rehabilitation centre was higher in the BTKA group (55 %) than in the unilateral TKA group (33 %). However, the proportion of patients readmitted within 12 months of surgery for condition related to the knee surgery was higher in the unilateral TKA group (12 %) than in the BTKA group (5 %). The majority of re-admission was due to limited range of motion requiring manipulation under anesthesia.

## Drawbacks of Single-Stage Bilateral Total Knee Arthroplasty

Numerous studies report significantly higher complication rates for single-stage BTKA procedures [14–21] including increased mortality, cardiac complications, pulmonary complications, post-operative confusion, wound infection, use of allogenic blood transfusions, and discharge to tertiary rehabilitation centres (Table 23.2). The pathophysiology of bilateral procedures may be in part explained by the increased surgical insult, blood loss and embolic load affecting the various organ systems.

**Table 23.2** Studies reporting on comparative unilateral TKA and BTKA surgery (*blank cells* indicate no significant difference observed)

| Author (year) [Type of study] | Procedure type | Number of patients | Significantly higher local complications | Significantly higher systemic complications | Significantly higher mortality |
|---|---|---|---|---|---|
| Gradillas et al. [30] (1979) [Re] | UTKA | 40 | Yes (1a) | | |
| | SSBTKA (sequential) | 41 | | Yes (1b) | |
| Soudry et al. [39] (1985) [Re] | UTKA | 156 | | | |
| | SSBTKA (sequential) | 56 | | | |
| | SBTKA (1 wk to 5 mo) | 18 | | Yes (2) | |
| Morrey et al. [11] (1987) [Re] | UTKA | 501 | | | |
| | SSBTKA (simultaneous) | 145 | | | |
| | SBTKA (one admission) | 228 | | | |
| | SBTKA (two admissions) | 117 | | | |
| Jankiewicz et al. [32] (1994) [Re] | SSBTKA (simultaneous) | 99 | | | |
| | SBTKA (9 mo) | 56 | | | |
| Worland et al. [84] (1996) [Re] | UTKA | 107 | | | |
| | SSBTKA (simultaneous) | 213 | | | |
| Lynch et al. [71] (1997) [Re] | UTKA | 98 | | | |
| | SSBTKA (simultaneous) | 98 | | Yes (3) | |
| Cohen et al. [29] (1997) [Re] | UTKA | 100 | | | |
| | SSBTKA (simultaneous) | 86 | | | |
| Lane et al. [18] (1997) [Pr] | UTKA | 100 | | | |
| | SSBTKA (simultaneous) | 100 | | Yes (4) | |
| Ritter et al. [70] (1997) [Re—DTB] | SSBTKA (simultaneous) | 12,622 | | Yes (5b) | Yes |
| | SBTKA (6 wk) | 4,354 | Yes (5a) | Yes (5b) | |
| | SBTKA (3 mo) | 4,524 | Yes (5a) | | |
| | SBTKA (6 mo) | 9,829 | Yes (5a) | Yes (5b) | |
| | SBTKA (1 yr) | 31,401 | Yes (5a) | Yes (5b) | |
| Liu and Chen [50] (1998) [Re] | SSBTKA (simultaneous) | 64 | | | |
| | SBTKA (1 wk) | 24 | | | |
| Adili et al. [67] (2001) [Re]* | UTKA | 82 | | | |
| | SSBTKA (sequential) | 82 | | Yes (6) | |
| Lombardi et al. [15] (2001) [Re] | UTKA | 958 | | | |
| | SSBTKA (simultaneous) | 1,090 | | Yes (7) | |
| Mangaleshkar et al. [100] (2001) [Re] | UTKA | 367 | NA | NA | |
| | SSBTKA (simultaneous) | 54 | NA | NA | Yes (8) |
| | SBTKA (>15days) | 34 | NA | NA | |
| Parvizi et al. [19] (2001) [Re] | UTKA | 19,861 | NA | NA | |
| | SSBTKA (simultaneous) | 2,679 | NA | NA | Yes |
| Fick et al. [17] (2002) [Pr] | UTKA | 172 | | | |
| | SSBTKA (simultaneous) | 56 | | | |
| Mantilla et al. [94] (2002) [Re] | UTKA | 3,601 | | | |
| | BTKA (various types) | 1,410 | | Yes (9) | |
| Ritter et al. [10] (2003) [Re] | UTKA | 1,796 | Yes (10a) | | |
| | SSBTKA (simultaneous) | 2,050 | Yes (10b) | Yes (10c) | |
| | SBTKA (<1–3 yrs) | 152 | NA | NA | NA |
| Bullock et al. [16] (2003) [Re] | UTKA | 512 | | | |
| | SSBTKA (simultaneous) | 255 | | Yes (11) | |
| March et al. [48] (2004) [Pr] | UTKA | 97 | | | |
| | SSBTKA (simultaneous) | 56 | | Yes (12) | |
| Stubbs et al. [49] (2005) [Re] | UTKA | 125 | | | |
| | SSBTKA (simultaneous) | 61 | | | |
| | SBTKA (1 yr) | 38 | | | |
| Sliva et al. [101] (2005) [Re] | UTKA | 65 | Yes (13) | Yes (13) | |
| | SSBTKA (sequential) | 26 | | | |
| | SBTKA (4.5 days) | 241 | | | |

(continued)

**Table 23.2** (continued)

| Author (year) [Type of study] | Procedure type | Number of patients | Significantly higher local complications | Significantly higher systemic complications | Significantly higher mortality |
|---|---|---|---|---|---|
| Hutchinson et al. [102] (2006) [Pr] | UTKA | 741 | | | |
| | SSBTKA (simultaneous) | 438 | Yes (14a) | Yes (14b) | |
| | SBTKA (timing NA) | 125 | Yes (14a) | Yes (14b) | |
| Forster et al. [43] (2006) [Re] | SSBTKA (sequential) | 28 | | | |
| | SBTKA (1 wk) | 36 | | | |
| | SBTKA (29 mo) | 38 | | | |
| Urban et al. [72] (2006) [Re] | UTKA | 293 | NA | | |
| | SSBTKA (sequential) | 169 | NA | Yes (15) | |
| Powell et al. [64] (2006) [Re] | UTKA | 59 | | | |
| | SSBTKA (simultaneous) | 59 | | | |
| Shah et al. [103] (2007) [Pr] | UTKA | 174 | | | |
| | SSBTKA (sequential) | 87 | | | |
| Stefansdottir et al. [104] (2008) [Re—DTB] | SSBTKA (simultaneous) | 1,139 | NA | NA | Yes |
| | SBTKA (<1 yr) | 3,432 | NA | NA | |
| Kim et al. [12] (2009) [Re] | UTKA | 719 | | | |
| | SSBTKA (sequential) | 2,385 | | | |
| Luscombe et al. [1] (2009) [Re] | UTKA | 144 | | | |
| | SSBTKA (simultaneous) | 72 | Yes (16a) | Yes (16b) | |
| Memtsoudis et al. [45] (2009) [Re—DTB] | UTKA | 626,439 | | | |
| | SSBTKA (17a) | 25,179 | Yes (17b, 17c) | Yes (17d, 17e) | Yes (17 g) |
| | SBTKA | 8,483 | Yes (17b) | Yes (17d, 17f) | Yes (17 g) |
| Yoon et al. [69] (2010) [Re] | SSBTKA (simultaneous) | 119 | | Yes (18) | |
| | SBTKA (1 yr) | 265 | | | |
| Taylor et al. [44] (2010) [Re]** | UTKA | 151 | | | |
| | SSBTKA (simultaneous) | 148 | | | |
| Husted et al. [13] (2011) [Pr] | UTKA | 271 | | | |
| | SSBTKA (simultaneous) | 150 | | | |

*Abbreviations*: *UTKA* unilateral total knee arthroplasty, *SSBTKA* single-stage bilateral total knee arthroplasty, *SBTKA* staged bilateral total knee arthroplasty, *[Re]* retrospective, *[Pr]* prospective, *NA* not available, *Wk* week, *Mo* month, *Yr* year, *DTB* administrative or governmental database, *Asterisk* patients older than 75, *Double Asterisks* all obese patients

*Comments*: 1a. Higher rate of aseptic loosening compared to the single-stage BTKA group, 1b. Higher incidence of pulmonary embolism compared to unilateral TKA. 2. Higher incidence of thromboembolic disease. 3. Congestive heart failure and acute delirium were found to be significantly more frequent in the BTKA group than in the unilateral TKA group. 4. Increased incidence of cardiopulmonary complications and confusion in the single-stage BTKA group. 5a. Surgical and wound infections less frequent in the single-stage BTKA. 5b. With respect to 3-month staged procedure, higher rate of nosocomial infections. 6. Increased incidence of myocardial infarction. All affected patients had pre-existing cardiovascular conditions. 7. Higher incidence of gastrointestinal complications in patients younger than 80 years of age in the single-stage BTKA group. Higher incidence of pulmonary complications in patients older than 80 years of age in the single-stage BTKA group. 8. A significant increase in mortality rate in the single-stage BTKA group compared to SBTKA and unilateral TKA groups was only observed in patients older than 75 years of age. 9. Increased rate of pulmonary embolism. 10a. with respect to single-stage BTKA, increased incidence of superficial wound infection. 10b. with respect to unilateral TKA, increased incidence of thrombophlebitis. 10c. with respect to unilateral TKA, increased incidence of gastrointestinal ulcers and intestinal ileus. 11. Increased risk of confusion and myocardial infarction. 12. Increased risk of thromboembolic and cardiovascular disorders. 13. Minor complication rate (urinary retention, urinary tract infection, deep-vein thrombosis, pneumonia, superficial infection, early knee manipulation for poor motion, atrial fibrillation, and admission to the hospital without monitoring in the intensive care unit) was lower in the SBTKA compared with unilateral TKA. 14a. Increased incidence of deep vein thrombosis for both bilateral TKAs compared to unilateral. No difference between single-stage BTKA and SBTKA. 14b. Increased incidence of pulmonary embolism for both bilateral TKAs compared to unilateral TKA. No difference between single-stage BTKA and SBTKA. 15. Increased rate of new onset atrial fibrillation, hypoxemia, and confusion. 16a. Increased rate of superficial and deep wound infections. 16b. Increased risk of cardiac complications (MI, acute rhythm changes, acute episodes of heart failure) and chest infections. 17a. 9,688 of all entries for BTKA (43,350) did not allow for determination of timing of one or both procedures and were therefore excluded from the subgroup analysis. 17b. Higher peripheral vascular complications, vessel/nerve complications, wound dehiscence, infection rates in the BTKA group compared with unilateral TKA group. 17c. Higher rate of DVT in the single-stage BTKA group with respect to the staged BTKA group. 17d. Higher rate of PE, adult respiratory distress syndrome, respiratory complications, acute hemorrhagic anaemia, shock, central nervous system complications, gastrointestinal complications, genitourinary complications in the BTKA group compared with the unilateral TKA group. 17e. Higher rate of PE in the single-stage BTKA group compared with the staged BTKA group. 17f. Higher incidence of adult respiratory distress syndrome, post hemorrhagic anaemia, central nervous system complications, respiratory complications, gastrointestinal complications, genitourinary complications in the staged BTKA group with respect to the single-stage BTKA group. 17g. Higher in-hospital mortality rates in the BTKA group compared with the unilateral TKA group. 18. Higher incidence of overall systemic complications (hypovolemic shock, pneumonia, confusion, uremic encephalitis, acute renal failure, ICU care, thromboembolic disease, mortality). Within the single-stage BTKA group, high risk patients had significantly greater risk of systemic complications compared with low risk patients

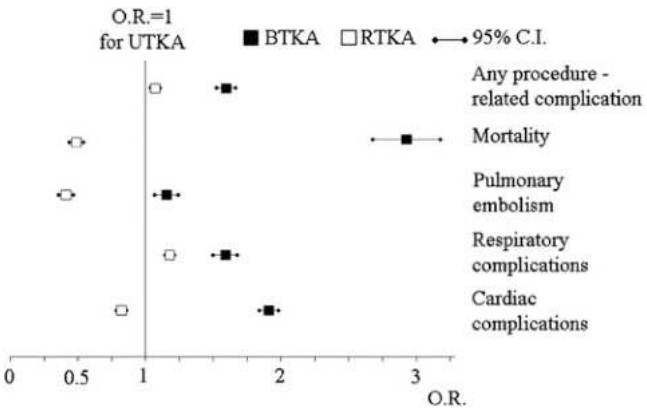


**Fig. 23.3** Odds ratios (ORs) and 95 % confidence intervals (95 % CIs) for in-hospital mortality and selected medical complications in patients undergoing BTKA and RTKA. (Referent is UTKA; OR, 1.) All ORs are different from UTKA = 1. *BTKA* bilateral TKA, *RTKA* revision TKA, *UTKA* unilateral TKA (Used with permission from Memtsoudis SG, Gonzalez Della Valle A, Besculides MC, Gaber L, Sculco TP: In-hospital complications and mortality of unilateral, bilateral, and revision TKA: based on an estimate of 4,159,661 discharges. Clin Orthop Relat Res 2008; 466:2617–27)

## Mortality

Only few studies in the literature have sufficient power to detect potential differences in mortality (Table 23.2). One study [70] reviewed 62,730 BTKAs (12,922 simultaneous, 4,354 staged 1 week apart, 4,524 staged 3 months apart, 9,829 staged 6 months apart, 31,401 staged 1 year apart) utilizing the Health Care Financing Administration's Medicare Provider Analysis and Review files between 1985 and 1990. The authors reported a 30-day mortality rate of 0.33 % for staged BTKA as opposed to 0.99 % for simultaneous BTKA ($p < 0.05$). Parvizi et al. [19] reviewed 19,861 unilateral TKAs and 2,679 single-stage BTKAs performed at their institution, reporting a 30-day mortality rate of 0.17 % and 0.49 %, respectively ($p < 0.05$). Other authors found contrasting results. Kim et al. [12] reported that the 90-day mortality rate of 2,385 sequential BTKA patients (0.3 %) and 719 unilateral TKA patients (0.7 %) was similar.

In our analysis of the National Hospital Discharge Survey from the years 1990 to 2004 [25], we found that the in-hospital mortality rate of BTKA patients (0.5 %) was higher than that of patients undergoing unilateral TKA (0.3 %). Our multivariate analysis controlling for type of surgery, age, gender, race, hospital bed size, US region, source of payment, and comorbidities revealed that the risk-adjusted mortality among patients undergoing BTKA was three times higher compared with those receiving unilateral TKA (Fig. 23.3). The discrepancy in mortality between BTKA and unilateral TKA was confirmed in our most recent analysis of nationally representative data collected for the Nationwide Inpatient Sample [45]. In both studies in-hospital mortality among BTKA patients was higher despite the fact that this population was younger and overall healthier than unilateral TKA recipients.

## Cardiac Complications

Several authors have expressed concern about a higher risk of cardiac complications in patients undergoing single-stage BTKA. The most frequently encountered cardiac complications include myocardial infarction (MI), arrhythmias, angina, and congestive heart failure [10, 11, 38, 67, 71]. Bullock et al. [16] observed myocardial ischemia to be 5 times more frequent in 255 simultaneous BTKA patients than in 514 unilateral TKA patients. Other authors encountered similar findings: the rates of myocardial infarction and arrhythmias were 4–6 times more frequent in patients undergoing single-stage BTKA (15.8 % and 24.5 %, respectively) than in patients undergoing unilateral TKA (3.7 % and 6.1 % respectively) [67, 71]. Our institutional experience [42, 72] demonstrated that single-stage BTKA is associated with a significantly higher risk of cardiovascular complications (mainly arrhythmias, congestive heart failure, and DVT) especially in patients with medical comorbidities such as pulmonary hypertension, congestive heart failure, chronic pulmonary disease, and renal disease. These findings are probably explained by the stress imposed by longer operative times, larger fluid shifts, a more significant hyperadrenergic state, risk for anaemia, and overall higher invasiveness of BTKA compared to unilateral TKA. Patients with reduced end-organ reserve and thus decreased ability to compensate for these insults may be at especially high risk [45].

## Pulmonary Complications Including Thromboembolism

Fat and pulmonary emboli are more frequent in patients undergoing single-stage BTKA than in those undergoing unilateral TKA. Some authors have proposed using a fluted intramedullary rod, slow rod insertion technique, and overdrilling the entry point for the guide rod [33, 73, 74] to reduce the risk of forcing medullary contents into the venous system. However, Lane et al. [18] concluded that even when no intramedullary rods are used during surgery, fat embolism is still a concrete threat.

Pulmonary embolism seems to be associated with increased operating time of single-stage BTKA, the cementing of the components, the surgical intervention at both lower extremities, and a prolonged duration of relative immobility [75]. Indeed, all of the aforementioned events

contribute to trigger the Virchow triad of venous stasis and turbulence, endothelial injury, and Hypercoagulability [76]. Our study of in-hospital complications of TKA surgery [25] based on an estimate of 4,159,661 discharges in the USA from 1990 to 2004, demonstrated a 50 % increased risk of pulmonary embolism in patients undergoing BTKA as opposed to unilateral TKA. These observations were made despite a more favourable comorbidity profile and younger age among patients undergoing BTKA. A comparable trend was also observed by Barrett et al. [77], who reported the adjusted risk of PE was 80 % higher in the BTKA group, and by Restrepo et al. [78], who reported an increased risk of PE in single-stage BTKA patients (odds ratio of 1.8). Although the majority of studies alert about a higher risk of pulmonary embolism in patients undergoing single-stage BTKA, one investigation reported a similar rate of asymptomatic deep venous thrombosis (41 %) in 116 single-stage BTKA patients and 111 unilateral TKA patients not receiving thromboprophylaxis [79].

Given the fact that the majority of studies have observed a higher risk of pulmonary complications including thromboembolism, it seems prudent to screen patients who are suspected of having increased pulmonary pressure or right heart dysfunction, including patients with sleep apnea, and those with a history of pulmonary embolism, and consider them at high risk. This is because these conditions may be associated with higher impedance to venous return due to increases in right heart pressures, especially after additional increases in pulmonary vascular resistance brought upon by embolizing debris after bilateral procedures [80–83]. In addition, we advocate routine thromboprophylaxis with Coumadin in patients undergoing single-stage BTKA surgery.

## Post-operative Confusion

There seems to be agreement on the higher rate of post-operative confusion after single-stage BTKA compared to unilateral TKA [18, 25, 84, 85]. The cause for this complication seems to lie within higher degree of systemic inflammation and higher rates of fat and debris embolization [18, 86]. Some researchers have conducted intraoperative hemodynamic monitoring, electroencephalography, and direct ultrasound imaging of the carotid artery in patients undergoing bilateral lower limb replacements, observing debris embolization into the arterial circulation especially upon tourniquet deflation immediately after the second of two sequential arthroplasty procedures [86, 87].

## Potential Increase in Wound Infection Rate

The literature reports contrasting opinions regarding wound infection rates following single-stage BTKA and unilateral TKA [1, 30, 69]. Those who have observed a higher infection rate in single-stage BTKA surgery [1, 30] blame the longer operating times, increased number of medical personnel in the operating room, and no re-scrubbing, no re-draping, and no instrument change for the second knee arthroplasty.

We studied the deep and superficial wound infection rates 1 year after single-stage bilateral total hip arthroplasties performed with 1 or 2 sets of sterile instruments [88]. The rate of infection in 271 patients who had a new sterile setting for the second hip was similar to that of 294 patients who had both hips done using the same instruments ($p \sim 1.0$).

Some authors suggested that BTKA surgery has a lower risk of perioperative infection in comparison to unilateral TKA. A large retrospective cohort study on almost 4,000 patients [10] observed a significantly lower rate of superficial infection risk for BTKA (0.3 %) compared to unilateral TKAs (0.8 %) ($p = 0.0243$). Similarly, our study on in-hospital complications of over four million TKAs in the USA showed that despite the higher rate of obesity in patients undergoing BTKA (8.3 % vs. 6.3 % in unilateral TKA patients), those undergoing unilateral TKA had higher rates of procedure-related in-hospital infection (0.1 % vs. 0.2 % in the unilateral TKA group) [25]. This may be explained by the fact that the latter group had an increased prevalence of other comorbidities, some that are linked to an increased risk of infection, i.e. diabetes [89].

## Use of Allogenic Blood Transfusions

Predictably, the incidence of post-hemorrhagic anaemia is greater after single-stage BTKA than unilateral TKA. Utilizing nationally representative data we found the incidence of post-operative anaemia to be around 28.6 % in BTKA and 15.3 % in unilateral TKA patients [25]. Besides twice the blood loss related to the second procedure, Bould et al. [90] showed a prolongation in the prothrombin time, activated partial thromboplastin time, and thrombin time after release of the first tourniquet, hypothetically due to tissue trauma, tourniquet application with decrease in clotting factors, and perioperative hypothermia.

The increased risk of allogenic blood transfusions after single-stage BTKA has been reported to be as high as 17-fold [15, 18, 42, 91]. In order to limit the need for allogenic

blood transfusion, Breakwell et al. [92] recommended the use of a cell saver. In their study of 33 patients undergoing simultaneous BTKA randomized to receive allogenic blood only, or a combination of collected and re-infused blood, an average of 1,000 ml of drainage blood was salvaged in the study group, resulting in a significant reduction in allogenic blood requirements from 6.3 to 3.8 units in total ($p = 0.002$).

### Use of Tertiary Rehabilitation Centers

There is an increased proportion of patients undergoing single-stage BTKA surgery that are discharged to an acute/subacute rehabilitation facility, than following unilateral TKA surgery [9, 17, 18, 25, 64, 67]. In our study reporting on the trends of TKA surgery in the USA between 1990 and 2004, we observed that 37.2 % of 153,259 BTKA patients in comparison to 19.6 % of 3,672,247 unilateral TKA patients were discharged to short- or long-term facilities [25]. The reason for this seems to lie not solely in the slower post-operative mobilization of patients undergoing BTKA but also in surgeon, physical therapist, and social worker expectation that dedicated rehabilitation after the hospital stay would be more frequently necessary in BTKA compared to unilateral TKA patients. The decision to transfer a patient to a rehabilitation facility is strongly affected by the patient ability to ambulate at the time of discharge. This difference can be accounted for by the fact that patients undergoing unilateral TKA most commonly have only unilateral OA, and thus may be less affected in the ability to ambulate. This is in contrast to BTKA patients who have bilateral disease.

## Timing of Surgery for BTKA

There is evidence that suggests that BTKA surgery performed during the same hospitalization should be performed under a single anesthetic (single-stage). We analyzed the perioperative outcomes of unilateral TKA and BTKA patients using 670,305 admissions in the Nationwide Inpatient Sample (NIS) between 1998 and 2006 [45]. Among patients undergoing BTKA during the same hospitalization, 74.8 % were performed under the same anesthetic, while the remainder was performed on separate days of the hospital admission (average: 3.6 days apart). Procedure related complications were less frequent in single-stage BTKA patients ($p < 0.0001$). Such complications included: central nervous system, peripheral vascular, respiratory, gastrointestinal, genitourinary, wound dehiscence, infection, and others. For all mentioned categories, staged procedures during the same hospitalization had a significantly higher incidence of complications. However, venous thrombosis and pulmonary embolism occurred more frequently among single-stage procedure recipients [1.48 % vs. 1.22 % ($p = 0.0002$) and 0.89 % vs. 0.77 % ($p = 0.0218$), respectively]. No statistical difference in the rates of in-hospital mortality was seen between groups.

Ritter et al. [70] studied the ideal timing between surgeries for BTKA patients. Their data from the Health Care Financing Administration's Medicare Provider Analysis and Review files in the USA between 1985 and 1990 included information on 12,922 single-stage BTKAs, 4,354 staged BTKAs (6 weeks apart), 4,524 staged BTKAs (3 months apart), 9,829 staged BTKAs (6 months apart), and 31,401 staged BTKAs (1 year apart). They observed that no single group had the lowest complication rate on all measures. Surgery-related complications (i.e. wound dehiscence, wound infection, post-operative haemorrhage, and mechanical complications of orthopedic devices) were almost 50 % higher in all staged BTKA groups compared with the single-stage BTKA group. Vascular complications were lowest in the 6-week group and highest in the 1-year group (4.1 % and 6.8 %, respectively). Nosocomial infections were lowest in the 3-month staged BTKA group ($p < 0.05$). Wound infections were significantly lower in the simultaneous BTKA group (0.05 %). In terms of mortality, despite the very low cumulative 30-day, 3-month and 6-month mortality rates (1 %, 1.5 %, and 2 %, respectively), simultaneous BTKA patients were almost 50 % more likely to die. The authors concluded that none of the bilateral groups performed categorically better than the others, although 3-month staged BTKA was associated with the most favourable profile. The previously mentioned data and suggestions are particularly important in light of findings by other authors, who reported that patients with equally severe bilateral knee osteoarthritis have a 75 % probability of having both knees replaced within 1 year of each other [93].

## Recommendations for Patient Selection

In view of the presented facts and figures and in order to diminish the rate of perioperative life-threatening complications of surgery and mortality for this elective procedure, it seems reasonable and prudent to carefully select patients that are candidates for BTKA surgery. We conducted a study aiming at identifying risk factors for morbidity and mortality following BTKA surgery using data from the Nationwide Inpatient Sample [81]. Of the 42,003 entries identified, representing an estimated 206,573 elective BTKA procedures performed in the USA between 1998 and 2007, 9.5 % developed major complications or mortality during their hospitalization. Increasing age was an independent risk factor for major

**Table 23.3** Contraindications to single-stage BTKA

| | Absolute contraindication | Relative contraindication | Suggested further evaluation |
|---|---|---|---|
| Extreme age (>80) | X | | |
| ASA class: 3 or greater | X | | |
| Obesity | | X | Echocardiography |
| Sleep apnea | | X | Echocardiography |
| COPD | | X | Echocardiography |
| History of thromboembolism | | X | Echocardiography |

morbidity and mortality. Patients younger than 45 years were half as likely to have a major complication or mortality with respect to patients in the age group between 45 and 64 years (odds ratio:0.49—confidence interval 0.30;0.81). Comparatively, the risk for patients aged 65–74 and greater than 75 years rose significantly (odds ratio: 1.81, confidence interval 1.67–2.30 and odds ratio: 2.52, confidence interval 2.30–2.77, respectively). Advanced age as a risk factor has been further supported by findings published by other authors [19, 94]. This is likely associated with the fact that older patients have a physiologic decline in end organ reserve putting them in a more vulnerable position. Age as a risk factor and its consideration when contemplating BTKA becomes especially a problem when considering that a large number of joint arthroplasty recipients falls into this category. Male gender was associated with increased odds for adverse outcome (odds ratio: 1.5, confidence interval 1.44–1.66); however, reasons for this finding have to remain speculative. A number of comorbidities were identified as independent risk factors for major complications and mortality: pulmonary hypertension, congestive heart failure, fluid and electrolyte abnormalities, cardiac valve disease, renal failure, neurologic disease, coagulopathies, and chronic lung disease. Specifically, pulmonary hypertension and congestive heart failure were the most significant comorbidities associated with increased odds (odds ratio: 4.10 and 5.55, respectively) for adverse outcome.

Our experience, body of research and review of the literature has lead to the creation of guidelines for the selection of appropriate candidates for single-stage BTKA, in a desire to reconcile benefits and concerns for safety (Table 23.3).

Although conclusive evidence is limited, the literature suggests that the following points should be considered when contemplating single-stage BTKA:

1. *Exclusion based on age*: The findings of several authors [10, 19, 26, 67, 71, 72, 94–97] support that single-stage BTKA surgery in patients of extreme age should be avoided.
2. *Exclusion based on American Society of Anesthesiologists (ASA) classification*: The findings of several authors [26, 42, 69, 72, 81, 98] support the exclusion of patients with significant end organ dysfunction, i.e. an ASA physical status of 3 or greater.
3. *Exclusion based on specific comorbidities*: Patients at risk for occult derangements of pulmonary hemodynamics and right heart dysfunction (i.e. the morbidly obese and those with sleep apnea, chronic obstructive pulmonary disease, and previous pulmonary embolism) should undergo cardiopulmonary evaluation with echocardiography to rule out significant pre-existing increases in pulmonary artery pressures, which may predispose patients to increased morbidity and mortality. Besides pulmonary hypertension, congestive heart failure, and chronic lung disease, other comorbidities should be used as exclusion criteria, including coronary artery disease, renal failure, neurological disease, hepatic dysfunction, and coagulopathies.

Furthermore, recognizing the need for guidance on the subject, a national group of experts participated in an elaborate consensus project to produce guidelines on the perioperative management of patients requiring single-stage BTKA [105]. These represent a consensus of specialized institutions.

## Summary

In our experience and with the awareness of the previously mentioned recommendations, single-stage BTKA represents a valid option for the treatment of severe pain produced by bilateral knee osteoarthritis in the carefully selected patient. The advantages include good clinical results, the use of a single anesthetic, a shorter overall surgical time, and similar or less pain with respect to unilateral TKA (especially after post-operative day 1), reflected in a lower use of narcotics. Additionally, total recovery time compared with staged BTKA is faster, predictably accelerating return to everyday life and work. Patient satisfaction is qualitatively and quantitatively at least equivalent to that of unilateral TKA, with the overwhelming majority of patients who have experienced single-stage BTKA declaring they would opt for the same procedure again. Finally, cost-effectiveness of single-stage BTKA represents a major advantage of the procedure, with overall savings between 18 % and 58 % compared with the cost of staged procedures.

On the other hand, the disadvantages of single-stage BTKA must be considered when evaluating a potential candidate. The higher mortality rate in single-stage BTKA compared with unilateral TKA patients represents the most feared outcome. Although most studies in the literature do not reach significant power to actually detect potential differences in mortality, the latter seems to be significantly increased in single-stage compared to unilateral procedures. Cardiac complications, in particular myocardial infarctions, arrhythmias, angina, and congestive heart failure are more prevalent in single-stage BTKA patients. These findings are possibly related to stress imposed by longer operative times, larger fluid shifts, a more significant hyperadrenergic state, risk for anaemia, and overall higher invasiveness of BTKA compared with unilateral TKA. Pulmonary complications including thromboembolism and post-operative confusion are also a concern when selecting patients for single-stage BTKA. Greater wound infection rates seem to be controversial. Further drawbacks of single-stage BTKA include the increased use of allogenic blood transfusions. Finally, the greater use of tertiary rehabilitation centers might be regarded as a disadvantage of BTKA. While an increased proportion of patients undergoing single-stage BTKA surgery are discharged to an acute/subacute rehabilitation facility compared to unilateral TKA recipients, patients belonging to the latter group appear to be more likely readmitted for post-operative knee stiffness.

In light of the presented data and according to our experience at the Hospital for Special Surgery, single-stage BTKA represents a valuable option to restore knee function and well-being in patients with bilateral knee osteoarthritis. However, despite the low prevalence of life-threatening complications, thorough patient selection is advised, with the ideal candidate for single-stage BTKA being motivated, young, and healthy. The need for prospective randomized studies remains crucial to further support of clinical recommendations for patient selection.

**Summary Bullet Points**

- Bilateral total knee arthroplasties can be performed during a single surgical session, sequential or simultaneous, or staged during different surgeries
- Single-stage bilateral knee arthroplasty may be associated with reduced hospital costs and the advantage of a single hospitalization.
- Single-stage surgery may be associated with increased risk for perioperative complications in the unselected patient population.
- In order to reconcile higher risk with the benefits of single-stage bilateral knee arthroplasty institutions and clinicians may want to consider the utilization of strict screening criteria to guide patient selection.

## Case Study

A case study for this chapter is included in Appendix M at the end of this book.

## References


1. Luscombe JC, Theivendran K, Abudu A, Carter SR. The relative safety of one-stage bilateral total knee arthroplasty. Int Orthop. 2009;33:101–4.
2. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am. 2007;89:780–5.
3. Singh JA, Vessely MB, Harmsen WS, Schleck CD, Melton 3rd LJ, Kurland RL, et al. A population-based study of trends in the use of total hip and total knee arthroplasty, 1969–2008. Mayo Clin Proc. 2010;85:898–904.
4. Kurtz S, Mowat F, Ong K, Chan N, Lau E, Halpern M. Prevalence of primary and revision total hip and knee arthroplasty in the United States from 1990 through 2002. J Bone Joint Surg Am. 2005;87:1487–97.
5. Memtsoudis SG, Gonzalez Della Valle A, Besculides MC, Gaber L, Laskin R. Trends in demographics, comorbidity profiles, in-hospital complications and mortality associated with primary knee arthroplasty. J Arthroplasty. 2009;24:518–27.
6. Mont MA, Mitzner DL, Jones LC, Hungerford DS. History of the contralateral knee after primary knee arthroplasty for osteoarthritis. Clin Orthop Relat Res. 1995:145–50.
7. Walmsley P, Murray A, Brenkel IJ. The practice of bilateral, simultaneous total knee replacement in Scotland over the last decade. Data from the Scottish Arthroplasty Project. Knee. 2006;13:102–5.
8. Alemparte J, Johnson GV, Worland RL, Jessup DE, Keenan J. Results of simultaneous bilateral total knee replacement: a study of 1208 knees in 604 patients. J South Orthop Assoc. 2002;11:153–6.
9. Reuben JD, Meyers SJ, Cox DD, Elliott M, Watson M, Shim SD. Cost comparison between bilateral simultaneous, staged, and unilateral total joint arthroplasty. J Arthroplasty. 1998;13:172–9.
10. Ritter MA, Harty LD, Davis KE, Meding JB, Berend M. Simultaneous bilateral, staged bilateral, and unilateral total knee arthroplasty. A survival analysis. J Bone Joint Surg Am. 2003;85-A:1532–7.
11. Morrey BF, Adams RA, Ilstrup DM, Bryan RS. Complications and mortality associated with bilateral or unilateral total knee arthroplasty. J Bone Joint Surg Am. 1987;69:484–8.
12. Kim YH, Choi YW, Kim JS. Simultaneous bilateral sequential total knee replacement is as safe as unilateral total knee replacement. J Bone Joint Surg Br. 2009;91:64–8.
13. Husted H, Troelsen A, Otte KS, Kristensen BB, Holm G, Kehlet H. Fast-track surgery for bilateral total knee replacement. J Bone Joint Surg Br. 2011;93:351–6.
14. Leonard L, Williamson DM, Ivory JP, Jennison C. An evaluation of the safety and efficacy of simultaneous bilateral total knee arthroplasty. J Arthroplasty. 2003;18:972–8.
15. Lombardi AV, Mallory TH, Fada RA, Hartman JF, Capps SG, Kefauver CA, Dodds K, Adams JB. Simultaneous bilateral total knee arthroplasties: who decides? Clin Orthop Relat Res. 2001:319–29.
16. Bullock DP, Sporer SM, Shirreffs Jr TG. Comparison of simultaneous bilateral with unilateral total knee arthroplasty in terms of perioperative complications. J Bone Joint Surg Am. 2003;85-A:1981–6.

17. Fick D, Crane T, Shakespeare D. A comparison of bilateral vs. unilateral total knee arthroplasty mobilised using a flexion regime. Knee. 2002;9:285–9.
18. Lane GJ, Hozack WJ, Shah S, Rothman RH, Booth RE, Jr, Eng K, Smith P. Simultaneous bilateral versus unilateral total knee arthroplasty. Outcomes analysis. Clin Orthop Relat Res. 1997: 106–12.
19. Parvizi J, Sullivan TA, Trousdale RT, Lewallen DG. Thirty-day mortality after total knee arthroplasty. J Bone Joint Surg Am. 2001;83-A:1157–61.
20. Kim YH. Incidence of fat embolism syndrome after cemented or cementless bilateral simultaneous and unilateral total knee arthroplasty. J Arthroplasty. 2001;16:730–9.
21. Sulek CA, Davies LK, Enneking FK, Gearen PA, Lobato EB. Cerebral microembolism diagnosed by transcranial Doppler during total knee arthroplasty: correlation with transesophageal echocardiography. Anesthesiology. 1999;91:672–6.
22. Memtsoudis SG, Ma Y, Chiu YL, Walz JM, Voswinckel R, Mazumdar M. Perioperative mortality in patients with pulmonary hypertension undergoing major joint replacement. Anesth Analg. 2010;111:1110–6.
23. Memtsoudis SG, Gonzalez Della Valle A, Besculides MC, Esposito M, Koulouvaris P, Salvati EA. Risk factors for perioperative mortality after lower extremity arthroplasty: a population-based study of 6,901,324 patient discharges. J Arthroplasty. 2010;25:19–26.
24. Memtsoudis SG, Besculides MC, Reid S, Gaber-Baylis LK, Gonzalez Della Valle A. Trends in bilateral total knee arthroplasties: 153,259 discharges between 1990 and 2004. Clin Orthop Relat Res. 2009;467:1568–76.
25. Memtsoudis SG, Gonzalez Della Valle A, Besculides MC, Gaber L, Sculco TP. In-hospital complications and mortality of unilateral, bilateral, and revision TKA: based on an estimate of 4,159,661 discharges. Clin Orthop Relat Res. 2008;466:2617–27.
26. Memtsoudis SG, Besculides MC, Gaber L, Liu S, Gonzalez Della Valle A. Risk factors for pulmonary embolism after hip and knee arthroplasty: a population-based study. Int Orthop. 2009;33: 1739–45.
27. Benjamin J, Tucker T, Ballesteros P. Is obesity a contraindication to bilateral total knee arthroplasties under one anesthetic? Clin Orthop Relat Res. 2001:190–5.
28. Brotherton SL, Roberson JR, de Andrade JR, Fleming LL. Staged versus simultaneous bilateral total knee replacement. J Arthroplasty. 1986;1:221–8.
29. Cohen RG, Forrest CJ, Benjamin JB. Safety and efficacy of bilateral total knee arthroplasty. J Arthroplasty. 1997;12:497–502.
30. Gradillas EL, Volz RG. Bilateral total knee replacement under one anesthetic. Clin Orthop Relat Res. 1979:153–8.
31. Hardaker Jr WT, Ogden WS, Musgrave RE, Goldner JL. Simultaneous and staged bilateral total knee arthroplasty. J Bone Joint Surg Am. 1978;60:247–50.
32. Jankiewicz JJ, Sculco TP, Ranawat CS, Behr C, Tarrentino S. One-stage versus 2-stage bilateral total knee arthroplasty. Clin Orthop Relat Res. 1994:94–101.
33. Kolettis GT, Wixson RL, Peruzzi WT, Blake MJ, Wardell S, Stulberg SD. Safety of 1-stage bilateral total knee arthroplasty. Clin Orthop Relat Res. 1994:102–9.
34. McLaughlin TP, Fisher RL. Bilateral total knee arthroplasties. Comparison of simultaneous (two-team), sequential, and staged knee replacements. Clin Orthop Relat Res. 1985:220–5.
35. Ritter MA, Meding JB. Bilateral simultaneous total knee arthroplasty. J Arthroplasty. 1987;2:185–9.
36. Ritter MA. Simultaneous knee replacement is better for the patient. Orthopedics. 1998;21:415. 418.
37. Ritter MA. Bilateral simultaneous TKR: doing what's best for the patient. Orthopedics. 2000;23:538.
38. Ritter MA, Harty LD. Debate: simultaneous bilateral knee replacements: the outcomes justify its use. Clin Orthop Relat Res. 2004:84–6.
39. Soudry M, Binazzi R, Insall JN, Nordstrom TJ, Pellicci PM, Goulet JA. Successive bilateral total knee replacement. J Bone Joint Surg Am. 1985;67:573–6.
40. Stanley D, Stockley I, Getty CJ. Simultaneous or staged bilateral total knee replacements in rheumatoid arthritis. A prospective study. J Bone Joint Surg Br. 1990;72:772–4.
41. Vince KG. Bilateral total knee arthroplasty under one anesthesia: a safe protocol. Mayo Clin Proc. 1997;72:883–5.
42. Pavone V, Johnson T, Saulog PS, Sculco TP, Bottner F. Perioperative morbidity in bilateral one-stage total knee replacements. Clin Orthop Relat Res. 2004:155–61.
43. Forster MC, Bauze AJ, Bailie AG, Falworth MS, Oakeshott RD. A retrospective comparative study of bilateral total knee replacement staged at a one-week interval. J Bone Joint Surg Br. 2006; 88:1006–10.
44. Taylor BC, Dimitris C, Mowbray JG, Gaines ST, Steensen RN. Perioperative safety of two-team simultaneous bilateral total knee arthroplasty in the obese patient. J Orthop Surg Res. 2010;5:38.
45. Memtsoudis SG, Ma Y, Gonzalez Della Valle A, Mazumdar M, Gaber-Baylis LK, MacKenzie CR, et al. Perioperative outcomes after unilateral and bilateral total knee arthroplasty. Anesthesiology. 2009;111:1206–16.
46. Memtsoudis SG, Starcher B, Gonzalez Della Valle A, Ma Y, Jules-Elysee K, Sculco TP. Urine desmosine as a marker of lung injury following total knee arthroplasty. A pilot study. HSS J. 2009; 5:154–8.
47. Hunter DJ, March L, Sambrook PN. Knee osteoarthritis: the influence of environmental factors. Clin Exp Rheumatol. 2002;20:93–100.
48. March LM, Cross M, Tribe KL, Lapsley HM, Courtenay BG, Cross MJ, et al. Two knees or not two knees? Patient costs and outcomes following bilateral and unilateral total knee joint replacement surgery for OA. Osteoarthritis Cartilage. 2004;12:400–8.
49. Stubbs G, Pryke SE, Tewari S, Rogers J, Crowe B, Bridgfoot L, et al. Safety and cost benefits of bilateral total knee replacement in an acute hospital. ANZ J Surg. 2005;75:739–46.
50. Liu TK, Chen SH. Simultaneous bilateral total knee arthroplasty in a single procedure. Int Orthop. 1998;22:390–3.
51. Abdel-Salam A, Eyres KS. Effects of tourniquet during total knee arthroplasty. A prospective randomised study. J Bone Joint Surg Br. 1995;77:250–3.
52. Klenerman L. Is a tourniquet really necessary for knee replacement? J Bone Joint Surg Br. 1995;77:174–5.
53. Pedowitz RA. Tourniquet-induced neuromuscular injury. A recent review of rabbit and clinical experiments. Acta Orthop Scand Suppl. 1991;245:1–33.
54. Shaw JA, Murray DG. The relationship between tourniquet pressure and underlying soft-tissue pressure in the thigh. J Bone Joint Surg Am. 1982;64:1148–52.
55. Sapega AA, Heppenstall RB, Chance B, Park YS, Sokolow D. Optimizing tourniquet application and release times in extremity surgery. A biochemical and ultrastructural study. J Bone Joint Surg Am. 1985;67:303–14.
56. Saunders KC, Louis DL, Weingarden SI, Waylonis GW. Effect of tourniquet time on postoperative quadriceps function. Clin Orthop Relat Res. 1979:194–9.

57. Patterson S, Klenerman L. The effect of pneumatic tourniquets on the ultrastructure of skeletal muscle. J Bone Joint Surg Br. 1979; 61-B:178–83.
58. Klenerman L. The tourniquet in surgery. J Bone Joint Surg Br. 1962;44-B:937–43.
59. Klenerman L. The tourniquet in operations on the knee: a review. J R Soc Med. 1982;75:31–2.
60. Padala PR, Rouholamin E, Mehta RL. The role of drains and tourniquets in primary total knee replacement: a comparative study of TKR performed with drains and tourniquet versus no drains and adrenaline and saline infiltration. J Knee Surg. 2004; 17:24–7.
61. McGrath BJ, Hsia J, Epstein B. Massive pulmonary embolism following tourniquet deflation. Anesthesiology. 1991;74:618–20.
62. Lundgren CE, Zederfeldt BH. Influence of low oxygen pressure on wound healing. Acta Chir Scand. 1969;135:555–8.
63. Stephens FO, Hunt TK. Effect of changes in inspired oxygen and carbon dioxide tensions on wound tensile strength: an experimental study. Ann Surg. 1971;173:515–9.
64. Powell RS, Pulido P, Tuason MS, Colwell Jr CW, Ezzet KA. Bilateral vs unilateral total knee arthroplasty: a patient-based comparison of pain levels and recovery of ambulatory skills. J Arthroplasty. 2006;21:642–9.
65. Shetty GM, Mullaji A, Bhayde S, Chandra Vadapalli R, Desai D. Simultaneous bilateral versus unilateral computer-assisted total knee arthroplasty: a prospective comparison of early postoperative pain and functional recovery. Knee. 2010;17:191–5.
66. Ethgen O, Bruyere O, Richy F, Dardennes C, Reginster JY. Health-related quality of life in total hip and total knee arthroplasty. A qualitative and systematic review of the literature. J Bone Joint Surg Am. 2004;86-A:963–74.
67. Adili A, Bhandari M, Petruccelli D, De Beer J. Sequential bilateral total knee arthroplasty under 1 anesthetic in patients $>$ or $=$ 75 years old: complications and functional outcomes. J Arthroplasty. 2001;16:271–8.
68. Severson EP, Mariani EM, Bourne MH. Bilateral total knee arthroplasty in patients 70 years and older. Orthopedics. 2009; 32:316.
69. Yoon HS, Han CD, Yang IH. Comparison of simultaneous bilateral and staged bilateral total knee arthroplasty in terms of perioperative complications. J Arthroplasty. 2010;25:179–85.
70. Ritter M, Mamlin LA, Melfi CA, Katz BP, Freund DA, Arthur DS. Outcome implications for the timing of bilateral total knee arthroplasties. Clin Orthop Relat Res. 1997:99–105.
71. Lynch NM, Trousdale RT, Ilstrup DM. Complications after concomitant bilateral total knee arthroplasty in elderly patients. Mayo Clin Proc. 1997;72:799–805.
72. Urban MK, Chisholm M, Wukovits B. Are postoperative complications more common with single-stage bilateral (SBTKR) than with unilateral knee arthroplasty: guidelines for patients scheduled for SBTKR. HSS J. 2006;2:78–82.
73. Fahmy NR, Chandler HP, Danylchuk K, Matta EB, Sunder N, Siliski JM. Blood-gas and circulatory changes during total knee replacement. Role of the intramedullary alignment rod. J Bone Joint Surg Am. 1990;72:19–26.
74. Ries MD, Rauscher LA, Hoskins S, Lott D, Richman JA, Lynch F, Jr. Intramedullary pressure and pulmonary function during total knee arthroplasty. Clin Orthop Relat Res. 1998:154–60.
75. Patil N, Wakankar H. Morbidity and mortality of simultaneous bilateral total knee arthroplasty. Orthopedics. 2008;31:780–9. quiz 790–1.
76. Virchow RLK. Gesammelte Abhandlungen zur Wissenschaftlichen Medicin [Frankfurt, Meidinger Sohn & Co., 1856]. In: Virchow RLK, editor. Thrombosis and emboli (1846–1856). Matzdorff AC, Bell WR (transl). Canton: Science History Publications; 1998. p. 5–11. 110.
77. Barrett J, Baron JA, Losina E, Wright J, Mahomed NN, Katz JN. Bilateral total knee replacement: staging and pulmonary embolism. J Bone Joint Surg Am. 2006;88:2146–51.
78. Restrepo C, Parvizi J, Dietrich T, Einhorn TA. Safety of simultaneous bilateral total knee arthroplasty. A meta-analysis. J Bone Joint Surg Am. 2007;89:1220–6.
79. Kim YH, Kim JS. Incidence and natural history of deep-vein thrombosis after total knee arthroplasty. A prospective, randomised study. J Bone Joint Surg Br. 2002;84:566–70.
80. Memtsoudis SG, Salvati EA, Go G, Ma Y, Sharrock NE. Perioperative pulmonary circulatory changes during bilateral total hip arthroplasty under regional anesthesia. Reg Anesth Pain Med. 2010;35:417–21.
81. Memtsoudis SG, Ma Y, Chiu YL, Poultsides L, Gonzalez Della Valle A, Mazumdar M. Bilateral total knee arthroplasty: risk factors for major morbidity and mortality. Anesth Analg. 2011;113:784–90.
82. Bradley TD. Right and left ventricular functional impairment and sleep apnea. Clin Chest Med. 1992;13:459–79.
83. Kline JA, Steuerwald MT, Marchick MR, Hernandez-Nino J, Rose GA. Prospective evaluation of right ventricular function and functional status 6 months after acute submassive pulmonary embolism: frequency of persistent or subsequent elevation in estimated pulmonary artery pressure. Chest. 2009;136: 1202–10.
84. Worland RL, Jessup DE, Clelland C. Simultaneous bilateral total knee replacement versus unilateral replacement. Am J Orthop (Belle Mead NJ). 1996;25:292–5.
85. Oakes DA, Hanssen AD. Bilateral total knee replacement using the same anesthetic is not justified by assessment of the risks. Clin Orthop Relat Res. 2004:87–91.
86. Weiss SJ, Cheung AT, Stecker MM, Garino JP, Hughes JE, Murphy FL. Fatal paradoxical cerebral embolization during bilateral knee arthroplasty. Anesthesiology. 1996;84:721–3.
87. Edmonds CR, Barbut D, Hager D, Sharrock NE. Intraoperative cerebral arterial embolization during total hip arthroplasty. Anesthesiology. 2000;93:315–8.
88. Gonzalez Della Valle A, Walter WL, Peterson MG, Pellicci PM, Sculco TP, Salvati EA. Prevalence of infection in bilateral total hip arthroplasty: a comparison of single-stage 565 bilateral procedures performed with 1 or 2 sets of instruments. J Arthroplasty. 2006;21:157–60.
89. Meding JB, Reddleman K, Keating ME, Klay A, Ritter MA, Faris PM, Berend ME. Total knee replacement in patients with diabetes mellitus. Clin Orthop Relat Res. 2003:208–16.
90. Bould M, Freeman BJ, Pullyblank A, Newman JH. Blood loss in sequential bilateral total knee arthroplasty. J Arthroplasty. 1998;13:77–9.
91. Bottner F, Pavone V, Johnson T, Heitkemper S, Sculco TP. Blood management after bilateral total knee arthroplasty. Clin Orthop Relat Res. 2003:254–61.
92. Breakwell LM, Getty CJ, Dobson P. The efficacy of autologous blood transfusion in bilateral total knee arthroplasty. Knee. 2000; 7:145–7.
93. Minter JE, Dorr LD. Indications for bilateral total knee replacement. Contemp Orthop. 1995;31:108–11.
94. Mantilla CB, Horlocker TT, Schroeder DR, Berry DJ, Brown DL. Frequency of myocardial infarction, pulmonary embolism, deep venous thrombosis, and death following primary hip or knee arthroplasty. Anesthesiology. 2002;96:1140–6.
95. Laskin RS. Total knee replacement in patients older than 85 years. Clin Orthop Relat Res. 1999:43–9.
96. Adam RF, Noble J. Primary total knee arthroplasty in the elderly. J Arthroplasty. 1994;9:495–7.
97. Hosick WB, Lotke PA, Baldwin A. Total knee arthroplasty in patients 80 years of age and older. Clin Orthop Relat Res. 1994:77–80.

98. Noble J, Goodall JR, Noble DJ. Simultaneous bilateral total knee replacement: a persistent controversy. Knee. 2009;16:420–6.
99. Williams-Russo P, Urquhart BL, Sharrock NE, Charlson ME. Post-operative delirium: predictors and prognosis in elderly orthopedic patients. J Am Geriatr Soc. 1992;40:759–67.
100. Mangaleshkar SR, Prasad PS, Chugh S, Thomas AP. Staged bilateral total knee replacement—a safer approach in older patients. Knee. 2001;8:207–11.
101. Sliva CD, Callaghan JJ, Goetz DD, Taylor SG. Staggered bilateral total knee arthroplasty performed four to seven days apart during a single hospitalization. J Bone Joint Surg Am. 2005;87:508–13.
102. Hutchinson JR, Parish EN, Cross MJ. A comparison of bilateral uncemented total knee arthroplasty: simultaneous or staged? J Bone Joint Surg Br. 2006;88:40–3.
103. Shah K, Smith J, Jones B, Hullin M. Bilateral total knee replacement under a single anaesthetic, using a cementless implant is not unsafe. Knee Surg Sports Traumatol Arthrosc. 2007;15:269–75.
104. Stefansdottir A, Lidgren L, Robertsson O. Higher early mortality with simultaneous rather than staged bilateral TKAs: results from the Swedish Knee Arthroplasty Register. Clin Orthop Relat Res. 2008;466:3066–70.
105. Memtsoudis SG, Hargett M, Russell LA, Parvizi J, Cats-Baril WL, Stundner O, et al. Consensus statement from the consensus conference on bilateral total knee arthroplasty group. Clin Orthop Relat Res. 2013;471:2649–57.

# Compartment Syndrome and Orthopedic Surgery: Diagnosis and Management

24

Matthew R. Garner, Samuel A. Taylor, Milton T.M. Little, and John P. Lyden

**Objectives**

- To define compartment syndrome and understand its etiology and incidence
- To explain how to identify and diagnose compartment syndrome
- To elucidate the spectrum of compartment syndromes
- To discuss treatment options and timing to surgical intervention
- To describe the most common post-treatment complications and patient outcomes

**Key Points**

- Compartment syndrome is defined as an elevation of intracompartmental pressure to a level that impairs arterial flow.
- Compartment syndrome of the upper and lower extremities can have multiple etiologies, including traumatic, exertional, and iatrogenic in the perioperative setting.
- Early identification and diagnosis enabling prompt intervention is essential to providing patients the best possible outcomes.
- In cases of acute compartment syndrome, emergent fasciotomy is generally indicated. Delayed fasciotomies more than 24 h after onset of symptoms are not recommended as they increase morbidity and mortality; however, it is often difficult to establish a time zero for onset or irreversibility
- Even with timely treatment, multiple surgeries are often necessary to ensure adequate wound debridement, appropriate soft tissue coverage and satisfactory wound closure. Long-term sequelae range from cosmetic concerns secondary to wound complications, the use of skin grafts, limb deformity, amputation, or systemic complications associated with rhabdomyolysis.

## Introduction

Compartment syndrome is defined as an increase in intracompartmental pressure sufficient to impair the micro and/or macrovascular circulation to a level that can cause ischemia and necrosis of tissue [1]. A group of muscles bound by fascia are considered a compartment in the extremities, although paraspinal compartment syndrome has been described [2–6]. Quantitatively, relative ischemia of muscle begins when tissue pressures rise to within 30 mmHg of the patient's diastolic pressure. Experimental studies have shown significant muscle necrosis at sustained absolute pressures of 30 mmHg [7–12]. Diagnostic values vary based on institutional preference and surgeon experience, but our threshold for the diagnosis of acute compartment syndrome is a ΔP (diastolic blood pressure - intracompartmental pressure) of less than 30 mmHg in one or more compartment

Compartment syndrome exists on a spectrum and ranges from acute to chronic. Despite a variety of causes, including burns, vascular injuries, and those that occur after surgical procedures, the vast majority of acute compartment

M.R. Garner • J.P. Lyden (✉)
Department of Orthopaedics, Hospital for Special Surgery, 535 E 70th Street, New York, NY 10021, USA
e-mail: lydenj@hss.edu

S.A. Taylor
Department of Sports Medicine, Hospital for Special Surgery, 535 E 70th Street, New York, NY 10021, USA

M.T.M. Little
Department of Orthopaedics, Harborview Medical Center, 722 10th Avenue East, Apartment 2, Seattle, WA 98102, USA

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_24, 

**Table 24.1** Blunt trauma conditions in which compartment syndrome is diagnosed

| Underlying condition | % of cases |
|---|---|
| Tibial shaft fracture | 36 |
| Soft tissue injury | 23.2 |
| Distal radius fracture | 9.8 |
| Crush syndrome | 7.9 |
| Diaphyseal forearm fracture | 7.9 |
| Femoral diaphyseal fracture | 3.0 |
| Tibial plateau fracture | 3.0 |
| Hand fracture(s) | 2.5 |
| Tibial pilon fractures | 2.5 |
| Foot fracture(s) | 1.8 |
| Ankle fracture | 0.6 |
| Elbow fracture dislocation | 0.6 |
| Pelvic fracture | 0.6 |
| Humeral diaphyseal fracture | 0.6 |

Data from: McQueen MM, Gaston P, Court-Brown CM. Acute compartment syndrome. Who is at risk? J Bone Joint Surg Br 2000;82:200–3

syndromes seen by orthopedic surgeons are diagnosed in the setting of blunt trauma. Based on a study of 164 patients from the UK, tibial shaft fractures account for 36 % of compartment syndromes associated with acute injuries [13]. Fractures in the upper extremity, hand and foot account for the majority of other clinical scenarios where compartment syndrome is an important concern (Table 24.1). The same study reports the average annual incidence in men to be 7.3 per 100,000 and 0.7 per 100,000 in women, a tenfold increased risk of acute traumatic compartment syndrome for males. However, for those who care for orthopedic patients on a regular basis, it is imperative to keep in mind that treatment modalities such as surgical fixation of fractures and casting can also result in compartment syndrome. For this reason, vigilance in the post-injury, as well as postoperative period is essential.

It is well documented that the primary cause of poor outcomes and failed treatment in compartment syndrome is delayed diagnosis [14–17]. A missed compartment syndrome may lead to additional surgical procedures, medical expenses, patient morbidity, and often results in legal ramifications for those involved. Bhattacharyya and Varhas retrospectively reviewed 19 closed malpractice claims and found the following factors to be associated with "poor legal outcome": documentation of abnormal neurologic examination but no action, poor physician communication (i.e., disregarding telephone calls), and delay in fasciotomy after initial presentation. Furthermore, the number of cardinal signs of compartment syndrome (pain out of proportion, pallor, paresthesias, paralysis, and pulselessness) was linearly associated with the dollar amount of payment ($p < 0.001$, $R = 0.74$) and an increased number was associated with an increased chance of indemnity payment ($p < 0.02$) [18]. Within this cohort, 11 patients required an average of 3.5 additional procedures. Sixteen cases were settled without trial over an average of 5.5 years. The decision ratio was 9:7 (patient:surgeon) with an average indemnity payment of $426,000. Three cases went to trial with all three verdicts favoring the treating surgeon. The average defense cost of these cases was $29,500. Overall, the most common sequelae alleged by the patients were need for additional procedures, loss of motion, foot drop, chronic pain, and difficulty walking.

**Table 24.2** Cardinal signs or the five "Ps" of compartment syndrome

| "P" | Description |
|---|---|
| Pain | Pain associated with injury or necrosis; typically seen early |
| Palor | Loss of normal skin tone and/or capillary refill |
| Poikothermia | Loss of body heat in area of injury |
| Paresthesias | Numbness or tingling sensation; typically seen late |
| Pulselessness | Loss of pulses distal to site of injury |

To limit the patient morbidity and legal sequelae associated with compartment syndrome, early and accurate diagnosis is essential. Despite modern diagnostic tools, history and clinical examination remain the primary means of diagnosing compartment syndrome. All providers caring for the orthopedic patient, including nursing assistants, registered nurses, nurse practitioners, physician assistants, residents, and attending surgeons should be aware of the diagnostic criteria and have a thorough understanding of injuries and surgical procedures that put patients at risk for compartment syndrome.

Primary and follow-up assessment of all traumatic injuries should include specific attention to the cardinal signs or the "Ps" of compartment syndrome (Table 24.2). Although pain out of proportion to examination (or increasing analgesic requirements in younger patients) is considered to be the first indication of an impending compartment syndrome, patients may present with any combination of signs or symptoms.

## Peri-op Considerations

### Acute Assessment

As stated previously, despite advances in quantitative diagnostic devices, history and physical examination are essential to diagnosing acute compartment syndrome.

In our institution, serial physical exams are performed every 2–4 h on all patients deemed to be at high risk. Such patients include tibial shaft and plateau fractures, crush injuries, and any patient with a concerning physical

exam at presentation (i.e., significant swelling, pain out of proportion to exam, etc.). It is also very important to recognize that specific operations such as intramedullary nailing and osteotomies may lead to postoperative compartment syndrome and thus these procedures mandate serial exams for a minimum of 24 h postoperatively. Lastly, to avoid iatrogenic compartment syndrome, all postoperative immobilization is performed with splints or bivalved casts to allow for tissue expansion and easy, rapid removal if necessary.

The use of catheter insertion to measure compartment pressure has become more common since the initial use of needle manometry in 1975 [7], but those using such devices should be aware that tissue pressures will vary based on distance from the site of injury with peak pressures being encountered within a few centimeters of fractures [19]. Often, such quantitative measures are used in the operating room to confirm a clinical diagnosis rather than to make a diagnosis.

## Anesthetic Considerations

Advances in regional anesthetic techniques over the past several decades have allowed for excellent perioperative pain control while limiting excessive narcotic use. A combination of spinal anesthesia for lower extremity procedures and short- and long-acting peripheral nerve blocks in both the upper and lower extremities is increasingly common. However, patients with suspected impending compartment syndrome or those undergoing high-risk surgical procedures should not be administered long-acting peripheral blocks under any circumstances. Such anesthetic techniques can mask pain associated with increased compartment pressures and severely limit a practitioner's assessment [20]. Any spinal or peripheral anesthetic used should be either short acting or easily titrated down to zero so that a formal assessment of pain and neurologic status can be obtained rapidly and accurately.

## Sign-out/Documentation

Orthopedic practice has seen a rapid increase in patient volume. Simultaneously, new regulations, such as residency work hour restrictions, have led to an increase in the number of care providers involved with a patient's care. The number of "sign-outs" is only increasing, with patients often changing hands several times each day. The potential for error, due to a failure of communication is great.

Given that compartment syndrome is one of the few, true orthopedic emergencies, any patient at risk for developing this condition should receive special attention during sign-out sessions. The outgoing team must personally relay the information to the person who will be assuming care of the patient. E-mail, a common form of communication in the healthcare field today and one that is frequently used as a sign-out tool at many institutions, is neither appropriate nor adequate when transferring care of a patient, especially one at risk for developing a compartment syndrome. Further, in such situations where a patient will be receiving compartment checks from more than one practitioner over a given time period, every attempt should be made for both individuals to see the patient together at the time care is transferred to establish an accurate baseline examination by the practitioner who is assuming care.

Given the medical-legal implications of delayed diagnosis and/or missed diagnosis of a compartment syndrome, timed documentation has become a point of emphasis for patients being monitored for a possible compartment syndrome. Each "compartment check" should be carefully documented and attention paid to both the patient's subjective complaints and objective findings. The patient should be asked specifically about their pain, subjective tightness, as well as any emerging neurologic symptoms such as decreased sensation and dysethesias. Objective findings and subjective complaints should be compared with prior exams.

The physical exam of a patient with possible compartment syndrome is fourfold. First, careful palpation of each compartment should be conducted, although findings are entirely subjective and have been shown unreliable. Shuler et al. showed that in a cadaveric model, palpation of compartments had a sensitivity of only 54 % for detection of elevated compartment pressures [21]. Next, the muscle groups of each compartment should be stretched passively. If compartment pressures are significantly elevated, muscle stretching within that compartment should elicit significant pain. Passive stretch is perhaps the earliest objective finding and arguably the most important component of examination. Third, a careful neurologic examination including both motor and sensation should be conducted. It is essential to include all potential nerve distributions, especially in the splinted patient where particular distributions may be more difficult to access. Lastly, vascular status should be assessed with palpation of pulses, skin temperature, and capillary refill. Patients who are sedated, intubated, or otherwise unresponsive (including the pediatric patient) and cannot express their symptoms may require manometric monitoring and a lower threshold for intervention.

As with any physical examination, that of a patient with compartment syndrome can vary widely with each subsequent exam. Cascio et al. retrospectively reviewed 30 consecutive patients undergoing fasciotomy for acute compartment syndrome over a 10-year period and found 90 % to be lacking in documentation of a complete

**Table 24.3** Of 30 consecutive patients undergoing fasciotomy for acute compartment syndrome over a 10-year period, 90 % are found to be lacking in documentation of a complete physical exam

| Core H&P findings | Patients with inadequate documentation ($n = 30$) |
|---|---|
| Tenseness | 3 (10 %) |
| Pain | 5 (17 %) |
| Compartment pressures | 6 (20 %) |
| Pulses | 7 (23 %) |
| Motor examination | 8 (27 %) |
| Sensory examination | 9 (30 %) |
| Pain on passive stretch | 10 (33 %) |
| Paresthesias | 11 (37 %) |
| Diastolic blood pressure | 16 (53 %) |
| Pallor | 28 (93 %) |
| Overall (excluding pallor) | 21 (70 %) |

Data from: Cascio BM. Documentation of acute compartment syndrome at an academic health-care center. J Bone Joint Surg Am 2005;87:346

physical exam (Table 24.3). Of the 30 patients, ten had permanent sequelae [22]. As stated previously, documentation of an abnormal neurologic examination and failure to act upon those findings is associated with indemnity payments during malpractice cases [18]. For these reasons, accurate documentation of a physical examination at the time it is performed, along with any actions taken at that time is crucial.

## Informed Consent/Patient Expectations

Perhaps one of the most overlooked issues surrounding the diagnosis and is treatment of compartment syndrome centers around the topic of informed consent. For any patient suspected of having an acute compartment syndrome, an impending compartment syndrome, or a surgical procedure associated with a high risk of compartment syndrome, it is the responsibility of the treating surgeon and team to discuss with the patient the risks associated with the diagnosis, the treatment options, and the possible long-term sequelae associated with both the diagnosis itself and the treatment (i.e., fasciotomy). Proper expectations must be set. Consent should be obtained for possible fasciotomy in such patients. If proper consent is obtained and the patient has a through understanding of possible outcomes, sequelae can be looked at as expectations rather than a complication.

The importance of early fasciotomy as treatment for acute, traumatic compartment syndrome is well-documented dating back as early as 1914 [23]. Any compartment in question should undergo early fasciotomy, and in many cases prophylactic fasciotomies are performed on neighboring compartments—example being the tibial shaft fracture with elevated intracompartmental pressures in the anterior compartment that is treated with a four compartment fasciotomy. After fasciotomy, treating surgeons are frequently left with two issues, the first being fracture fixation, as the majority of compartment syndromes occur in the setting of osseous injury [24], and the second being wound closure. In order to decompress the compartments and allow for soft tissue swelling to subside, fasciotomy wounds are left open, frequently with negative pressure dressings (VAC). Delayed primary wound closure is typically attempted after 48 h, assuming there is viable muscle coverage of the underlying osseous structures and a tension-free closure can be achieved. Split thickness skin grafting or gradual closure techniques are indicated if the wound is under tension. For more severe cases, patients may require rotational or free muscle flap coverage and experience donor site morbidity, or they may require fitting of a prosthetic if amputation was required. The patient should be aware prior to fasciotomy that repeat procedures and possible plastic surgery intervention may be required, and, in some cases, amputation may be necessary.

Systemic complications of acute compartment syndrome should also be discussed with the patient and include sepsis stemming from infection of necrotic tissue and rhabdomyolysis with resulting renal failure. It is important to monitor serum CPK levels and renal function in patients suspected of compartment syndrome. Patients should also be counseled regarding cosmesis following wound closure, and muscle weakness secondary to necrosis and debridement.

It has been our experience that compartment syndromes of the foot is unique in that fasciotomy often results in poor functional outcomes. For these reason, we believe that select patients may be observed clinically, provided both the surgeon and patient are prepared to address the sequelae, which are often treatable with minor surgery and more tolerable than those associated with fasciotomy. Toe-clawing and contracture, fibrosis, stiffness and aching, atrophy of intrinsic muscles, and sensory disturbances [25] should all be discussed with the patient at length and the conversation documented before the decision is made to observe a diagnosed compartment syndrome.

## The Spectrum of Compartment Syndrome

As we have discussed, the criteria for diagnosis of compartments syndrome are predominately clinical. In the cases of acute compartment syndrome in a patient with a high-risk injury and rapid diagnosis, intervention is clear and well defined. The actual onset of compartment syndrome is often unknown, however. As is the case with many conditions in medicine and orthopedics, compartment syndrome frequently exists in a spectrum ranging from the

classic acute presentation to delayed timing to diagnosis to the late or "missed" case.

The delayed or late compartment syndrome is a particularly important consideration in the orthopedic patient, especially in patients unable to convey their pain or symptoms (pediatric or ICU patient) or the patient transferred from an outside hospital facility hours or days following injury.

While some studies indicate no increased risk with late fasciotomies [17], others suggested that fasciotomy-related morbidity, particularly with regard to infection, increases with delay in diagnosis as necrotic muscle exposed to the outside environment at the time of surgery is highly susceptible to bacterial pathogens [26,27]. In fact some authors have reported increased morbidity and mortality in patients treated with fasciotomies more than 24 h after diagnosis [28]. Sheridan and Matsen noted that early fasciotomy patients had a complication rate of only 4.5 %, while those treated with late fasciotomies were exposed to a 54 % morbidity rate—half of which ultimately proceeded to amputation [27]. Finkelstein et al. reported a case series of five patients with closed lower extremity injuries who underwent late fasciotomies, more than 35 h after injury (average 56 h) [29]: one patient died from sepsis while the other four ultimately required amputations (3 secondary to infection and 1 secondary to lack of function). Prior to the era of renal dialysis, death from crush/compartment syndrome occurred most commonly from renal failure. The authors contend, however, that with modern means of dialysis, death from these injuries is predominately due to infection. They conclude that late fasciotomies convert a closed fracture into an open injury and put the patient at risk of overwhelming infection and related morbidity and mortality. Further to this end, Ritenour et al. more recently reported a twofold increase in amputation and threefold increase in mortality in trauma patients treated with delayed fasciotomies [30]. Recent data, however, suggest that delayed treatment of compartment syndrome in the pediatric population may allow for acceptable results with a low risk of infection. Flynn et al. retrospectively reviewed 43 cases of acute traumatic compartment syndrome of the lower leg treated at two institutions with fasciotomy [31]. Of the 43 cases, nine had fasciotomies beyond 24 h post-injury (up to 118 h). 7/9 had excellent outcomes, 2/9 had fair outcomes with fasciotomies at 82.5 and 86 h (weakness with dorsiflexion) and there were no cases of infection.

Compartment syndrome following hip and knee arthroplasty is relatively rare. Lasanios and colleagues reviewed the literature for cases in which compartment syndrome complicated total joint arthroplasty and identified 41 such cases, with nearly a 50/50 split between hip and knee arthroplasty [32]. The most common site of compartment syndrome following total hip arthroplasty was gluteal, accounting for nearly 73 %. Not surprisingly, the most common site of compartments syndrome following total knee arthroplasty was the calf (61 %), but gluteal compartment syndrome occurred with relative frequency (17 %). The mean time to diagnosis was 26 h and the mean time to surgical intervention was 53 h. Gluteal compartment syndrome was almost exclusively attributed to body habitus and prolonged positioning either intraoperatively or postoperatively.

Gluteal compartment syndrome most commonly is atraumatic in etiology. This is of particular importance when considering the obese orthopedic patient who undergoes a prolonged procedure. Henson et al. performed a systematic review of seven publications including 28 patients diagnosed with gluteal compartment syndrome [33]. They noted that the most common cause of gluteal compartment syndrome was prolonged immobilization in men with an average age of 45 years. The patient's body weight was connected with the condition in 50 % of the cases studied. 21 % of the cases occurred in the contralateral (down side) of postoperative total joint arthroplasty patients. Trauma was identified as the causative source in less than one quarter of patients. Less than half of the patients were diagnosed with quantitative pressure assessments with the remainder diagnosed based on history and physical examination. Only 71 % of diagnosed gluteal compartment syndromes were treated with surgical decompression. Of those treated without surgical intervention, the majority of cases included delayed presentation or diagnosis. Patient outcomes are variable based upon the compartments involved, extent of damage, and chronicity of diagnosis.

## Special Consideration in the Perioperative Patient

While the most common etiology of compartment syndrome is trauma, it is crucial to recognize other potential causes in the perioperative orthopedic patient. Iatrogenic compartment syndromes may be prevented with attention to patient positioning, selection, appropriate tourniquet use, and careful application of immobilization devices.

It was initially thought that intramedullary nailing increased compartment pressures and thus increased the risk of postoperative compartment syndrome. Two studies, however, refute this notion. Tornetta and French prospectively evaluated 56 tibial shaft fractures without compartment syndrome preoperatively, each case being treated within 72 h of incident injury [34]. They performed continuous pressure monitoring of the anterior compartment and found transient increase in intracompartmental pressures highest during manual reduction (34 mmHg) and undreamed nail passage (26 mmHg), but noted immediate return to baseline pressures following nail passage. Nassif and colleagues reported on 49 tibial shaft fractures treated with

intramedullary nailing within 72 h of injury [35]. They measured anterior and deep posterior compartment pressures and compared reamed and unreamed techniques. Their pressure measurements were similar to those found by Tornetta and French, noting rapid return to baseline. Further, they found no significant difference in reamed versus unreamed nailing on anterior compartment pressures, but statistically significant lower pressure in the deep posterior compartment for reamed nails. In each case, there were no cases of postoperative compartment syndrome.

The use of modern pneumatic tourniquets during orthopedic surgery is commonplace and allows improved visualization in a relatively bloodless operative field and reduced surgical blood loss. Temporary stoppage of blood flow to a limb results in tissue hypoxia and acidosis [36]. Inappropriate use, both pressure and duration, however, can lead to postsurgical complications including compartment syndrome. More than 2 h of sustained extremity ischemia may lead to post-tourniquet syndrome including pallor, swelling, and stiffness without neurologic symptoms due to myocyte injury [37,38]. Post-tourniquet syndrome typically resolves within 1 week [37]. In extreme cases, however, extended tourniquet duration or excessive pressure can lead to frank compartment syndrome. Current guidelines for tourniquet use include duration less than 2 h [39]. In prolonged surgical cases, requiring greater than the recommended 2 h tourniquet time, Townsend et al. recommends a 30-min interval off tourniquet prior to reinflation [40]. The magnitude of tourniquet inflation should be 50–75 mmHg above preoperative systolic pressure for upper extremity surgery and 100–150 mmHg for lower extremity surgery [39]. Even with proper tourniquet use, however, compartment syndrome can occur. Hypervigilance and an open differential diagnosis are critical to recognition.

Compartment syndrome has also been reported in the well leg of patients undergoing orthopedic procedures on the traction table [41–44]. Development of this pathology is thought to be associated with direct compression of the lateral calf on the supportive post and the relative hypoperfusion of the limb in the elevated position. Hypoperfusion of the limb may also be exacerbated in the patient undergoing regional anesthesia.

Application of pre- and postoperative splints and bandages must be undertaken with care and caution as over constriction of a limb may lead to the development of iatrogenic compartment syndrome [45]. Hinderland et al. reported a case of iatrogenic isolated lateral lower leg compartment syndrome in a 44-year-old man caused by ill-fitting compression stockings placed for DVT prophylaxis [46]. Others have reported cases of IV infiltration leading to compartment syndromes of the forearm and foot [47].

As noted earlier in this chapter, compartment syndrome of the calf is most common, accounting for 36 % of cases. This pathology can occur in any fascial bound muscle group including the foot, hand, and gluteal region. Regardless of the location, diagnosis and management occurs in a similar fashion. With regard to the less common regions, however, the most important diagnostic factor is a high clinical suspicion and inclusion of compartment syndrome on the differential diagnosis of pain. Roberts and coauthors looked at several of the less common compartment syndromes and noted that compartment pressures were performed in 64 % of patients with compartment syndrome of the foot and less than 50 % in the other less common areas such as the forearm, gluteal compartment, and the thigh [48].

Ojike and coauthors reviewed compartment syndrome of the foot in a systematic review and note the most common etiologies to be crush injuries, falls from height, and motor vehicle accidents in 28 %, 26 %, and 34 % of cases, respectively [49]. Calcaneal fractures and Lisfranc fracture dislocations accounted for nearly half of the cases studied. While foot compartment syndrome following elective corrective osteotomies has not been reported, these are certainly to be considered a potential source of foot compartment syndrome. There exists, significant debate as to the necessity of surgical decompression for treatment of foot compartment syndrome. Advocates argue that fasciotomies decrease the incidence of sequelae such as claw toes, impaired mobility, stiffness, and sensory deficits. Others argue, however, that the morbidity associated with surgical intervention may outweigh the morbidity of observation and later corrective procedures.

Sequelae of treated and untreated compartments syndrome have significant functional and aesthetic ramifications. Nerve deficits and stiffness are the most common sequelae following compartment syndrome regardless of the location. Ultimately, a timely and accurate diagnosis is provides patients with the most optimal circumstances for recovery.

## Summary

Compartment syndrome has devastating implications for surgeons and patients alike. The sequelae include patient morbidities, both functional and cosmetic. Failure to identify and document findings can have profound ramifications. The most effective treatment is early diagnosis.

Diagnosis of compartment syndrome is overwhelmingly clinical. Members of the medical or surgical care team must pay particular attention to the earliest findings—pain out of proportion, increasing analgesic requirements, and pain with passive stretch of muscles in a suspect fascial compartment. Other findings such as palpation for fullness are subjective and have been linked with poor interobserver reliability. Further the other traditional findings (pallor, paresthesias, paralysis, and pulselessness) are late findings.

Compartment syndrome exists on a spectrum ranging from acute to delayed to late recognition. An acute compartment syndrome should undergo immediate fasciotomies. Some more recent literature points to observation in cases of late compartment syndrome, as exposing necrotic muscle dramatically increases the risk of infection. Unfortunately, there is often an unclear distinction between these phases of compartment syndrome. As such, the authors urge fasciotomy in any case where there is a question as to the timing to onset of the condition.

While compartment syndrome is traditionally thought of as occurring in the setting of trauma (fracture or crush), there are a number of other etiologies including iatrogenic ones. As a medical community we have the opportunity to limit these risks by paying particular attention to details such as positioning, placement of stockings, and splints. Further, we have an obligation to identify those at particular risk, perform appropriate examination, communicate with colleagues, and take immediate action as a patient's condition changes.

**Summary Bullet Points**

- Compartment syndrome is typically seen in the setting of acute trauma and osseous injury; however, patients undergoing specific operative interventions are at risk in the perioperative period, along with those treated with restrictive dressings (i.e., casts).
- A timely diagnosis of acute compartment syndrome can be difficult with patients experiencing a wide range of signs and symptoms but is essential to allowing for the best clinical outcomes. Compartment pressure measurements may be helpful, but serial clinical examinations are still the most important diagnostic tool.
- In most cases, urgent fasciotomy with adequate release of elevated compartment pressures will allow for the best possible clinical outcomes; however, all patients should be made aware that they may require multiple procedures and of the complications associated with both compartment syndrome and its treatment.

## Case Studies

Case studies for this chapter are included in Appendix N at the end of this book.

## References


1. McQueen MM. Acute compartment syndrome. In: Fractures in adults. 7th ed. Philadelphia: Lippincott Williams & Wilkins; 2010:689.
2. Sava J, Moelleken A, Waxman K. Cardiac arrest caused by reperfusion injury after lumbar paraspinal compartment syndrome. J Trauma. 1999;46:196–7.
3. Carr D, Gilbertson L, Frymoyer J, Krag M, Pope M. Lumbar paraspinal compartment syndrome. A case report with physiologic and anatomic studies. Spine (Phila Pa 1976). 1985;10:816–20.
4. Ferreira J, Galle C, Aminian A, et al. Lumbar paraspinal rhabdomyolysis and compartment syndrome after abdominal aortic aneurysm repair. J Vasc Surg. 2003;37:198–201.
5. Minnema BJ, Neligan PC, Quraishi NA, Fehlings MG, Prakash S. A case of occult compartment syndrome and nonresolving rhabdomyolysis. J Gen Intern Med. 2008;23:871–4.
6. Paryavi E, Jobin CM, Ludwig SC, Zahiri H, Cushman J. Acute exertional lumbar paraspinal compartment syndrome. Spine (Phila Pa 1976). 2010;35:E1529–33.
7. Whitesides TE, Haney TC, Morimoto K, Harada H. Tissue pressure measurements as a determinant for the need of fasciotomy. Clin Orthop Relat Res. 1975;113:43–51.
8. Heckman MM, Whitesides Jr TE, Grewe SR, Rooks MD. Compartment pressure in association with closed tibial fractures. The relationship between tissue pressure, compartment, and the distance from the site of the fracture. J Bone Joint Surg Am. 1994;76:1285–92.
9. Matava MJ, Whitesides Jr TE, Seiler 3rd JG, Hewan-Lowe K, Hutton WC. Determination of the compartment pressure threshold of muscle ischemia in a canine model. J Trauma. 1994;37:50–8.
10. McQueen MM, Christie J, Court-Brown CM. Compartment pressures after intramedullary nailing of the tibia. J Bone Joint Surg Br. 1990;72:395–7.
11. White TO, Howell GE, Will EM, Court-Brown CM, McQueen MM. Elevated intramuscular compartment pressures do not influence outcome after tibial fracture. J Trauma. 2003;55:1133–8.
12. Ovre S, Hvaal K, Holm I, Stromsoe K, Nordsletten L, Skjeldal S. Compartment pressure in nailed tibial fractures. A threshold of 30 mmHg for decompression gives 29 % fasciotomies. Arch Orthop Trauma Surg. 1998;118:29–31.
13. McQueen MM, Gaston P, Court-Brown CM. Acute compartment syndrome. Who is at risk? J Bone Joint Surg Br. 2000;82:200–3.
14. McQuillan WM, Nolan B. Ischaemia complicating injury. A report of thirty-seven cases. J Bone Joint Surg Br. 1968;50:482–92.
15. Matsen 3rd FA, Clawson DK. The deep posterior compartmental syndrome of the leg. J Bone Joint Surg Am. 1975;57:34–9.
16. Rorabeck CH, Macnab L. Anterior tibial-compartment syndrome complicating fractures of the shaft of the tibia. J Bone Joint Surg Am. 1976;58:549–50.
17. Rorabeck CH. The treatment of compartment syndromes of the leg. J Bone Joint Surg Br. 1984;66:93–7.
18. Bhattacharyya T. The medical-legal aspects of compartment syndrome. J Bone Joint Surg Am. 2004;86-A:864.
19. Heckman MM, Whitesides Jr TE, Grewe SR, Judd RL, Miller M, Lawrence 3rd JH. Histologic determination of the ischemic threshold of muscle in the canine compartment syndrome model. J Orthop Trauma. 1993;7:199–210.
20. Hyder N. Compartment syndrome in tibial shaft fracture missed because of a local nerve block. J Bone Joint Surg Br. 1996;78:499.
21. Shuler FD. Physicians' ability to manually detect isolated elevations in leg intracompartmental pressure. J Bone Joint Surg Am. 2010;92:361.
22. Cascio BM. Documentation of acute compartment syndrome at an academic health-care center. J Bone Joint Surg Am. 2005;87:346.

23. Murphy JB. Myositis. JAMA. 1914;63:1249.
24. Twaddle BC, Amendola A. Compartment syndromes. In: Skeletal trauma. 4th ed. St. Louis, MO: Saunders Company; 2008:359.
25. Fulkerson E, Razi A, Tejwani N. Review: acute compartment syndrome of the foot. Foot Ankle Int. 2003;24:180–7.
26. Rollins DL, Bernhard VM, Towne JB. Fasciotomy: an appraisal of controversial issues. Arch Surg. 1981;116:1474–81.
27. Sheridan GW, Matsen 3rd FA. Fasciotomy in the treatment of the acute compartment syndrome. J Bone Joint Surg Am. 1976;58:112–5.
28. Reis ND, Michaelson M. Crush injury to the lower limbs. Treatment of the local injury. J Bone Joint Surg Am. 1986;68:414.
29. Finkelstein JA, Hunter GA, Hu RW. Lower limb compartment syndrome: course after delayed fasciotomy. J Trauma. 1996;40:342–4.
30. Ritenour AE, Dorlac WC, Fang R, et al. Complications after fasciotomy revision and delayed compartment release in combat patients. J Trauma. 2008;64:S153–61. discussion S161–2.
31. Flynn JM. Acute traumatic compartment syndrome of the leg in children: diagnosis and outcome. J Bone Joint Surg Am. 2011;93:937.
32. Lasanianos NG, Kanakaris NK, Roberts CS, Giannoudis PV. Compartment syndrome following lower limb arthroplasty: a review. Open Orthop J. 2011;5:181–92.
33. Henson JT, Roberts CS, Giannoudis PV. Gluteal compartment syndrome. Acta Orthop Belg. 2009;75:147–52.
34. Tornetta 3rd P, French BG. Compartment pressures during nonreamed tibial nailing without traction. J Orthop Trauma. 1997;11:24–7.
35. Nassif JM, Gorczyca JT, Cole JK, Pugh KJ, Pienkowski D. Effect of acute reamed versus unreamed intramedullary nailing on compartment pressure when treating closed tibial shaft fractures: a randomized prospective study. J Orthop Trauma. 2000;14:554–8.
36. Wilgis EF. Observations on the effects of tourniquet ischemia. J Bone Joint Surg Am. 1971;53:1343–6.
37. Ward CM. Oedema of the hand after fasciectomy with or without tourniquet. Hand. 1976;8:179–85.
38. Macfarlane MG, Spooner SJ. Chemical changes in muscle during and after ischaemia. Br J Exp Pathol. 1946;27:339–48.
39. Wakai A, Winter DC, Street JT, Redmond PH. Pneumatic tourniquets in extremity surgery. J Am Acad Orthop Surg. 2001;9:345–51.
40. Townsend HS, Goodman SB, Schurman DJ, Hackel A, Brock-Utne JG. Tourniquet release: systemic and metabolic effects. Acta Anaesthesiol Scand. 1996;40:1234–7.
41. Carlson DA, Dobozi WR, Rabin S. Peroneal nerve palsy and compartment syndrome in bilateral femoral fractures. Clin Orthop Relat Res. 1995;320:115–8.
42. Cascio BM, Buchowski JM, Frassica FJ. Well-limb compartment syndrome after prolonged lateral decubitus positioning. A report of two cases. J Bone Joint Surg Am. 2004;86-A:2038–40.
43. Anglen J, Banovetz J. Compartment syndrome in the well leg resulting from fracture-table positioning. Clin Orthop Relat Res. 1994;301:239–42.
44. Mathews PV, Perry JJ, Murray PC. Compartment syndrome of the well leg as a result of the hemilithotomy position: a report of two cases and review of literature. J Orthop Trauma. 2001;15:580–3.
45. Danner R, Partanen K, Partanen J, Kettunen K. Iatrogenic compartment syndrome, a follow-up of four cases caused by elastic bandage. Clin Neurol Neurosurg. 1989;91:37–43.
46. Hinderland MD, Ng A, Paden MH, Stone PA. Lateral leg compartment syndrome caused by ill-fitting compression stocking placed for deep vein thrombosis prophylaxis during surgery: a case report. J Foot Ankle Surg. 2011;50:616–9.
47. Talbot SG, Rogers GF. Pediatric compartment syndrome caused by intravenous infiltration. Ann Plast Surg. 2011;67:531–3.
48. Roberts CS, Gorczyca JT, Ring D, Pugh KJ. Diagnosis and treatment of less common compartment syndromes of the upper and lower extremities: current evidence and best practices. Instr Course Lect. 2011;60:43–50.
49. Ojike NI, Roberts CS, Giannoudis PV. Foot compartment syndrome: a systematic review of the literature. Acta Orthop Belg. 2009;75:573–80.

# Bone Health and Orthopedic Surgery

25

Linda A. Russell

**Objectives**
- To introduce the concept of bone health.
- To appreciate the magnitude of bone disease and its implications to orthopedic surgery.
- To appreciate the evolving role for bone active therapies in the orthopedic setting.

**Key Points**
- Vitamin D levels at the time of an orthopedic procedure may affect outcome.
- Bisphosphonates may be beneficial after total joint arthroplasty.
- Medications used to treat osteoporosis may affect fracture repair.
- Teriparatide may improve the rate of bony fusion and outcome after spine fusion.
- Maximizing bone health preoperatively should be the goal for all orthopedic procedures.

## Introduction

Traditionally, orthopedists have not evaluated the quality of bone prior to orthopedic procedures. Nonetheless, in recent years an assortment of pharmacological agents targeting bone quality has been developed; the agents are in common use, mainly in the treatment of osteoporosis. Growing evidence suggests that the maximization of bone quality and health perioperatively will result in better surgical outcomes. This chapter reviews current knowledge concerning this clinical experience, examining specifically vitamin D, its putative role in orthopedic surgery; the use of various medications in the setting of total joint arthroplasty, in spinal fusion, and in the fracture repair is presented.

L.A. Russell (✉)
Department of Rheumatology, Hospital for Special Surgery,
535 E 70th Street, New York, NY 10021, USA
e-mail: Russelll@hss.edu

## Background

Osteoporosis is a common condition. One half of US women and ¼ of men over 50 years suffer an osteoporotic fracture during their lifetime, with more anticipated as the population ages. Many will require orthopedic procedures, including total joint arthroplasty, spinal fusion and procedures to address fracture, most significantly of the hip. To best care for these patients and to promote successful outcomes, efforts directed at the optimization of bone, both its strength and quality have become important perioperative imperatives. Nonetheless observations of contemporary orthopedic practice have shown how infrequently bone health is even evaluated. In perhaps the most important domain, the fracture setting, few patients currently receive bone-directed therapy; indeed 60 % of patients in one study were instructed to take calcium alone as a treatment for their osteoporosis [1, 2].

An osteoporotic fracture is defined as a fracture that results from a standing height or from a low energy activity (i.e., raking leaves). Although many patients feel that they fell so firmly that "anyone would have broken their wrist," patients must be educated about this fallacy as all will benefit from therapy for osteoporosis. Supporting the recommendation for treatment are observations that the strongest predictor of osteoporotic fracture is prior fracture and that treatment does work. Indeed medications for osteoporosis have been shown to reduce the risk of subsequent fracture within 6 months of their administration [3]. Thus, based on these observations, practices ensuring that a patient's bone health is addressed after osteoporotic fracture have been advocated [4].

The other important clinical domain also largely ignored in orthopedic practice and in the perioperative medicine literature is the preoperative evaluation of bone health in

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_25, 

patients undergoing orthopedic surgery. There are many ways in which poor bone health could affect surgical outcome. For instance in patients with low bone formation rates, fracture repair and bone fusion may be impaired. One of the more common and treatable causes of impaired bone formation is tobacco use. Tobacco is directly toxic to the osteoblast; therefore counseling patients on the importance of smoking cessation when undergoing orthopedic procedures is critical [5]. However, if the patient requires a smoking cessation aide, it should not be a nicotine product, as nicotine also impairs bone formation.

Patients should have an up-to-date bone density prior to undergoing an orthopedic procedure. The US Preventative Task Force recommends a bone density on all women 65 years of age (earlier if there are risk factors); no recommendations for assessment of bone density in men have been developed by this organization. Alternatively, the National Osteoporosis Foundation (NOF) recommends that all women have a baseline bone density at menopause and men at 70 years of age; earlier if there are risk factors. The current literature does not fully address the benefit of vitamin D and parathyroid hormone determinations preoperatively. Nonetheless it seems intuitive that for overall bone health, it would be advisable to insure normal vitamin D levels and an absence of hyperparathyroidism, prior to an orthopedic procedure.

Another modifiable risk factor includes the evaluation of balance in every patient, and in those with deficits, balance straining should be prescribed. The home environment should be inspected for falls risk, a procedure usually performed by a visiting nurse in conjunction with a physical therapist.

In patients with a history of an osteoporotic fracture or those who plan to undergo an orthopedic procedure, the medical history should be reviewed to assess both medical conditions and medications that predispose to poor bone health. Conditions known to be associated with poor bone health include hyperparathyroidism, diabetes, hypogonadism, hyperthyroidism, depression, fragility/inactivity, celiac disease, and multiple myeloma. Medications associated with poor bone health and osteoporosis include glucocorticoids, aromatase inhibitors, lupron/androgen inhibitors, lithium, and thyroid replacement resulting in oversuppression, common in patients with a history of thyroid cancer, thiazolidinediones, probably proton pump inhibitors, serotonin reuptake inhibitors, and many anti-seizure medications. Whenever possible, these problems should be addressed by employing such measures as using the lowest possible steroid dosage or through the aggressive treatment of poorly controlled diabetes. Recognizing such risk factors will, at a minimum, sensitize physicians that bone quality may be worse than expected. Indeed in patients with a *Z*-score more than one standard deviation below age-matched controls, a metabolic bone evaluation should be considered (Table 25.1).

**Table 25.1** Bone biomarkers

| Markers of bone formation | Markers of bone resorption |
|---|---|
| Osteocalcin | Urine N-telopeptide |
| Bone alkaline phosphatase | Serum C-telopeptide |
| P1NP | Urine C-telopeptide |

Although there are many as yet unanswered questions in the area of perioperative bone health, certain areas are emerging as topics for further study. Does the preoperative vitamin D level influence orthopedic outcomes? Does vitamin D repletion diminish the rate of falls? Does it improve timed walking distance? What influence does bisphosphonate therapy have on total joint arthroplasty? What are the potential effects of osteoporosis medications on fracture repair? What are the beneficial and detrimental effects of antiresorptive and anabolic therapy on spine fusion? These and other question are addressed in this chapter.

## Vitamin D and Orthopedic Procedures

Vitamin D is essential for bone development, skeletal remodeling, and fracture repair. An Institute of Medicine (IOM) report has recently recommended adult levels of 20 ng/ml or greater. In patients with osteoporosis, most experts argue that even higher levels are beneficial and that calcium and vitamin D intake should be sufficient to prevent secondary hyperparathyroidism (that leads to further bone loss).

A serum vitamin D level is the best indicator of adequate calcium and vitamin D intake in any given patient yet many questions exist concerning the optimal vitamin D level in the setting of orthopedic procedures. Does an adequate vitamin D level promote successful fracture repair and enhance fusion in spinal surgery? What about the effects of vitamin D in total joint arthroplasty? Do adequate perioperative vitamin D levels facilitate postoperative rehabilitation and prevent postoperative falls?

A retrospective review of 723 patients undergoing surgery at an orthopedic hospital revealed that 40 % of patients were vitamin D deficient by IOM standards with 25-OH vitamin D levels $\leq$ 20 ng/ml [6]. A smaller study in patients undergoing total hip and knee arthroplasty examined the association between bone mineral density (BMD), vitamin D, and osteoarthritis; 84.7 % of patients had a level of vitamin D $\leq$ 30 ng/ml with *T*-scores below $-2.5$, indicative of osteoporosis, demonstrated in 20 % of men and 23.2 % of women [7]. In a large prospective study the association between baseline vitamin D status, BMD, and the development of radiographic osteoarthritis of the knee, those with

the lowest levels of vitamin D at baseline had the most rapid progression of knee osteoarthritis [8]. In a study evaluating vitamin D level and attainment of in-hospital functional milestones after total hip arthroplasty, low vitamin D levels (≤32 ng/ml) did not compromise short-term functional outcomes [9]; therefore the authors concluded that surgery did not have to be postponed if a low preoperative vitamin D level was detected but vitamin D should be corrected postoperatively.

There is a considerable literature concerning the effect of vitamin D on muscle function. In general adequate vitamin D levels appear to promote muscle strength and balance, although all studies have not demonstrated a benefit. One study comparing a 3 month daily course of 5,000 IU was more effective at raising vitamin D levels when compare to 2,000 IUs; however, both doses showed trends in improvements in muscle strength [10]. Another study showed that 25-OH vitamin D levels of ≥ 20 ng/ml were needed for better muscle function and strength [11]. Also a recent review of vitamin D supplementation on muscle strength, gait, and balance in older adults demonstrated that supplemental vitamin D with daily doses of as low as 800–1,000 IU showed consistent beneficial effects on these parameters [12]. One other study of postmenopausal woman examined the effects of a three monthly oral 150,000 IU supplementation of cholecalciferol (verses placebo) on falls, mobility, and muscle strength failed to demonstrate benefit [13].

## Total Joint Arthroplasty

As many people who require a total joint arthroplasty (TJA) are older and therefore more likely to have low bone mass, the bone health of patients undergoing TJA has also come under scrutiny. In one observational study, DEXAs were performed on 199 patients, age 65–80 years, awaiting total knee and hip replacement. The overall rate of osteoporosis (any site) was 23 % while an additional 43 % had osteopenia [14]. Another, smaller ($n = 53$) study, examined the prevalence of osteoporosis in women scheduled for cementless total hip arthroplasty (THA); 28 % were osteoporotic, 45 % had osteopenia [15]. Thus the prevalence of low bone mass appears high (>2/3) in this patient population.

The clinical significance of this overall bone deficiency is compounded by observations concerning decreased bone density at the bone prosthetic (cement) interface. These conditions, acting in concert, raise concern that such poor bone stock may increase the subsequent risk of periprosthetic fracture. Though not frequently encountered, this postoperative complication is associated with significant morbidity. In order to address this issue, a group of investigators compared the periprosthetic BMD in patients undergoing cemented TKA to patients undergoing uncemented TKA. In both groups ($n = 30$ per group) bone density determinations at a median of 4 years after surgery was reduced at various periprosthetic sites, regardless of method of TKA [16]. The important point of this study is that, after TKA, there is a decrease in periprosthetic BMD perhaps due to disuse. Taking these observations another step, a population-based study examined the risk of peri-prosthetic fracture for 5 years after THA and TKA. The rate of fracture was as follows: 0.9 % after primary THR, 4.2 % after revision THR, 0.6 % after primary TKR, and 1.7 % after revision TKR. Fractures were more likely in females over the age of 70 years [17]. More recently it has been appreciated that during computer navigated TKA, a procedure in which pinholes are drilled in the femur and tibia for the placement of navigation trackers, fractures associated with these pin holes have been reported. One study postulates that the presence of osteoporosis serves to intensify stresses around the pinholes and may thereby increase the risk of fracture [18]. Further another study found that osteoporosis affected tibial component position in computer-assisted navigation TKA [19].

Also relevant to this discussion is the debate in the literature concerning the use of cement in THA. The current view is that in patients with normal bone quality, cementless THA is preferred as the patient's bone would readily integrate into a porous implant. In contrast, if a patient with poor bone quality received a cementless implant the risk of component migration prior to fixation has been felt to be significant. Further if revision THR is required, it tends to be easier to remove the implant if cement has not been used. Traditionally cement has been used in patients 50 years and older; currently, there is a trend to use cementless implants perhaps only in patients felt to have good bone quality intraoperatively, regardless of age. A recent study evaluated the quality of intertrochanteric cancellous bone as a predictor of femoral stem migration in THA. Intraoperative biopsy from the site of stem implantation was performed and subjected to structural analysis with μCT. Unexpectedly, the major differences observed in the quality of trochanteric cancellous bone had only a minor relationship to the migration of the femoral stems [20]. This is an area that requires much more orthopedic research because if there is early migration of the femoral component the patient will often need a revision procedure.

Resurfacing THA has gained in popularity for young patients who require THA, though most will ultimately require revision arthroplasty later. While there is better bone preservation in hip resurfacing as compared to THA, a major argument for this procedure, this advantage should be juxtaposed against the greater risk of femoral neck fracture after hip resurfacing. Thus patient selection for resurfacing arthroplasty should include the evaluation of a patient's bone health prior to surgery. Precise criteria are not yet well understood and the development of guidelines remains an important area of research. One group of investigators has shed light on

this problem. This work involves 20 postmenopausal (53–60 years) women with either osteoporosis or osteopenia by hip BMD. Surgery was delayed for 12 months in order to treat patients with a bisphosphonate, calcium, and vitamin D. Among the 12 patients who showed an improvement in BMD, resurfacing THA was performed. None subsequently suffered an intraoperative fracture [21]. The major importance of these observations is the need for a better understanding of the impact of bone health and specifically how it may affect outcome after TJA.

## Fracture

### Bisphosphonate Therapy

Fracture repair involves both bone resorption and bone formation and since bisphosphonates slow bone resorption, there is concern that they may negatively affect fracture repair. Several animal models of fracture healing have demonstrated that for fractures healing by enchondral ossification, bisphosphonates increase callus volume, trabecular bone volume, and bone mineral content, though delay the maturation and remodeling of the callus [22, 23]. Thus the initiation of callus formation appears unaffected by bisphosphonate therapy; however, once a calcified cartilage is formed, both its remodeling to woven bone and the subsequent remodeling to mature lamellar bone are delayed. This remodeling delay has not been considered to be clinically significant but clinical evidence is sparse [24]. From a prospective study, zoledronic acid given after hip fracture has been shown to reduce the risk of subsequent (hip) fracture, improve overall mortality, as well as improve quality of life [25]. This benefit was observed if the bisphosphonate was given within 2 weeks of hip fracture, however. Why this is so is not clear but the observation has prompted a recommendation to delay intravenous bisphosphonate therapy for up to 6 weeks after hip fracture repair, a caution that may not be true for oral bisphosphonates as they are given in divided doses rather than as a single yearly dose [26].

The effect of bisphosphonate therapy on stress fracture repair has not been well studied. Nonetheless, stress fractures mend through direct bone remodeling, a healing process unaffected by bisphosphonates [26]. Apropos of this observation it is therefore relevant that bisphosphonates do not prevent the deterioration of mechanical properties of rat bone subjected to repeated cyclic loading and, further, did not prevent stress fractures in military recruits during basic training [27, 28].

### Denosumab

Denosumab is a new antiresorptive agent approved for the treatment of osteoporosis; its mechanism of action is the slowing of osteoclast differentiation. In animal models of fracture healing, denosumab did not show significant effects on rate of fracture healing. Similar to the effect seen with bisphosphonate treatment, denosumab use was associated with increased callus volume and delayed remodeling. Mechanical properties were not compromised [29]. Its role in the setting of fracture remains unclear.

### Teriparatide

Teriparatide is a human derivative of parathyroid hormone. FDA approved for the treatment of postmenopausal osteoporosis, steroid-induced osteoporosis, and male hypogonadal osteoporosis, it is administered by daily, self-administered subcutaneous injection. As the first approved anabolic agent for the treatment of osteoporosis, it induces true bone formation on all bone surfaces including trabeculae, endosteal, and periosteal bone [30]. In animal models, supraphysiologic doses of PTH demonstrate increased fracture site strength and callus quality in treated animals [31]. To date, only one clinical trial assessing the potential role of parathyroid hormone in fracture repair has been conducted [32]. This study, in postmenopausal women, compared a 20 versus 40 mcg daily dosage in the setting of fracture of the distal radius. The 20 mcg daily dose, not the 40 mcg dose, demonstrated accelerated healing. Nonetheless, multiple case reports suggest accelerated fracture (acute and nonunion) healing in patients treated with teriparatide. Such clinical observation suggests differential benefit, more in trabecular bone than in cortical bone. Teriparatide may hasten pelvic fracture healing; a randomized study is under way.

## Spinal Fusion

Despite the large number of orthopedic spine surgeries performed worldwide, the effect of osteoporosis on the outcome of various spine procedures has not been well studied. In addition, the most widely used test to evaluate bone density, DEXA, often gives a falsely elevated bone density in an arthritic spine. While this is the case for many with degenerative spine disease, others have shown that patients with degenerative spine disease can have lower BMD than controls without degenerative spine disease [33]; this was attributed to less weight-bearing activity. This study also

demonstrated that patients with degenerative spine disease had higher levels of bone resorption; this has been correlated with a higher fracture rate.

There is concern that successful use of hardware in spine stabilization procedures will be compromised in patients with low bone mass. Bennett measured cadaveric vertebral bone densities using computed tomographic scans and correlated these findings to the measured bone densities [34]. While average BMD varied widely among the specimens, the average bone densities of the pedicle and of the vertebral body for individual specimens were well correlated. He demonstrated that the unstable spine can be stabilized using fixation, but the immediate stability provided by pedicle screws is greater in the lumbar vertebrae with the higher bone density.

So what is known about bone augmentative medications and spine surgery? Many animal studies suggest that bisphosphonate therapy may hinder spine fusion. Huang studied posterolateral lumbar fusion in rats in the setting of alendronate therapy demonstrating lower rates in the alendronate groups as compared to controls [35]. Despite the lower fusion rates, increased fusion mass area and optical density were noted with the alendronate groups. In addition, Sama et al. have looked at the effect of alendronate on osteoclast and osteoblast function in a pseudoarthrosis model in rats [36]; no notable differences between groups were reported. However, in animals receiving alendronate at supratheraputic doses, qualitatively limited histiological remodeling and poor osteoclastic and osteoblastic function was noted. The percent of osteoblasts per surface area were also lower in the high dose alendronate group, suggesting a possible negative effect on spine fusion. Another study demonstrated a decrease in fusion mass remodeling but not a decrease in fusion rate in a porcine model of posterior lateral spine fusion [37]. Babat looked at spine fusion in a rat model. Pamidronate, but not calcitonin, leads to a less mechanically robust fusion [38].

Other studies have demonstrated improved spine fusion or no effect, in patients receiving bisphosphonate therapy around the time of spine fusion. In a rabbit model, a single dose of zoledronic acid, in combination with iliac crest bone graft increased fusion-mass size and bone mineral content. There was also an increased fusion rate compared to animals that had iliac crest bone grafting alone [39]. Two recent publications by Xue demonstrated that alendronate treatment in a porcine model increased the bone purchase of stainless screws and did not inhibit bone formation within biphasic calcium phosphate ceramics [40, 41]. Nagahama looked prospectively at lumbar fusion in 40 patients with osteoporosis; bridging bone formation was more frequently observed in the alendronate group at all assessment periods. Specifically, at 1-year follow-up a solid fusion was achieved in 95 % of the patients in the alendronate group as compared to 65 % in the controls [42]. Nakao has also demonstrated that in an animal model, alendronate was effective for radiologic, biochemical, and histiologic success of spine fusion [43]. Another study looked at the effect of zoledronic acid and hyperbaric oxygen on posterior fusion in a rat model. Treatment improved radiographic, biomechanical, and histiologic outcomes.

O'Loughlin studied the use of parathyroid hormone [1–34] on a posterolateral rabbit spinal fusion model [44]. Animals treated with PTH had a significantly greater rate of fusion than controls (81 % vs. 30 %). Bone mass and histiologic determinants were also improved in the PTH group. Another study suggests teriparatide enhances histiologic spinal fusion in rats compared to controls and compared to calcitonin [45]. In postmenopausal women with osteoporosis, teriparatide enhanced lumbar posteroplateral fusion [46]. When teriparatide and bisphosphonate therapy were studies in the use of pedical screws, the incidence of pedicle screw loosening was less in the teriparatide group; the extent of pedicle screw loosening was similar in the risedronate group compared to controls [47]. Thus as teriparatide is FDA approved for the treatment of osteoporosis, it may also be appropriate for a select patient population undergoing spinal fusion. Additional studies are underway to assess the potential benefits of teriparatide in this surgical setting.

Taken collectively, although there is conflicting evidence of the effect of bisphosphonate therapy on spine fusion, there are enough human and animal data that suggests that bisphosphonate therapy can slow and impede bone fusion. This would not be surprising as fusion requires bone remodeling, i.e., both bone formation and bone resorption; bisphosphonates impede bone resorption and intellectually it is reasonable to hypothesize that bisphosphonates could impair bone fusion. Parathyroid hormone, an anabolic agent may enhance spinal fusion and appears to have positive effects on spine surgery outcome.

## The Clinical Assessment of Bone Health

Although our current biomarkers of bone turnover have limitations, the use of biomarkers in treatment decision-making can be helpful. Markers of bone formation include osteocalcin, bone alkaline phosphatase, and P1NP (Table 25.1). For example a patient may have a low rate of bone formation if on an antiresorptive for a prolonged period especially with ongoing tobacco use and in old age. A low rate of bone formation may lead the clinician to consider an anabolic agent, such as teriparitide. In this situation, teriparatide may foster spinal fusion and help in fracture repair; it may also help bone ingrowth into porous joint implants. Markers of bone resorption include urine *n*-telopeptide, serum C-telopeptide, and urine C-telopeptide. If a patient was found to have a high rate of

**Table 25.2** Fracture risk assessment tool FRAX®

| |
|---|
| Tool developed by WHO to evaluate fracture risk of patients |
| Gives 10-year probability of hip fracture and major osteoporotic fracture (clinical spine, forearm, hip or shoulder fracture) |
| *Variables* |
| Ethnicity |
| Age |
| Weight |
| Height |
| Previous fracture |
| History of parental hip fracture |
| Current tobacco use |
| Use of glucocorticoids |
| Rheumatoid arthritis |
| Secondary osteoporosis |
| Alcohol $\geq$ 3 units/day |
| Femoral neck BMD |
| Treatment with an FDA-approved medication for osteoporosis is recommended if the risk of overall fracture is $\geq$20 % or the risk of hip fracture is $\geq$3 % |

bone resorption, the clinician may opt to treat a patient with an antiresorptive agent, such as a bisphosphonate or denosomab. This would suffice after joint arthroplasty. Although, still an active area of research presently, it seems prudent to avoid antiresorptive agents until fractures have healed and spinal fusion completed, as antiresorptives may delay and prevent proper healing.

Treatment of low bone density should be strongly considered in all patients with osteoporosis and in patients with osteopenia who have an elevated FRAX®. FRAX®, an assessment tool developed by the World Health Organization, allows the clinician to import patient-specific information and calculates the overall risk of (any) fracture and the risk of hip fracture, over the next 10 years, if the patient is not treated for low bone mass. If the overall risk of fracture over the next 10 years is $\geq$20 % or risk of hip fracture is $\geq$3 %, treatment is indicated (Table 25.2).

Thus, the evaluation and treatment of bone health perioperatively should result in better outcomes. Recognizing that an important opportunity to address bone health is frequently missed, a consensus conference concerning this issue has been held. Entitled *Treatment of Osteoporosis for Orthopedic Surgeons*, the conference was an attempt to educate the orthopedic community concerning treatment options in osteoporosis [48]. Similarly the American Academy of Orthopedic Surgeons has adopted the "Own the Bone Program" the intent of which is similar [49]. Other approaches include a Fracture Liaison Service, dedicated to the evaluation and treatment of patients with fragility fractures [50]. Standing discharge orders have also been offered as a solution [51].

## Summary

Until recently bone health and its optimization was a concept associated mainly with the prevention and treatment of osteoporosis. Spurred on by an advancing science and pharmacology, the importance of this nascent field to orthopedics cannot be overstated. As discussed in this chapter, current interest is focused on problems arising in specific clinical settings, that of fracture repair, total joint arthroplasty, and in spinal fusion. Other applications are doubtless on the horizon. As essentially medical therapies, this area presents opportunities for an enhanced collaboration between orthopedics and internal medicine. Further it is likely to become an important content domain in the field of perioperative medicine where these considerations are, at present, under appreciated.

**Summary Points**

- The prevalence of vitamin D deficiency and diminished bone density is high in orthopedic populations and despite widely available therapy is largely ignored.
- The preoperative evaluation of bone strength and quality may improve outcomes after orthopedic procedures.
- Relevant clinical problems include fracture repair, total joint arthroplasty, and spinal fusion.
- Bone health as a concept is an emerging area with relevance to orthopedic surgeons and others involved in perioperative care.

## Case Studies

Case studies for this chapter are included in Appendix O at the end of this book.

## References

1. Smith MD, Ross W, Ahern MJ. Missing a therapeutic window of opportunity: an audit of patients attending a tertiary teaching hospital with potentially osteoporotic hip and wrist fractures. J Rheumatol. 2001;28(11):2504–8.
2. Castel H, Bonneh DY, Sherf M, Liel Y. Awareness of osteoporosis and compliance with management guidelines in patients with newly diagnosed low-impact fractures. Osteoporos Int. 2001;12(7):559–64.
3. Adachi JD, Rizzoli R, Boonen S, Li Z, Meredith MP, Chesnut 3rd CH. Vertebral fracture risk reduction with risedronate in postmenopausal women with osteoporosis: a meta-analysis of individual patient data. Aging Clin Exp Res. 2005;17(2):150–6.
4. Rebolledo BJ, Unnanuntana A, Lane JM. A comprehensive approach to fragility fractures. J Orthop Trauma. 2011;25(9):566–73.

5. Fini M, Giavaresi G, Salamanna F, et al. Harmful lifestyles on orthopedic implantation surgery: a descriptive review on alcohol and tobacco use. J Bone Miner Metab. 2011;29(6):633–44.
6. Bogunovic L, Kim AD, Beamer BS, Nguyen J, Lane JM. Hypovitaminosis D in patients scheduled to undergo orthopaedic surgery: a single-center analysis. J Bone Joint Surg Am. 2010;92 (13):2300–4.
7. Breijawi N, Eckardt A, Pitton MB, et al. Bone mineral density and vitamin D status in female and male patients with osteoarthritis of the knee or hip. Eur Surg Res. 2009;42(1):1–10.
8. Bergink AP, Uitterlinden AG, Van Leeuwen JP, et al. Vitamin D status, bone mineral density, and the development of radiographic osteoarthritis of the knee: the Rotterdam study. J Clin Rheumatol. 2009;15(5):230–7.
9. Unnanuntana A, Rebolledo BJ, Gladnick BP, et al. Does vitamin D status affect the attainment of in-hospital functional milestones after total hip arthroplasty? J Arthroplasty. 2012;27(3):482–9.
10. Diamond T, Wong YK, Golombick T. Effect of oral cholecalciferol 2,000 versus 5,000 IU on serum vitamin D, PTH, bone and muscle strength in patients with vitamin D deficiency. Osteoporos Int. 2013;24(3):1101–5.
11. Mastaglia SR, Seijo M, Muzio D, Somoza J, Nunez M, Oliveri B. Effect of vitamin D nutritional status on muscle function and strength in healthy women aged over sixty-five years. J Nutr Health Aging. 2011;15(5):349–54.
12. Muir SW, Montero-Odasso M. Effect of vitamin D supplementation on muscle strength, gait and balance in older adults: a systematic review and meta-analysis. J Am Geriatr Soc. 2011;59 (12):2291–300.
13. Glendenning P, Zhu K, Inderjeeth C, Howat P, Lewis JR, Prince RL. Effects of three monthly oral 150,000 IU cholecalciferol supplementation on falls, mobility and muscle strength in older postmenopausal women: a randomised controlled trial. J Bone Miner Res. 2012;27(1):170–6.
14. Lingard EA, Mitchell SY, Francis RM, et al. The prevalence of osteoporosis in patients with severe hip and knee osteoarthritis awaiting joint arthroplasty. Age Ageing. 2010;39(2):234–9.
15. Makinen TJ, Alm JJ, Laine H, Svedstrom E, Aro HT. The incidence of osteopenia and osteoporosis in women with hip osteoarthritis scheduled for cementless total joint replacement. Bone. 2007;40 (4):1041–7.
16. Kamath S, Chang W, Shaari E, Bridges A, Campbell A, McGill P. Comparison of peri-prosthetic bone density in cemented and uncemented total knee arthroplasty. Acta Orthop Belg. 2008;74 (3):354–9.
17. Meek RM, Norwood T, Smith R, Brenkel IJ, Howie CR. The risk of peri-prosthetic fracture after primary and revision total hip and knee replacement. J Bone Joint Surg Br. 2011;93(1):96–101.
18. Kim K, Kim YH, Park WM, Rhyu KH. Stress concentration near pin holes associated with fracture risk after computer navigated total knee arthroplasty. Comput Aided Surg. 2010;15(4–6):98–103.
19. Lee DH, Padhy D, Lee SH, Nha KW, Park JH, Han SB. Osteoporosis affects component positioning in computer navigation-assisted total knee arthroplasty. Knee. 2012;19(3):203–7.
20. Moritz N, Alm JJ, Lankinen P, Makinen TJ, Mattila K, Aro HT. Quality of intertrochanteric cancellous bone as predictor of femoral stem RSA migration in cementless total hip arthroplasty. J Biomech. 2011;44(2):221–7.
21. Popescu D, Ene R, Cirstoiu C. Resurfacing total hip replacement—a therapeutical approach in postmenopausal women with osteoporosis and hip arthrosis. J Med Life. 2011;4(2):178–81.
22. McDonald MM, Dulai S, Godfrey C, Amanat N, Sztynda T, Little DG. Bolus or weekly zoledronic acid administration does not delay endochondral fracture repair but weekly dosing enhances delays in hard callus remodeling. Bone. 2008;43(4):653–62.
23. Li J, Mori S, Kaji Y, Kawanishi J, Akiyama T, Norimatsu H. Concentration of bisphosphonate (incadronate) in callus area and its effects on fracture healing in rats. J Bone Miner Res. 2000;15 (10):2042–51.
24. Jorgensen NR, Schwarz P. Effects of anti-osteoporosis medications on fracture healing. Curr Osteoporos Rep. 2011;9(3):149–55.
25. Adachi JD, Lyles KW, Colon-Emeric CS, et al. Zoledronic acid results in better health-related quality of life following hip fracture: the HORIZON-recurrent fracture trial. Osteoporos Int. 2011;22 (9):2539–49.
26. Bukata SV. Systemic administration of pharmacological agents and bone repair: what can we expect. Injury. 2011;42(6):605–8.
27. Barrett JG, Sample SJ, McCarthy J, Kalscheur VL, Muir P, Prokuski L. Effect of short-term treatment with alendronate on ulnar bone adaptation to cyclic fatigue loading in rats. J Orthop Res. 2007;25(8):1070–7.
28. Milgrom C, Finestone A, Novack V, et al. The effect of prophylactic treatment with risedronate on stress fracture incidence among infantry recruits. Bone. 2004;35(2):418–24.
29. Gerstenfeld LC, Sacks DJ, Pelis M, et al. Comparison of effects of the bisphosphonate alendronate versus the RANKL inhibitor denosumab on murine fracture healing. J Bone Miner Res. 2009;24(2):196–208.
30. Friedl G, Turner RT, Evans GL, Dobnig H. Intermittent parathyroid hormone (PTH) treatment and age-dependent effects on rat cancellous bone and mineral metabolism. J Orthop Res. 2007;25 (11):1454–64.
31. Andreassen TT, Ejersted C, Oxlund H. Intermittent parathyroid hormone (1-34) treatment increases callus formation and mechanical strength of healing rat fractures. J Bone Miner Res. 1999;14 (6):960–8.
32. Aspenberg P, Genant HK, Johansson T, et al. Teriparatide for acceleration of fracture repair in humans: a prospective, randomized, double-blind study of 102 postmenopausal women with distal radial fractures. J Bone Miner Res. 2010;25(2):404–14.
33. Kim HJ, Lee HM, Kim HS, et al. Bone metabolism in postmenopausal women with lumbar spinal stenosis: analysis of bone mineral density and bone turnover markers. Spine (Phila Pa 1976). 2008;33 (22):2435–9.
34. Bennett GJ, Serhan HA, Sorini PM, Willis BH. An experimental study of lumbar destabilization. Restabilization and bone density. Spine (Phila Pa 1976). 1997;22(13):1448–53.
35. Huang RC, Khan SN, Sandhu HS, et al. Alendronate inhibits spine fusion in a rat model. Spine (Phila Pa 1976). 2005;30(22):2516–22.
36. Sama AA, Khan SN, Myers ER, et al. High-dose alendronate uncouples osteoclast and osteoblast function: a study in a rat spine pseudarthrosis model. Clin Orthop Relat Res. 2004(425):135–42.
37. Xue Q, Li H, Zou X, et al. The influence of alendronate treatment and bone graft volume on posterior lateral spine fusion in a porcine model. Spine (Phila Pa 1976). 2005;30(10):1116–21.
38. Babat LB, McLain R, Milks R, Ferrara L, Sohn MJ. The effects of the antiresorptive agents calcitonin and pamidronate on spine fusion in a rabbit model. Spine J. 2005;5(5):542–7.
39. Bransford R, Goergens E, Briody J, Amanat N, Cree A, Little D. Effect of zoledronic acid in an L6-L7 rabbit spine fusion model. Eur Spine J. 2007;16(4):557–62.
40. Xue Q, Li H, Zou X, et al. Alendronate treatment improves bone-pedicle screw interface fixation in posterior lateral spine fusion: an experimental study in a porcine model. Int Orthop. 2010;34 (3):447–51.
41. Xue QY, Ji Q, Li HS, et al. Alendronate treatment does not inhibit bone formation within biphasic calcium phosphate ceramics in posterolateral spinal fusion: an experimental study in porcine model. Chin Med J (Engl). 2009;122(22):2770–4.
42. Nagahama K, Kanayama M, Togawa D, Hashimoto T, Minami A. Does alendronate disturb the healing process of posterior lumbar

interbody fusion? A prospective randomized trial. J Neurosurg Spine. 2011;14(4):500–7.
43. Nakao S, Minamide A, Kawakami M, Boden SD, Yoshida M. The influence of alendronate on spine fusion in an osteoporotic animal model. Spine (Phila Pa 1976). 2011;36(18):1446–52.
44. O'Loughlin PF, Cunningham ME, Bukata SV, et al. Parathyroid hormone (1-34) augments spinal fusion, fusion mass volume, and fusion mass quality in a rabbit spinal fusion model. Spine (Phila Pa 1976). 2009;34(2):121–30.
45. Lehman Jr RA, Dmitriev AE, Cardoso MJ, et al. Effect of teriparatide [rhPTH(1,34)] and calcitonin on intertransverse process fusion in a rabbit model. Spine (Phila Pa 1976). 2010;35 (2):146–52.
46. Ohtori S, Inoue G, Orita S, et al. Teriparatide accelerates lumbar posterolateral fusion in women with postmenopausal osteoporosis: prospective study. Spine (Phila Pa 1976). 2012;37(23):E1464–8.
47. Ohtori S, Inoue G, Orita S, et al. Comparison of teriparatide and bisphosphonate treatment to reduce pedicle screw loosening after lumbar spinal fusion surgery in postmenopausal women with osteoporosis from a bone quality perspective. Spine (Phila Pa 1976). 2013;38(8):E487–92.
48. Johnell O, Kannus P, Obrant KJ, Jarvinen M, Parkkari J, Nordic Orthopedic Federation. Management of the patient after an osteoporotic fracture: guidelines for orthopedic surgeons—consensus conference on treatment of osteoporosis for orthopedic surgeons, Nordic Orthopedic Federation, Tampere, Finland 2000. Acta Orthop Scand. 2001;72(4):325–30.
49. http://www.ownthebone.org/.
50. McLellan AR, Gallacher SJ, Fraser M, McQuillian C. The fracture liaison service: success of a program for the evaluation and management of patients with osteoporotic fracture. Osteoporos Int. 2003;14(12):1028–34.
51. Skedros JG. The orthopaedic surgeon's role in diagnosing and treating patients with osteoporotic fractures: standing discharge orders may be the solution for timely medical care. Osteoporos Int. 2004;15(5):405–10.

# Perioperative Care of the Complex Spine and Scoliosis Surgery Patient

26

Darren R. Lebl and Michael K. Urban

**Objectives**

- To explore the complex nature of modern spine surgery and to understand the need for a multidisciplinary team approach to the care of the spine surgery patient.
- To review the risk factors for complications associated with spine and scoliosis surgery with special considerations to the increased risk of complications involving the cardiopulmonary system.
- To review the usefulness of intra-operative neurologic monitoring and the special anesthetic considerations imposed by this monitoring.
- To review strategies for blood management in complex spine and scoliosis surgery.
- To explore the approaches to postoperative pain management and rehabilitation.

**Key Points**

- Modern spinal surgery can range from relatively simple ambulatory micro-discectomy to complex anterior, lateral, and/or posterior approaches to deformity correction and spinal fusion. Patients are best served by a multidisciplinary team including surgeons, perioperative medical specialists, intensivists, subspecialty trained anesthesiologists, nursing, and physical therapy.
- Complications are an unfortunately intrinsic reality of complex modern spine surgery in a subset of patients. Complications are observed more commonly as the complexity of the surgery is increased as well as in patients with preoperative medical comorbidities. Cardiopulmonary complications are the most common necessitating careful preoperative evaluation and optimization.
- Intra-operative neurologic monitoring has become the standard of care and has benefitted from recent technological advances such as the ability to monitor motor-evoked potentials (MEPs). Specialized anesthetic techniques including total intravenous anesthesia may improve the accuracy and effectiveness of the monitoring.
- Postoperative vision loss occurs infrequently following complex and prolonged spinal procedures. The most common cause is ischemic optic neuropathy. The etiology of postoperative ION at present is unknown and unpredictable. However, several possible pathogenic factors have been suggested including: duration in the prone position, blood loss, anemia, hypotension, abnormal optic nerve blood supply, low cup-to-disc ratio, use of vasopressors, excessive crystalloid infusion, and patient comorbidities; particularly smoking, diabetes, and vascular disease. The ASA practice advisory on POVL recommends the use of both colloids and crystalloids to maintain intravascular volume in spine surgery patients who have substantial blood loss. Since ION occurs in the absence of vascular injury to other critical organs and in cases where neither hypotension or anemia are reported, optic nerve blood supply may be uniquely vulnerable to hemodynamic perturbances in the prone position.

D.R. Lebl (✉)
Department of Orthopaedic Surgery, Hospital for Special Surgery, 535 E70th Street, New York, NY 10021, USA
e-mail: drlebl@stanfordalumni.org

M.K. Urban
Department of Anesthesiology, Hospital for Special Surgery, 535 E70th Street, New York, NY 10021, USA

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_26, © Springer New York 2014

- Blood management should include preoperative autologous donation. Antifibrinolytic agents have been demonstrated to be a useful adjunct in reducing perioperative blood loss.
- Pain management can be a challenging problem for the complex spine patient. Patient controlled intravenous analgesia is associated with higher patient satisfaction. Specialized pain management teams will often provide for better resource and pain management utilization.

## Introduction

The modern practice of spinal surgery and therefore the associated perioperative considerations may encompass a wide spectrum of procedures ranging from outpatient microdiscectomies for acute disk herniations to complex reconstructive surgery for spinal deformities requiring postoperative critical care. These procedures may involve anterior approaches to the cervical spine, posterior decompression, and instrumentation at the base of the skull, thoracotomy, trans-abdominal/retroperitoneal exposures, or extensive dissection of the posterior spinal musculature with corrective osteotomy to name a few. As such, the optimal surgical treatment of spinal disorders requires not only a detailed understanding of the anatomy of the axial skeleton from all perspectives but may also require inter-disciplinary collaboration between surgical, anesthesia, medical, nursing, ENT, and physical therapy teams.

Complications after spinal surgery are associated with surgical complexity, age of the patient and preexisting comorbidities [1–3]. In a large database of mandatory surgeon morbidity and mortality reporting by its member surgeons, the Scoliosis Research Society identified a series of complications in 108,419 spinal operations. Patients with higher American Society of Anesthesiology (ASA) grades were found to have significantly higher morbidity [4]. New neurologic deficits were identified to occur more commonly in revision cases (1.25 %) than primary cases (0.89 %), and more often in pediatric procedures (1.32 %) then adult (0.83 %) [5]. In the adult scoliosis patient, an overall complication rate of 13.4 % was found, most commonly a dural tear (2.9 %), and higher complication rates have been found in patients requiring osteotomies, revision surgery, and/or combined anterior-posterior surgery [6]. Of the 23,918 pediatric cases reported in the database, the most common medical complications were respiratory (0.9 %) and these were also the most likely cause of mortality.

Complications are unfortunately an intrinsic reality of spine surgery for a small subset of patients. Both patient and clinician demand for improved clinical outcomes have created driving forces towards less invasive, faster, cheaper, and now biologically augmented spinal surgery. Patient age, cardiac disease, preoperative neurologic abnormality, prior wound infection, corticosteroid use, history of sepsis, and prolonged operative times have been found to be independent risk factors for complications [7]. The avoidance of complications and successful surgical treatment of patients with spinal disorders begins with a thorough preoperative evaluation and planning.

## Preoperative Evaluation

The extent of preoperative evaluation is a function of the individual patient age, presentation, diagnosis, and comorbidities. For instance, the polytrauma patient with spinal fracture or dislocation has a high associated rate of intra-abdominal injury, pulmonary contusion, long-bone fracture, etc. Patient care in this setting requires effective communication between the various consultant services and is usually coordinated by the trauma surgical team. Oncology patients pose a unique set of considerations and risk profile as well. The most frequent spinal tumor in the spine is metastatic spread from a distant primary tumor which may be accompanied by impairment in visceral organ function or immunosuppression from chemotherapeutic treatment. Prior to consideration of spinal surgical intervention, an organ system-based approach may help minimize the patient's perioperative risk.

## Cardiac Risk

A major risk factor for perioperative mortality after orthopedic surgery (including spine surgery) is advanced age, and the most common organ system involved in perioperative complications is cardiac [1, 8, 9]. The reported incidence of a postoperative myocardial infarction (PMI—elevated Troponin I) after non-ambulatory orthopedic surgery is relatively low at 0.6 %. However, in the patient population with preoperative cardiac risk factors the incidence increases to 6.5 % [9]. The patient population with the highest risk for PMI is the one undergoing posterior spinal fusion. Long posterior spinal fusion constructs may be associated with relatively high blood loss and perioperative fluid shifts, not to mention catecholamine surge from postoperative pain [10]. These factors may be additive in the perioperative stress response leading to tachycardia, hypertension, increased oxygen demand, and ultimately myocardial ischemia.

The preoperative assessment of patient cardiac functional status is often limited due to musculoskeletal limitations in patient mobility. Limited data are available that preoperative risk stratification and/or coronary revascularization may have an effect on postoperative outcome. A recent report by Salerno et al. [8] suggested that preoperative abnormal noninvasive cardiac testing rarely changed medical management prior to orthopedic surgery. The Decrease-II study questioned the value of preoperative cardiac testing in patients of intermediate risk before noncardiac surgery [11]. In the CASS registry, Eagle reported that CABG surgery offered no advantage before orthopedic surgery in reducing cardiac mortality [12]. Similar results have been obtained using percutaneous coronary intervention (PCI). According to previous reports, PMI and death have not been reduced for non-cardiac surgery in patients at cardiac risk when preceded by PCI [13, 14]. Furthermore, in patients in which PCI includes stenting, there are the added risks of restenosis and thrombosis if antiplatelet therapy is discontinued before surgery and perioperative bleeding if they are not discontinued [15]. Patients who have been revascularized with drug eluting stents (DES) may require treatment with dual anti-platelet medication for at least 1 year, which may make it necessary to delay elective spinal surgery. For non-DES the required period for dual anti-platelet therapy is shortened to about 2 months. In all cases, low dose aspirin may need to be continued perioperatively when bleeding risk at the surgical site is low.

Preoperative cardiac testing and revascularization have not been conclusively shown to lower postoperative cardiac morbidity; however, hemodynamic stress reduction may minimize the risk of cardiac event perioperatively. Numerous studies have indicated that the use of perioperative β-blockers can reduce myocardial ischemia and PMIs [11, 16, 17]. Recent reports have questioned the efficacy of β-blockers in preventing postoperative cardiac complications, particularly in patients at intermediate risk [18, 19]. In patients on chronic β-blockers therapy, continuation of β-blockers may have benefit and in patients at high cardiac risk, β-blockers may be initiated with a target heart rate of less than 80 beats per min [17, 20].

## Pulmonary Optimization

Pulmonary complications are also relatively common following major spine surgical procedures. Prolonged intubation, prone positioning, long operating times, and advanced age may predispose patients to postoperative pulmonary issues. With each decade of life, a progressive decrease in arterial oxygen tension, an increase in closing volumes and a decrease of approximately 10 % in FEV1 occurs. These time dependent changes may be influenced by alterations of chest wall mechanics, which can be exacerbated in the elderly patient with osteoarthritic spinal pathology. Patients with preexisting pulmonary disease, such as chronic obstructive pulmonary disease (COPD), are at elevated risk of postoperative pulmonary complications [21]. Preoperative spirometry in this population may have limited value with the exception of patients with severe COPD in which the surgical procedure is extensive or involves thoracotomy [22]. Patients with reactive airway disease such as asthma or a broncho-spastic component to their COPD may benefit from bronchodilator therapy. Cigarette smoking not only increases the risk of postoperative pulmonary complications but also has a clear negative impact on the success of spinal fusions and wound healing [23]. Patients are encouraged to stop smoking at least 8 weeks prior to surgery in order to reduce the risk of pulmonary complications to that of nonsmokers [24].

Patients with spinal deformities, large main thoracic idiopathic scoliosis, may have a reduced chest cavity volume with decreased chest wall compliance and restrictive lung disease. These patients are at an increased risk for pulmonary complications [25]. Preoperative exercise tolerance provides a functional assessment of pulmonary function; however, formal pulmonary function tests (PFTs) provide objective quantification of the extent of disease. PFTs may guide the surgical and anesthesia teams regarding the extent of surgery, considerations for staged procedures, and the potential requirement for postoperative ventilatory support. A vital capacity of less than 40 % of normal is predictive of the necessity for postoperative ventilation. In this setting, arterial blood gases may reveal hypoxemia secondary to ventilation–perfusion inequalities caused by alveolar hypoventilation, elevated pulmonary vascular resistance, and may ultimately result in cor pulmonale. An echocardiogram to evaluate for pulmonary hypertension and right ventricular hypertrophy (RVH) in spinal deformity patients may reveal moderate to severe pulmonary hypertension which may require the surgeon consider curtailing the invasiveness of the planned procedure or staged procedure options [26].

## Perioperative Glycemic Management

Patients with diabetes are not only at increased risk for perioperative complications from associated comorbidities (myocardial ischemia, vascular disease), but also have a higher incidence of postoperative infection and death from sepsis [27, 28]. Although tight perioperative glucose control has been advocated to reduce these complications, more recent reports suggest that non-fluctuating glucose levels below 200 mg/dl may be safer [28–30]. Our institutional policy is that HgbA1C >10 is a hard stop for elective spinal

surgery, and recent data suggest that even lower levels with further minimize the risk of perioperative infection [31].

## Intubation and Airway Considerations

Cervical spine instability, severe cervical stenosis, thoracic hyperkyphosis with compensatory cervical hyperextension, and advanced cervical spine spondylosis are a few examples of spinal pathologies that may make routine tracheal intubation challenging. Awake, sedated fiberoptic intubation of many of these patients is the safest approach to general anesthesia. These patients are intubated first with a flexible fiberoptic bronchoscope under light sedation, then positioned prone for surgery and then spinal cord integrity is assessed with voluntary movements of both upper and lower extremities before the induction of general anesthesia. Baseline neuromonitoring potentials both before and after prone positioning can be utilized assess any potential cervical injury during the positioning process itself.

Patients with rheumatoid arthritis (RA) and achondroplasia have a high incidence of occipitocervical instability and deserve focused preoperative consideration (Fig. 26.1a–f). Patients with ankylosing spondylitis (AS) have a high rate of occult fracture and altered biomechanics resulting in highly unstable fracture patterns. Anterior subluxation of C1 on C2 (atlantoaxial subluxation) may occur in up to 40 % of patients with RA, with symptoms of progressive neck pain, headache, and myelopathy. Basilar invagination/vertical migration of the odontoid process inside of the foramen magnum may also be associated with RA, degenerative processes, or infection. Gross movement of the head in the presence of occipitocervical instability may result in the displacement of the odontoid process into the cervical spine and medulla, compression of the vertebral arteries, and catastrophic sequelae such as quadriparesis, spinal shock, and death.

When possible, preoperative cervical spine flexion–extension radiographs may provide preoperative information about the stability of the occipitocervical complex. Awake fiberoptic tracheal intubation may be performed with the cervical spine protected in a hard cervical collar during the procedure. Additionally, systemic inflammatory conditions such as AS may present additional challenges to intubation due to the reduced movement of both the cervical spine and TMJ joint. Increased rigidity of the thoracic spine in cases of AS may present additional challenges and may require intraoperative controlled mechanical ventilation. The syndromic spine patient or congenital spine patient such as certain Klippel-Feil subtypes or achondroplastic dwarfs also deserve special consideration prior to intubation. Conventional laryngoscopy and tracheal intubation may be both difficult and dangerous in this patient population. Awake fiberoptic tracheal intubation is the safest approach to securing the airway in these patients. Once the airway is secured, dwarfs can still represent an anesthetic challenge secondary to restrictive lung disease and pulmonary hypertension.

## Preoperative Assessment of Bone Health

Osteoarthritis is a disease of the aging, affecting 70 % of adults over 55 years old in the western world. Hence older patients with multiple comorbidities are more likely to have spinal conditions requiring surgery for degenerative spondylotic processes. It is the author's preferred practice to order DEXA bone density studies on all female patients over age 55 and all male patients over age 65 prior to consideration for any instrumented spinal procedures. Rigid implant fixation systems may be problematic in the setting of low bone density with high potential for implant subsidence, screw pullout, and peri-implant fracture. Collaboration with a metabolic bone specialist and preoperative assessment of Vit D and Ca levels, NTX, and consideration for medical management, e.g., teriparatide (TPTD) 1,34, PTH prior to any spinal surgery. TPTD has been shown to stimulate new bone formation and shift the bone homeostasis pathways towards a positive bone balance with increased bone mass [32–34]. Delay of spinal fusion procedures may be required for up to a year or more while the substrate bone mineral density is optimized such that rigid fixation and stabilization may be safely obtained.

## Anterior Thoracic Spine Surgery

Surgical spinal corrections involving high anterior thoracic levels or video-assisted thorascopic surgery (VATS) may require the isolation of one lung (OLV). OLV has been traditionally achieved with a double-lumen endotracheal tube (ETT). In single-staged anterior then posterior spinal fusions, before the postoperative procedure the double-lumen ETT should be replaced with a single-lumen ETT. Transthoracic interbody cages have been placed in recent years with newer less invasive techniques and may require this anesthetic technique [35]. A single-lumen ETT with an enclosed bronchial blocker can also provide OLV, but has the advantage of being left in place as a single-lumen ETT with the blocker deflated at the end of the anterior procedure [36]. In patients with restrictive lung disease adequate oxygenation may be difficult during OLV and may require CPAP to the non-ventilated lung and PEEP to the ventilated lung.

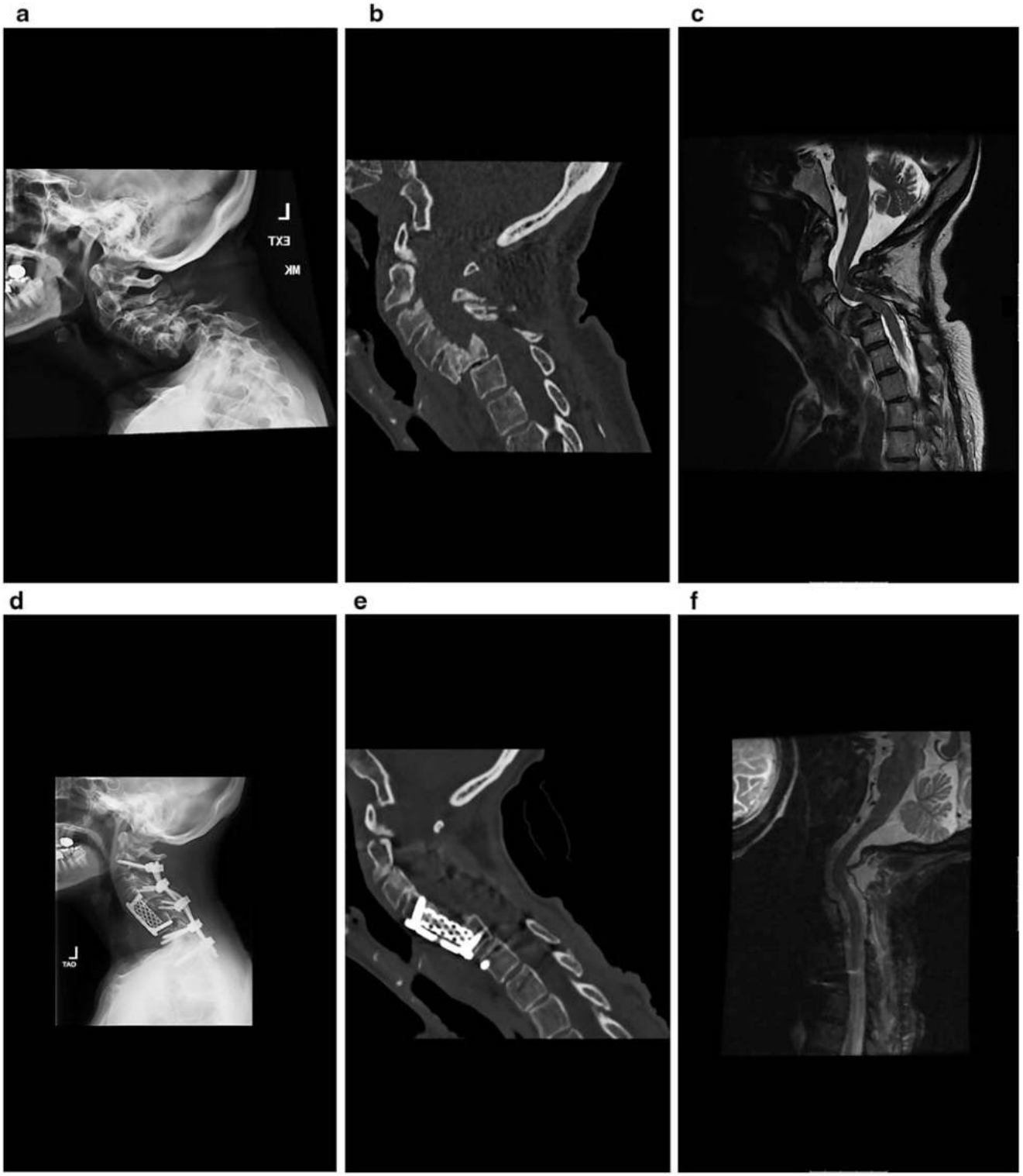


**Fig. 26.1** 70-year-old rheumatic female with spontaneous subaxial cervical spine dislocation requiring preoperative Gardner-Wells Tong traction, anterior cervical corpectomy, and cage reconstruction with posterior decompression and fusion. Preoperative lateral cervical spine X-ray (**a**), CT scan (**b**), and MRI scan (**c**), and postoperative images (**d–f**)

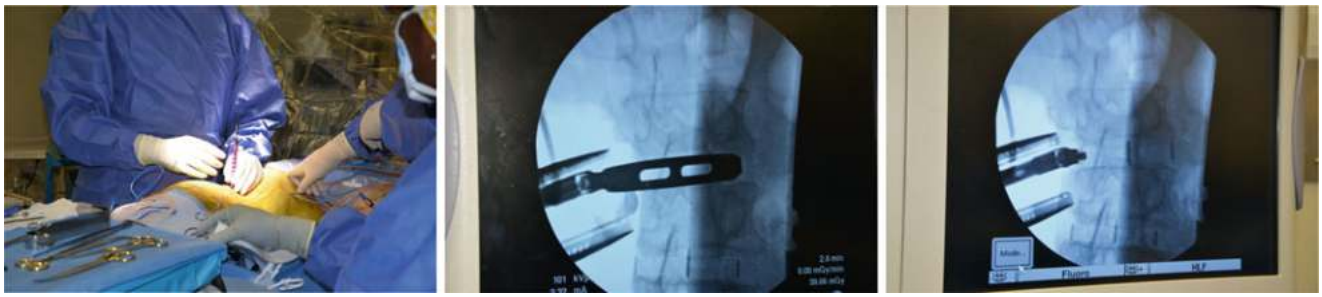

**Fig. 26.2** Placement of percutaneous dilators through minimally invasive retroperitoneal approach (left), trialing of intervertebral disk space after complete diskectomy (middle), and placement of interbody cage (right)

## Positioning

The careful positioning of patients for spinal surgery is an important shared responsibility of the anesthesiologist and surgeon. As stated previously, patients at risk for spinal cord compression may be best positioned under light sedation, then observed for upper and lower extremity movement prior to inducing general anesthesia. Prone positioning on a Hall-Relton frame allows the abdominal contents to hang freely to reduce venous pressure with four-poster pads on either iliac crest and the anterior chest wall (with care to leave the axillae free from compression).

Complex spinal deformity procedures will often require both anterior and posterior approaches to the spine. For a low lumbar-sacral anterior lumbar interbody fusion (ALIF) approaches, the patient is supine with their legs spread widely apart. Since pelvic retraction during this procedure may compromise blood flow to the legs, a pulse oximeter may be placed on a toe. Anterior thoraco-lumbar procedures are usually positioned in the lateral decubitus position with an axillary support and attention must be focused on the dependent arm and leg, and the position of the neck.

Lateral access/retroperitoneal minimally invasive procedures for lumbar interbody fusion are being performed on an increasingly widespread basis. A report of 600 transpsoas cases recently identified perioperative complications in 6.2 % of patients including surgery-related events in 1.5 %. These unique complications of this approach will need to be weighed with the purported benefits of decreased blood loss, shorter hospital lengths of stay and operative times, and improved interbody bone support on the outer apophyseal ring. Vertebral body fracture [37], approach-related hip flexor trauma, ipsilateral [38], and contralateral neurologic deficits [39] have been reported to occur and require careful preoperative consideration of both bone quality and neuroanatomy. Positioning with the hip and knee slightly flexed will reduce the tension on the psoas and lumbosacral plexus to help minimize the risk of iatrogenic neurological deficit during placement of percutaneous dilators on the lateral lumbar disk spaces (Fig. 26.2).

## Intraoperative Neurological Evaluation

Stagnara [40] introduced the concept of a "wake-up text" during spinal surgery to determine spinal cord function intraoperatively. The Stagnara wake-up test is limited to gross motor movements of the lower extremities and can be influenced by anesthetics and the cognitive responsiveness of the patient. In addition, the potential for inadvertent extubation during movement in the prone position or air embolism during a deep inspiration exist.

Multimodal intraoperative monitoring has become the standard of care for complex reconstructive spinal surgery in recent years [41]; somatosensory (SSEP), MEP, and EMG monitoring are options. EMGs may be used to monitor nerve root impulses during pedicle screw insertion, spinal deformity corrective maneuvers, and neurological decompressions. The posterior, sensory, portion of the spinal cord is evaluated using SSEP monitoring. MEPs assess the integrity of the motor portions of the anterior cord (e.g., corticospinal tracts). There are several potential adverse effects of MEP monitoring, including cognitive deficits, seizures, bite injuries, intraoperative awareness, scalp burns, and cardiac arrhythmias. A soft bite block may be employed during MEP monitoring to prevent tongue biting and dental injury. MEP monitoring avoidance is recommended in patients with active seizures, vascular clips in the brain, and cochlear implants. SSEPs involve sending an electrical impulse from a peripheral nerve that is subsequently measured centrally as a cortical response. Conversely, MEPs involve an impulse that is triggered in the brain and monitored as movement of a specific muscle group in the trunk or extremities. SSEPs and MEPs are evaluated with regard to amplitude and strength of the electrical signal and latency, and duration of time it takes the signal to travel through the nerve and spinal cord. These data are then compared to the patient's perioperative, nonsurgical baseline values to make conclusions about any untoward intraoperative event.

A number of physiological factors may attenuate SSEP and MEP monitoring, including hypotension, hypothermia,

hypocarbia, hypoxemia, anemia, and anesthetics. The potent inhalational agents reduce the amplitude and increase the latency of spinal cord monitoring. In addition potent inhalational agents reduce systemic vascular resistance and act as negative inotropes, which can contribute to hypotension and reduced tissue perfusion. If an inhalational agent is used for the anesthetic, the concentration should be kept at about half MAC (minimum alveolar concentration) and at a constant blood concentration throughout the procedure. Nitrous oxide is a preferred inhalational anesthetic since it provides amnesia and can be eliminated rapidly; however, it produces a decrease in the amplitude of the signal during MEP monitoring. Furthermore, nitrous oxide is poorly tolerated in patients with preexisting pulmonary hypertension and restrictive lung disease. Total intravenous anesthesia (TIVA) has been used successfully for both MEP and SSEP monitoring. MEPs are the least affected by narcotics, midazolam, and ketamine, but are depressed by propofol. However, the depressant effect of propofol can be diminished with ketamine. Ketamine, an NMDA antagonist (*N*-methyl-D-aspartate) will also reduce narcotic requirements and may prevent postoperative hyper-analgesia. The best TIVA anesthetic for complex spinal procedures then would include an infusion of a synthetic narcotic (fentanyl, remifentanil), ketamine at subanesthetic doses to potentiate the effects of the narcotic and reduce the MEP-negative effects of the intravenous anesthetic and propofol [42, 43].

Muscle relaxants are usually not administered during MEP monitoring, but a low concentration infusion may be employed to reduce the background "muscle noise" degrading the SSEP signal. This TIVA anesthetic should provide hemodynamic stability and not contribute to the attenuation or loss of spinal cord monitoring during the procedure. Then if a problem occurs with spinal cord monitoring, other causes can be investigated, including hypotension, hypothermia, hypocarbia, anemia, and surgical correction. At this point the TIVA can be rapidly eliminated and the "wake-up" test performed. In most spinal corrective surgery a stable intravenous anesthetic should provide the environment for reliable spinal cord monitoring and eliminate the need for a "wake-up" test.

## Intraoperative Hemodynamic Management

Complex spine surgery, particularly corrective deformity surgery, may be associated with high blood loss and large volume shifts perioperatively. Multiple factors have been suggested to influence the magnitude of this blood loss, including surgical technique, operative time, number of vertebral levels fused, anesthetics, mean arterial blood pressure, platelet abnormalities, dilutional coagulopathy, and primary fibrinolysis [44]. Several techniques have been employed to reduce this blood loss and limit the need for homologous blood transfusions: proper positioning of the patient to reduce intra-abdominal pressure; surgical hemostasis; deliberate controlled hypotensive anesthesia; reinfusion of salvaged blood; intra-operative normovolemic hemodilution; the use of pharmacological agents which promote clot formation; and the preoperative donation of autologous blood. Although widely practiced in the United States, the predonation of autologous blood for these procedures suffers from several disadvantages: patients often are anemic on the day of surgery; the pre-donation and storage of autologous blood is expensive; it does not eliminate the risk of a patient receiving the "wrong" unit of blood; blood is stored as packed RBCs, which eliminates coagulation factors; and if the surgery is rescheduled the stored unit may expire. Predonation of blood in combination with erythropoietin injections to restore a normal hemoglobin has been shown to be effective in some studies [45]. In patients with normal preoperative hematocrits, whole blood can be removed in the operating room prior to surgery and replaced with colloid or crystalloid such that the patient remains normovolemic [46]. This technique permits a reduction in red cell mass intraoperatively and the blood which has been removed contains platelets and coagulation factors not present in stored packed red blood cells. In patients undergoing posterior lumbar fusions this technique has been shown to reduce the need for additional blood transfusions [44].

Synthetic lysine analogues, such as Aminocaproic acid and Aprotinin, a polypeptide with serine protease inhibitor activity, have also been used to limit blood loss during these procedures by reducing fibrinolysis [47]. In a randomized control trial comparing Amicar and Aprotonin to reduce blood loss during sequential anterior-posterior reconstructive spinal surgery, the Aprotinin group had a significant reduction in blood loss, transfusion requirements, and postoperative respiratory complications. The authors suggested that the anti-inflammatory effects of Aprotinin may have contributed to the reduction in lung injury. However, several studies have questioned the safety profile of Aprotinin which is not available except under specific requests [48]. Recently, recombinant-activated Factor VII has been shown to reduce blood loss and transfusion requirements during spine surgery [49]. Concerns with this agent still exist with regard to the cost–benefit ratio and the potential for promoting thrombosis.

Controlled hypotensive anesthesia has become the standard of care in limiting blood loss during idiopathic scoliosis corrections in adolescents, but must be used with caution in older patients [50] (Fig. 26.3a, b). In a young healthy patient an MAP of 50–60 mmHg is well tolerated, but higher pressures may be required in the adult population with cardiovascular disease. In addition, perfusion of the spinal cord during deformity correcting surgery may by exquisitely

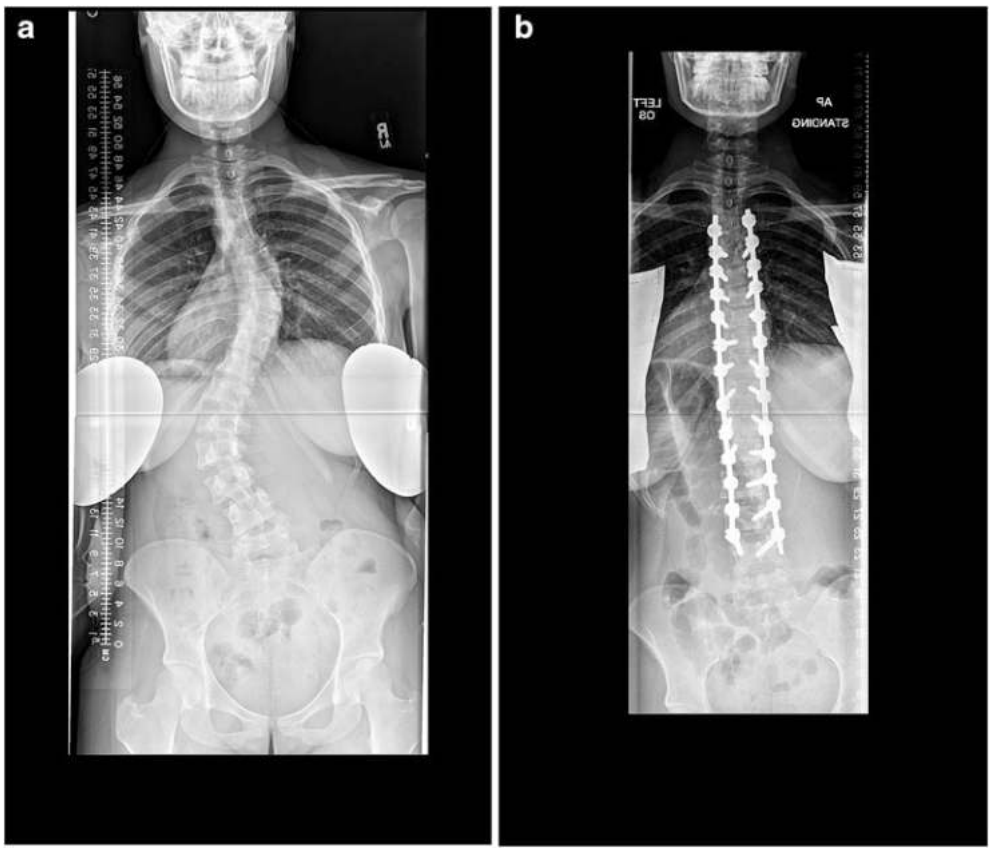


**Fig. 26.3** 19-year-old female with double major idiopathic scoliosis preoperatively (**a**) and after posterior spinal fusion (**b**)

sensitive to low perfusion pressures. Furthermore, the adequacy of end organ perfusion may be difficult to predict. Hypotension is usually achieved through a direct acting α-blocker, such as sodium nitroprusside. However, this often triggers a reflex tachycardia which may also be indicative of anemia, hypovolemia, or "light anesthesia," hence the combined use of an alpha and β-blocker for hypotensive anesthesia reduces the risk of myocardial ischemia and ameliorates rennin release with concomitant pressure rebound once the surgery has terminated. The use of a calcium channel blocker, nicardipine, eliminates the problem of reflex tachycardia and in a few studies demonstrated reduced intraoperative blood loss [47, 51]. Nitroprusside has a more pronounced effect on venous dilatation and this venous congestion may in some circumstances contribute to greater blood loss.

The role of the anesthesiologists during complex spine surgery is to maintain end organ perfusion despite large blood losses in an attempt to prevent complications such as spinal cord ischemia, renal failure, myocardial ischemia, stroke, and ION. The consequence of replacing assumed perioperative deficits with large volumes of crystalloid solution, however, can also result in severe complications [52]. How, then, is end organ perfusion best achieved during complex spine surgery? Theoretically the adequacy of end organ perfusion can be estimated with invasive monitoring, urine output and periodic arterial blood gas (ABG) analysis looking for evidence of metabolic acidosis. Despite the ubiquitous use of central venous pressure (CVP) monitoring during large blood loss procedures, the majority of the published literature suggests a poor correlation between CVP and blood volume and the inability of changes in CVP to predict the hemodynamic response to a fluid challenge [53]. Volume resuscitation with a pulmonary artery catheter (PAC) has been shown to be beneficial during adult reconstructive spinal surgery [54]. However, multiple published reports have questioned the value of PAC monitoring [55]. Oliguria during corrective spinal surgery may be a consequence of excess antidiuretic hormone release rather than hypovolemia [56]. Therefore, attempts to increase urine output intraoperatively may result in excessive fluid administration. ABG and central venous blood gas analysis provide information regarding tissue oxygenation requirements and perfusion [57]. At 6 h into the operation, with an estimated blood loss (EBL) of about 4 L, the hemodynamic parameters (MAP and HR) remain relatively stable and the hemoglobin concentration of 8 g/dl should be more than adequate to provide the tissues with sufficient oxygen. However, both the ABG which reveals a metabolic acidosis and

the reduced central venous oxygen saturation indicate poor tissue perfusion. Patients can be successfully resuscitated at this point, although evidence exists that a deleterious physiological response to under perfusion has already been triggered [58, 59]. These patients develop an SIRS-like pattern (systemic inflammatory response syndrome) which manifests itself as acute lung injury (ALI), systemic hypotension, multiple organ dysfunction, and coagulopathies. This syndrome can be quantified by the release of inflammatory cells in lung alveoli and both pulmonary and systemic increase in cytokines. The inflammatory response correlated with the magnitude of blood loss and severity of ALI.

Recently, clinicians have been investigating newer methods to determine tissue perfusion and fluid responsiveness (physiological assessment of intravascular fluid requirements). Devices which measure arterial pulse pressure variation and provide noninvasive cardiac output measurements have demonstrated utility in tracking fluid responsiveness during large blood loss procedures [60]. In hypovolemic patients, large changes in arterial pulse pressure variation will occur because of a decline in right ventricular preload, a relative increase in right ventricular afterload and a decrease in systemic vascular resistance [61]. When the Edwards Lifesciences™ Vigilo/Flo Trac (Irvine, CA) device was used to assess and track stroke volume variation (SVV) during a large blood loss spinal procedure, the SVV increased prior to changes in oxygenation tissue perfusion use of such monitors may permit early intervention and volume resuscitation, before an SIRS has been initiated.

## Postoperative Visual Loss

In addition to postoperative neurological deficits, postoperative visual loss (POVL) is another devastating complication of spinal surgery. POVL has been reported to be as high as 0.2 % and as low as 0.028 % in a large surgical population from a single hospital [62, 63] after spinal surgery. In the US Nationwide Inpatient Sample from 1996 to 2005 the prevalence rate of POVL after spinal fusions was 0.0309 % [64]. This analysis also revealed that patients younger than 18-year-old (prevalence 0.345) and older than 65-year-old (prevalence 0.03) had the highest rates of POVL. In addition, although many physicians in this field had suspected that the incidence of POVL was increasing, the NIS analysis demonstrated that the incidence of POVL after spinal surgery had decreased from 0.063 % in 1996–1997 to 0.028 % in 2004–2005. Furthermore, the degree of surgical experience was not a factor in the development of POVL.

The primary causes of POVL are ischemic optic neuropathy (ION), retinal artery (CRAO) or vein occlusion, and cortical brain ischemia. CROA decreases blood supply to the entire retina while branch retinal artery occlusion (BROA) affects a portion of the retina. In an attempt to delineate the etiology of POVL, the ASA Committee on Professional Liability established the POVL Registry to collect detailed information on these cases [65]. Many patients with CROA had evidence of unilateral ocular trauma, suggesting that improper positioning may have played a role. Funduscopic findings associated with CROA included macular/retinal edema and a characteristic cherry red spot. Patients with CROA often had unilateral vision loss, no light perception, periorbital edema, eyelid edema, chemosis, proptosis, ptosis, and paresthesias of the supraorbital region [66]. In the ASA registry none of the patients with CROA were positioned with Mayfield tongs, while two were positioned on horseshoe headrest [65]. The use of head positioning devices, which include foam cutouts for the eyes and a mirror to view the eyes, should reduce the incidence of this complication. Retinal microemboli are another potential cause of CROA and more frequently in BROA.

ION was the most common cause of POVL after spinal surgery. ION can be divided into anterior (AION) or posterior (PION) ischemic optic neuropathy depending on the visual field cut and whether edema to the optic disk presence early (AION) or later (PION). Both are the result of reduced blood flow or oxygen delivery from endarteriole branches of the ophthalmic artery. Most cases occurring after spine surgery are PION and are often bilateral, while AION is more frequently reported after cardiac surgery. The etiology of postoperative ION at present is unknown and unpredictable. However, several possible pathogenic factors have been suggested including duration in the prone position, blood loss, anemia, hypotension, abnormal optic nerve blood supply, low cup-to-disc ratio, use of vasopressors, excessive crystalloid infusion, and patient comorbidities; particularly smoking, diabetes, and vascular disease. The ASA registry reported that prolonged procedures (>6 h) combined with substantial blood loss (44 % of EBL) increased the risk of ION after spine surgery. Intraocular ocular pressure (IOP) increases during anesthesia in the prone position, which could result in a decrease in ocular perfusion pressure despite the maintenance of normotension [67]. Hence, hypotension could be a causative factor in cases of abnormal optic nerve vascular autoregulation and/or decreased compensatory perfusion after hours in the prone position. However, in a retrospective case–control study of spine surgery, in patients with or without ION, anemia and hypotension were not associated factors [68]. In the ASA registry in 1/3 of the patients with ION the lowest systolic pressures were greater than 90 mmHg. Although, blood loss appears to be a risk for ION, several studies have been unable to determine how low or how long the hemoglobin level must decrease to lead to ION [66, 69]. The ASA practice guidelines do not recommend transfusing for hemoglobin values >8.0 g/dl, but POVL is often reported in the presence of excessive crystalloid infusion, leading to dilutional anemia [70].

**Fig. 26.4** Rigid cervical orthosis Cervical orthoses

In the ASA registry, patients with ION received an average of 9.7 L of crystalloid intra-operatively. Potentially, excessive orbital edema could result in a compartment syndrome in the optic nerve. However, there are no published reports demonstrating a relationship between periorbital edema and ION. The ASA practice advisory on POVL recommends the use of both colloids and crystalloids to maintain intravascular volume in spine surgery patients who have substantial blood loss. Since ION occurs in the absence of vascular injury to other critical organs and in cases where neither hypotension or anemia are reported, optic nerve blood supply may be uniquely vulnerable to hemodynamic perturbances in the prone position.

## Postoperative Ventilation

Many patients will require postoperative ventilation after complex reconstructive surgery. Those patients with preexisting pulmonary disease (restrictive lung disease, FEV $<$ 50 % of predicted), intraoperative blood loss greater than one body blood volume, intraoperative evidence of decreased perfusion (metabolic acidosis), changing ventilatory parameters (increasing peak inspiratory pressures), and evidence of impending ALI (pa02/FI02 $<$300) are candidates for postoperative ventilation. The goals for sedation for these patients include hemodynamic stability, analgesia, and tolerant of the ventilator but awake enough for regular neurological evaluations.

## Postoperative Orthoses and Mobilization

The utilization of an orthosis after spine spinal surgery procedures varies greatly according to individual surgeon preferences. In the cervical spine, hard cervical collars are often prescribed for spine stabilization following surgery for traumatic or degenerative conditions. Despite the routine use of hard cervical collars for postoperative bracing after spinal surgery for degenerative conditions in many centers, there is a lack of consensus on the indication, type of collar, and duration of immobilization [71] and there are data to suggest that for an unstable cervical spine an orthoses in insufficient for reduction of motion [72]. The reported adverse effects of hard cervical collars include pain, tissue ischemia, breathing restriction, increased risk of aspiration, and high cost [73]. A prospective, randomized control pilot trial of 34 patients compared various patient reported outcomes in patients both with and without postoperative hard cervical collar usage after ACDF. These data suggested that hard cervical collar usage may improve neck pain and disability 6 weeks postoperatively [74].

Theoretical arguments for the utilization of hard cervical collars postoperatively are the reduction of pain, increase in fusion rates, and a subjective increase in the individual patient's sense of security. For this reason, cervical orthoses such as the Miami J® hard cervical collar (Ossur, Foothill Ranch, CA) are commonly implemented in clinical practice. Identifying an optimal time period for hard cervical collar wear while achieving positive outcomes in ACDF patients would be beneficial in minimizing unnecessary patient discomfort are areas of ongoing research. The common practice at our institution is implementation of a hard cervical collar for a 2-week duration after a multilevel ACDF (Fig. 26.4).

Lumbosacral orthoses may provide additional support for the patient's core musculature after spinal decompression or fusion procedures of the lumbosacral spine (Fig. 26.5). Immobilization of the lower lumbar spine and lumbosacral (L5-S1) motion segment in particular is poor with a lumbosacral model orthosis and would require a cumbersome hip extension for effective stabilization [75]. Many patients report an improved sense of stability and security with a lumbosacral orthosis after lumbar or lumbosacral spinal procedures, although, with modern rigid pedicle screw fixation a contribution to fusion rates is unlikely.

**Fig. 26.5** Lumbosacral orthoses

## Postoperative Pain Management

Patients may experience considerable pain after multilevel spinal fusions with instrumentation. The majority of these patients will initially be treated with intravenous narcotics, but due to their multiple side effects a multi-modality approach with other agents has been recommended. For lumbar fusions, an epidural placed at a level above the incision can be used for PCEA infusions of local anesthetics and narcotics. For procedures involving more extensive spinal levels, intrathecal morphine administered during surgery has been shown to provide reliable postoperative pain control [76]. Pre-emptive and postoperative administration of pregabalin and celecoxib has also proved effective in the management of pain with few side effects [77]. However, NSAIDs may have a negative influence on the success of spinal fusions. For narcotic tolerant patients, subanesthetic doses (0.2 mg bolus, then 2 mcg/kg/h) of ketamine reduced postoperative pain after posterior spine fusions [78].

## Summary

Perioperative anesthetic management of the complex adult spine patient challenges the full scope of the clinician. These patient often have multiple medical comorbidities, the operative procedures are long with the potential for considerable blood loss, the anesthetic must match the requirement for continuous spinal cord monitoring yet provide enough depth to prevent intraoperative awareness and maintain hemodynamic stability, and the operative plan must extend into the postoperative period sometimes with postoperative ventilation and always with a consideration for analgesia.

**Summary Bullet Points**

- A multidisciplinary team including surgeons, perioperative medical specialists, intensivists, subspecialty trained anesthesiologists, nursing, and physical therapy best serves complex spinal and scoliosis surgery patient.
- Careful preoperative evaluation and optimization of comorbidities are essential, especially in order to avoid cardiac complications.
- Specialized anesthetic techniques including total intravenous anesthesia may improve the accuracy and effectiveness of the monitoring. This is especially essential as complications are an unfortunately intrinsic reality of complex modern spine surgery in a subset of patients.
- Intraoperative hemodynamic management and intraoperative neurological assessments can positively influence outcomes.
- The ASA practice advisory on POVL recommends the use of both colloids and crystalloids to maintain intravascular volume in spine surgery patients who have substantial blood loss. Since ION occurs in the absence of vascular injury to other critical organs and in cases where neither hypotension or anemia

are reported, optic nerve blood supply may be uniquely vulnerable to hemodynamic perturbances in the prone position.
- Blood management should include preoperative autologous donation, and antifibrinolytic agents have been demonstrated to be a useful adjunct in reducing perioperative blood loss.
- Many patients will require postoperative ventilation after complex reconstructive surgery. The goals for sedation for these patients include hemodynamic stability, analgesia, and tolerant of the ventilator but awake enough for regular neurological evaluations.
- Patient-controlled intravenous analgesia is associated with higher patient satisfaction. Specialized pain management teams will often provide for better resource utilization.

## References


1. Cloyd JM, Acosta Jr FL, Cloyd C, Ames CP. Effects of age on perioperative complications of extensive multilevel thoracolumbar spinal fusion surgery. J Neurosurg Spine. 2010;12(4):402–8.
2. Faciszewski T, Winter RB, Lonstein JE, Denis F, Johnson L. The surgical and medical perioperative complications of anterior spinal fusion surgery in the thoracic and lumbar spine in adults. A review of 1223 procedures. Spine (Phila Pa 1976). 1995;20(14):1592–9.
3. Fujita T, Kostuik JP, Huckell CB, Sieber AN. Complications of spinal fusion in adult patients more than 60 years of age. Orthop Clin North Am. 1998;29(4):669–78.
4. Fu KM, Smith JS, Polly Jr DW, Ames CP, Berven SH, Perra JH, McCarthy RE, Knapp Jr DR, Shaffrey CI. Correlation of higher preoperative American Society of Anesthesiology grade and increased morbidity and mortality rates in patients undergoing spine surgery. J Neurosurg Spine. 2011;14(4):470–4.
5. Hamilton DK, et al. Rates of new neurological deficit associated with spine surgery based on 108,419 procedures: a report of the scoliosis research society morbidity and mortality committee. Spine (Phila Pa 1976). 2011;36(15):1218–28.
6. Sansur CA, Smith JS, Coe JD, Glassman SD, Berven SH, Polly Jr DW, Perra JH, Boachie-Adjei O, Shaffrey CI. Scoliosis research society morbidity and mortality of adult scoliosis surgery. Spine (Phila Pa 1976). 2011;36(9):E593–7.
7. Schoenfeld AJ, Ochoa LM, Bader JO, Belmont Jr PJ. Risk factors for immediate postoperative complications and mortality following spine surgery: a study of 3475 patients from the National Surgical Quality Improvement Program. J Bone Joint Surg Am. 2011;93 (17):1577–82.
8. Salerno SM, Carlson DW, Soh EK, Lettieri CJ. Impact of perioperative cardiac assessment guidelines on management of orthopedic surgery patients. Am J Med. 2007;120(2):185.e1–6.
9. Urban M, Jules-Elysee K, Loughlin C. The one-year incidence of postoperative myocardial infarction in an orthopedic population. HSS J. 2009;5:27–30.
10. Sinatra RS, Torres J, Bustos AM. Pain management after major orthopaedic surgery: current strategies and new concepts. J Am Acad Orthop Surg. 2002;10(2):117–29.
11. Poldermans D, et al. Should major vascular surgery be delayed because of preoperative cardiac testing in intermediate-risk patients receiving beta-blocker therapy with tight heart rate control? J Am Coll Cardiol. 2006;48(5):964–9.
12. Eagle KA, Rihal CS, Mickel MC, Holmes DR, Foster ED, Gersh BJ. Cardiac risk of noncardiac surgery: influence of coronary disease and type of surgery in 3368 operations. CASS Investigators and University of Michigan Heart Care Program. Coronary Artery Surgery Study. Circulation. 1997;96(6):1882–7.
13. McFalls EO, et al. Coronary-artery revascularization before elective major vascular surgery. N Engl J Med. 2004;351 (27):2795–804.
14. Vicenzi MN, Meislitzer T, Heitzinger B, Halaj M, Fleisher LA, Metzler H. Coronary artery stenting and non-cardiac surgery—a prospective outcome study. Br J Anaesth. 2006;96(6):686–93.
15. Brilakis ES, Banerjee S, Berger PB. Perioperative management of patients with coronary stents. J Am Coll Cardiol. 2007;49 (22):2145–50.
16. Raby KE, Brull SJ, Timimi F, Akhtar S, Rosenbaum S, Naimi C, Whittemore AD. The effect of heart rate control on myocardial ischemia among high-risk patients after vascular surgery. Anesth Analg. 1999;88(3):477–82.
17. Urban MK, Markowitz SM, Gordon MA, Urquhart BL, Kligfield P. Postoperative prophylactic administration of beta-adrenergic blockers in patients at risk for myocardial ischemia. Anesth Analg. 2000;90(6):1257–61.
18. Devereaux PJ, Goldman L, Cook DJ, Gilbert K, Leslie K, Guyatt GH. Perioperative cardiac events in patients undergoing noncardiac surgery: a review of the magnitude of the problem, the pathophysiology of the events and methods to estimate and communicate risk. CMAJ. 2005;173(6):627–34.
19. Wiesbauer F, Schlager O, Domanovits H, Wildner B, Maurer G, Muellner M, Blessberger H, Schillinger M. Perioperative beta-blockers for preventing surgery-related mortality and morbidity: a systematic review and meta-analysis. Anesth Analg. 2007;104 (1):27–41.
20. Fleisher LA, et al. ACC/AHA 2006 guideline update on perioperative cardiovascular evaluation for noncardiac surgery: focused update on perioperative beta-blocker therapy—a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to Update the 2002 Guidelines on Perioperative Cardiovascular Evaluation for Noncardiac Surgery). Anesth Analg. 2007;104(1):15–26.
21. Kroenke K, Lawrence VA, Theroux JF, Tuley MR, Hilsenbeck S. Postoperative complications after thoracic and major abdominal surgery in patients with and without obstructive lung disease. Chest. 1993;104(5):1445–51.
22. Culver BH. Preoperative assessment of the thoracic surgery patient: pulmonary function testing. Semin Thorac Cardiovasc Surg. 2001;13(2):92–104.
23. Glassman SD, Anagnost SC, Parker A, Burke D, Johnson JR, Dimar JR. The effect of cigarette smoking and smoking cessation on spinal fusion. Spine (Phila Pa 1976). 2000;25(20):2608–15.
24. Nakagawa M, Tanaka H, Tsukuma H, Kishi Y. Relationship between the duration of the preoperative smoke-free period and the incidence of postoperative pulmonary complications after pulmonary surgery. Chest. 2001;120(3):705–10.
25. Rizzi PE, Winter RB, Lonstein JE, Denis F, Perra JH. Adult spinal deformity and respiratory failure. Surgical results in 35 patients. Spine (Phila Pa 1976). 1997;22(21):2517–30.
26. Ramakrishna G, Sprung J, Ravi BS, Chandrasekaran K, McGoon MD. Impact of pulmonary hypertension on the outcomes of noncardiac surgery: predictors of perioperative morbidity and mortality. J Am Coll Cardiol. 2005;45(10):1691–9.
27. Olsen MA, Nepple JJ, Riew KD, Lenke LG, Bridwell KH, Mayfield J, Fraser VJ. Risk factors for surgical site infection following orthopaedic spinal operations. J Bone Joint Surg Am. 2008;90 (1):62–9.

28. van den Berghe G, et al. Intensive insulin therapy in critically ill patients. N Engl J Med. 2001;345(19):1359–67.
29. Kao LS, Meeks D, Moyer VA, Lally KP. Peri-operative glycaemic control regimens for preventing surgical site infections in adults. Cochrane Database Syst Rev. 2009(3):CD006806.
30. Wiener RS, Wiener DC, Larson RJ. Benefits and risks of tight glucose control in critically ill adults: a meta-analysis. JAMA. 2008;300(8):933–44.
31. Stryker LS, Abdel MP, Morrey ME, Morrow MM, Kor DJ, Morrey BF. Elevated postoperative blood glucose and preoperative hemoglobin A1C are associated with increased wound complications following total joint arthroplasty. J Bone Joint Surg Am. 2013;95 (9):808–14. S1–2.
32. Neer RM, et al. Effect of parathyroid hormone (1-34) on fractures and bone mineral density in postmenopausal women with osteoporosis. N Engl J Med. 2001;344(19):1434–41.
33. Lindsay R, Nieves J, Formica C, Henneman E, Woelfert L, Shen V, Dempster D, Cosman F. Randomised controlled study of effect of parathyroid hormone on vertebral-bone mass and fracture incidence among postmenopausal women on oestrogen with osteoporosis. Lancet. 1997;350(9077):550–5.
34. Kaufman JM, Orwoll E, Goemaere S, San Martin J, Hossain A, Dalsky GP, Lindsay R, Mitlak BH. Teriparatide effects on vertebral fractures and bone mineral density in men with osteoporosis: treatment and discontinuation of therapy. Osteoporos Int. 2005;16 (5):510–6.
35. Karikari IO, Nimjee SM, Hardin CA, Hughes BD, Hodges TR, Mehta AI, Choi J, Brown CR, Isaacs RE. Extreme lateral interbody fusion approach for isolated thoracic and thoracolumbar spine diseases: initial clinical experience and early outcomes. J Spinal Disord Tech. 2011;24(6):368–75.
36. Campos JH. An update on bronchial blockers during lung separation techniques in adults. Anesth Analg. 2003;97(5):1266–74.
37. Brier-Jones JE, Palmer DK, Inceoglu S, Cheng WK. Vertebral body fractures after transpsoas interbody fusion procedures. Spine J. 2011;11(11):1068–72.
38. Moller DJ, Slimack NP, Acosta Jr FL, Koski TR, Fessler RG, Liu JC. Minimally invasive lateral lumbar interbody fusion and transpsoas approach-related morbidity. Neurosurg Focus. 2011;31 (4):E4.
39. Papanastassiou ID, Eleraky M, Vrionis FD. Contralateral femoral nerve compression: an unrecognized complication after extreme lateral interbody fusion (XLIF). J Clin Neurosci. 2011;18 (1):149–51.
40. Vauzelle C, Stagnara P, Jouvinroux P. Functional monitoring of spinal cord activity during spinal surgery. Clin Orthop Relat Res. 1973;93:173–8.
41. Eggspuehler A, Sutter MA, Grob D, Jeszenszky D, Dvorak J. Multimodal intraoperative monitoring during surgery of spinal deformities in 217 patients. Eur Spine J. 2007;16 Suppl 2:S188–96.
42. Kumar A, Bhattacharya A, Makhija N. Evoked potential monitoring in anaesthesia and analgesia. Anaesthesia. 2000;55(3):225–41.
43. Sihle-Wissel M, Scholz M, Cunitz G. Transcranial magnetic-evoked potentials under total intravenous anaesthesia and nitrous oxide. Br J Anaesth. 2000;85(3):465–7.
44. Nuttall GA, Horlocker TT, Santrach PJ, Oliver Jr WC, Dekutoski MB, Bryant S. Predictors of blood transfusions in spinal instrumentation and fusion surgery. Spine (Phila Pa 1976). 2000;25 (5):596–601.
45. Goodnough LT, et al. Increased preoperative collection of autologous blood with recombinant human erythropoietin therapy. N Engl J Med. 1989;321(17):1163–8.
46. Murray D. Acute normovolemic hemodilution. Eur Spine J. 2004;13 Suppl 1:S72–5.
47. Urban MK, Beckman J, Gordon M, Urquhart B, Boachie-Adjei O. The efficacy of antifibrinolytics in the reduction of blood loss during complex adult reconstructive spine surgery. Spine (Phila Pa 1976). 2001;26(10):1152–6.
48. Mangano DT, et al. Mortality associated with aprotinin during 5 years following coronary artery bypass graft surgery. JAMA. 2007;297(5):471–9.
49. Sachs B, Delacy D, Green J, Graham RS, Ramsay J, Kreisler N, Kruse P, Khutoryansky N, Hu SS. Recombinant activated factor VII in spinal surgery: a multicenter, randomized, double-blind, placebo-controlled, dose-escalation trial. Spine (Phila Pa 1976). 2007;32(21):2285–93.
50. Solomon DH, O'Driscoll K, Sosne G, Weinstein IB, Cayre YE. 1 alpha,25-dihydroxyvitamin D3-induced regulation of protein kinase C gene expression during HL-60 cell differentiation. Cell Growth Differ. 1991;2(4):187–94.
51. Hersey SL, O'Dell NE, Lowe S, Rasmussen G, Tobias JD, Deshpande JK, Mencio G, Green N. Nicardipine versus nitroprusside for controlled hypotension during spinal surgery in adolescents. Anesth Analg. 1997;84(6):1239–44.
52. Zausig YA, Weigand MA, Graf BM. Perioperative fluid management: an analysis of the present situation. Anaesthesist. 2006;55 (4):371–90.
53. Marik PE, Baram M, Vahid B. Does central venous pressure predict fluid responsiveness? A systematic review of the literature and the tale of seven mares. Chest. 2008;134(1):172–8.
54. Urban MK, Urquhart B, Boachie-Adjei O. Evidence of lung injury during reconstructive surgery for adult spinal deformities with pulmonary artery pressure monitoring. Spine (Phila Pa 1976). 2001;26(4):387–90.
55. Tuman KJ, Roizen MF. Outcome assessment and pulmonary artery catheterization: why does the debate continue? Anesth Analg. 1997;84(1):1–4.
56. Cregg N, Mannion D, Casey W. Oliguria during corrective spinal surgery for idiopathic scoliosis: the role of antidiuretic hormone. Paediatr Anaesth. 1999;9(6):505–14.
57. Rivers E, Nguyen B, Havstad S, Ressler J, Muzzin A, Knoblich B, Peterson E, Tomlanovich M. Early goal-directed therapy in the treatment of severe sepsis and septic shock. N Engl J Med. 2001;345(19):1368–77.
58. Pull ter Gunne AF, Skolasky RL, Ross H, van Laarhoven CJ, Cohen DB. Influence of perioperative resuscitation status on postoperative spine surgery complications. Spine J. 2010;10(2):129–35.
59. Urban MK, Jules-Elysee KM, Beckman JB, Sivjee K, King T, Kelsey W, Boachie-Adjei O. Pulmonary injury in patients undergoing complex spine surgery. Spine J. 2005;5(3):269–76.
60. Funk DJ, Moretti EW, Gan TJ. Minimally invasive cardiac output monitoring in the perioperative setting. Anesth Analg. 2009;108 (3):887–97.
61. Michard F, Lopes MR, Auler Jr JO. Pulse pressure variation: beyond the fluid management of patients with shock. Crit Care. 2007;11(3):131.
62. Chang SH, Miller NR. The incidence of vision loss due to perioperative ischemic optic neuropathy associated with spine surgery: the Johns Hopkins Hospital Experience. Spine (Phila Pa 1976). 2005;30(11):1299–302.
63. Patil CG, Lad EM, Lad SP, Ho C, Boakye M. Visual loss after spine surgery: a population-based study. Spine (Phila Pa 1976). 2008;33 (13):1491–6.
64. Shen Y, Drum M, Roth S. The prevalence of perioperative visual loss in the United States: a 10-year study from 1996 to 2005 of spinal, orthopedic, cardiac, and general surgery. Anesth Analg. 2009;109(5):1534–45.
65. Lee LA, Roth S, Posner KL, Cheney FW, Caplan RA, Newman NJ, Domino KB. The American Society of Anesthesiologists Postoperative Visual Loss Registry: analysis of 93 spine surgery cases with postoperative visual loss. Anesthesiology. 2006;105(4):652–9. quiz 867–8.

66. Roth S. Perioperative visual loss: what do we know, what can we do? Br J Anaesth. 2009;103 Suppl 1:i31–40.
67. Cheng MA, Todorov A, Tempelhoff R, McHugh T, Crowder CM, Lauryssen C. The effect of prone positioning on intraocular pressure in anesthetized patients. Anesthesiology. 2001;95(6):1351–5.
68. Holy SE, Tsai JH, McAllister RK, Smith KH. Perioperative ischemic optic neuropathy: a case control analysis of 126,666 surgical procedures at a single institution. Anesthesiology. 2009;110 (2):246–53.
69. Myers MA, Hamilton SR, Bogosian AJ, Smith CH, Wagner TA. Visual loss as a complication of spine surgery. A review of 37 cases. Spine (Phila Pa 1976). 1997;22(12):1325–9.
70. Task ASA. Force on perioperative blindness. Practice advisory for periopeartive visual loss associated with spine surgery. Anesthesiology. 2006;104:1319–28.
71. Bible JE, Biswas D, Whang PG, Simpson AK, Rechtine GR, Grauer JN. Postoperative bracing after spine surgery for degenerative conditions: a questionnaire study. Spine J. 2009;9(4):309–16.
72. Horodyski M, DiPaola CP, Conrad BP, Rechtine 2nd GR. Cervical collars are insufficient for immobilizing an unstable cervical spine injury. J Emerg Med. 2011;41(5):513–9.
73. Naylor JR, Mulley GP. Surgical collars: a survey of their prescription and use. Br J Rheumatol. 1991;30(4):282–4.
74. Abbott A, Halvorsen M, Dedering A. Is there a need for cervical collar usage post anterior cervical decompression and fusion using interbody cages? A randomized controlled pilot trial. Physiother Theory Pract. 2013;29(4):290–300.
75. Miller RA, Hardcastle P, Renwick SE. Lower spinal mobility and external immobilization in the normal and pathologic condition. Orthop Rev. 1992;21(6):753–7.
76. Urban MK, Jules-Elysee K, Urquhart B, Cammisa FP, Boachie-Adjei O. Reduction in postoperative pain after spinal fusion with instrumentation using intrathecal morphine. Spine (Phila Pa 1976). 2002;27(5):535–7.
77. Reuben SS, Buvanendran A, Kroin JS, Raghunathan K. The analgesic efficacy of celecoxib, pregabalin, and their combination for spinal fusion surgery. Anesth Analg. 2006;103(5):1271–7.
78. Urban MK, Ya Deau JT, Wukovits B, Lipnitsky JY. Ketamine as an adjunct to postoperative pain management in opioid tolerant patients after spinal fusions: a prospective randomized trial. HSS J. 2008;4(1):62–5.

# Management of Blood Products in Orthopedic Surgery

27

Jad Bou Monsef, Michelle Perna, and Friedrich Boettner

**Objectives**

- To review typical blood loss from orthopedic procedures and common treatments including allogeneic blood transfusions for the resulting acute blood loss anemia.
- To review the efforts towards bloodless surgery including the various modalities that have been devised to target different aspects of blood loss, which range from correcting preoperative anemia, reducing blood loss, and maximizing the use of autologous blood.
- To review strategies that aim at optimizing patient preoperative status and red blood cell stock.
- To explore operative approaches and surgical techniques as well as pharmacologic and other modalities that can minimize perioperative blood loss as opposed to simply replacing it.
- To discuss the threshold for transfusion and the choice of blood saving measure vary among patients. While there is no consensus on the appropriateness and benefit of each method, the blood management approach to orthopedic surgery holds the potential to minimize risks associated with transfusion.

**Key Points**

- This chapter illustrates current transfusion practices and highlights the risk-to-benefit ratio of allogeneic blood in elective orthopedic surgery.
- Exploring the various alternatives at our disposal is paramount to achieve adequate management of blood products.
- Striving for a "bloodless" surgical practice and enhanced safety depends on the integration of such modalities into algorithms tailored to specific patient needs.

## Introduction

Most orthopedic surgeries require extensive bone and soft tissue dissection. Coupled with the inability to cauterize bleeding bony surfaces, orthopedic procedures harbor the potential for substantial blood loss. Significant bleeding occurs in pelvic and long bone fractures as well as primary and revision joint replacements and spinal procedures. Blood loss ranges between 830 ml and 1,460 ml in elective total hip arthroplasty and between 570 ml and 1,360 ml in elective total knee, with an added average 900 ml in hidden blood loss corresponding to the extravasation of blood into the soft tissues [1]. The overall blood loss can reach 2.5 L in spinal fusion surgery and 3.3 L in scoliosis surgery [2]. The standard treatment for perioperative anemia remains transfusion of allogeneic blood. In light of the exponential increase in number of procedures, orthopedic surgery accounts for a considerable portion of the average 13 million yearly blood transfusions in the United States [3]. Inherent risks of such transfusions persist despite improvement in safety and management of allogeneic blood. Ranging from the relatively common nonhemolytic febrile transfusion reactions, febrile allergic reactions, and alloimmunization reactions to the less common but more serious transfusion-related acute lung injury (TRALI) and transfusion-related

J. Bou Monsef • M. Perna • F. Boettner (✉)
Department of Orthopedic Surgery, Hospital for Special Surgery, 535 E 70th Street, New York, NY 10021, USA
e-mail: boettnerf@hss.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_27, 

immunomodulation (TRIM), such adverse events undermine the safety of allogeneic transfusions. TRALI is thought to be induced by a capillary leak syndrome instigated by neutrophil-mediated endothelial cell cytotoxicity [4]. Characterized by acute onset of noncardiogenic pulmonary edema within 6 h of blood transfusion, it has been implicated as the leading cause of all transfusion-related fatalities [5]. TRIM is yet another immunosuppression-mediated syndrome caused by foreign blood. It is stipulated to increase the incidence of postoperative infections by up to 10 %, delay postoperative wound healing, and prolong hospitalization [6–8]. Contamination and transmission of infection remain the most feared complications. The potential risks coupled to worldwide shortage and increasing cost of blood units have triggered the search for alternatives to allogeneic blood [3]. This in turn has led to major changes in transfusion practice and perioperative blood management.

It is clear that blood management in surgery involves much more than transfusing blood to increase preoperative hemoglobin. This traditional rule for transfusion dates back to 1942, when based on clinical observations, Adams and Lundy recommended preoperative transfusion for patients who have a hemoglobin level of less than 10 g/dl before the operation [9]. The World Health Organization (WHO) Global Database on Anemia compiled data from 1993 to 2005 estimates a 24.8 % worldwide prevalence of anemia, with varying thresholds for the different population groups [10]. While the overall prevalence in the United Stated ranges from 2 to 5 % [10], this number rises rapidly after the age of 50, affecting 11 % of men and 10.2 % for women over 65, and 20 % of people 85 years and older. Preoperative anemia is prevalent in surgical patients [11] as iron-deficiency anemia, anemia of chronic disease, or both, as well as B12 or folate deficiency primarily affects the elderly. Identifying patients at higher risk for transfusions is key to reducing the routine use of allogeneic blood in elective procedures. Preoperative hemoglobin levels are the most consistent predictor for an increased risk of allogeneic blood transfusion [12]. Other factors such as age, gender, and body mass index contribute to transfusion risk when two or more of these parameters are present [13]. A hemoglobin of less than 10 g/dl before total joint arthroplasty implies a nearly 90 % chance of requiring transfusion, decreasing progressively to 40–60 % between 10 and 13.5 g/dl, and 15–25 % beyond 13.5 g/dl, reflecting the inverse relationship between preoperative hemoglobin and allogeneic transfusion risk [14].

An estimated 24 % of the patients scheduled for a hip or knee replacement are moderately anemic and at higher risk for transfusion, compared to 44 % of the patients undergoing surgical treatment for a hip fracture. The prevalence of anemia further increases after surgery, reaching up to 90 % on discharge [11]. Compounding the blood loss from the surgery, the ensuing systemic inflammatory response inhibits erythropoiesis through humoral mediators such as interleukin-1, interferon-γ, and tumor necrosis factor-α. This is achieved directly by suppressing erythroid colony growth and indirectly by suppressing erythropoietin production [15]. What follows is a state of functional iron deficiency in which iron is not available for erythropoiesis despite normal stores in the marrow macrophages [16].

Limiting the need for transfusion requires defining a transfusion threshold and optimizing the preoperative erythrocyte stock, surgical technique, and use of the patient's own blood. The importance of proper blood management to reduce exposure to allogeneic blood, transfusion-related complications, and cost reflects the need for a general strategy individualized to each patient and risk level:

1. Preoperatively, erythropoietin and autologous blood donation play part in optimizing surgical conditions, guided by presurgical workup.
2. Intraoperatively, adequate hemostasis remains the most important surgical option. Anesthesia techniques and topical or intravenous thrombotic agents offer the potential to reduce bleeding.
3. Postoperatively, reinfusion devices can make use blood lost up to 24 h after the surgery within 4-h collection intervals.

The efficacy of such interventions is measured by the reduction in blood loss or transfusion rates. However, the variations in parameters and study designs produce inconclusive results and have caused a lack of consensus between guidelines and practices. Taking into account that every blood conservation technique carries its own benefits as well as limitations and risks influenced by institutional and patient factors, no single method can be expected to represent the way to bloodless surgery. The best choice depends on the time available before surgery, the expected blood loss for the procedure, the patient's threshold for transfusion, and the efficacy of technique in the given setting [17].

## Preoperative Period

### Preoperative Workup

Effective preoperative evaluation of the patient undergoing elective orthopedic surgery is crucial for perioperative blood management. The process of detection, evaluation, and treatment of anemia begins with obtaining hemoglobin and hematocrit levels 30 days prior to the surgery, leaving room for further investigations if needed. The workup of anemia is guided by the mean corpuscular volume, warranting serum B12 and folate levels if greater than 100 fl or ferritin and transferrin saturation levels if below 80 fl. A microcytic anemia with ferritin saturation below

12 ng/ml or transferrin saturation less than 15 % indicates iron deficiency and the need for supplementation (and possible GI evaluation). Normocytic anemia could be the result of possible blood dyscrasia, hemolysis, blood loss, or chronic kidney disease, in which case the reticulocyte count and serum creatinine level should be screened. Anemia of chronic disease is a diagnosis of exclusion, where inadequate reticulocytosis is found despite sufficient iron stores and normal MCV [18].

Identification and optimal management of medical conditions or drugs that may interfere in coagulation and bleeding is paramount before surgery. Vitamin K antagonists, anti-platelet agents, or anticoagulants such as heparin or any thrombin inhibitor should be stopped preoperatively when possible. The bleeding risk with aspirin is increased by 2.5–20 %, reaching 30–50 % when aspirin and clopidogrel are combined [19]. The risk is similar for low-molecular-weight heparins (LMWH), vitamin K antagonists and aspirin. Unfractionated heparin carries the highest risk of bleeding [20]. Aspirin irreversibly inhibits platelet aggregation and requires discontinuation 7 days prior to the procedure.

Reconsidering the historic transfusion triggers of 30/10 has established that hemoglobin levels of 8 g/dl and even 7 g/dl can be safely tolerated in a patient with no major comorbidities. Nevertheless, anemia is an important risk factor for perioperative mortality. This is documented in patients who declined the use of blood products. A hemoglobin level less than 6 g/dL was found to increase the mortality risk within 1 month of surgery by a factor of 26 as compared to patients with a hemoglobin level of 12 g/dl [21].

## Preoperative Autologous Blood Donation

Preoperative donation of autologous blood emerged in the 1980s fueled by concerns over transmission of diseases, namely HIV, through allogeneic transfusions [22]. Albeit more and more unlikely, the devastating repercussions of such adverse events in addition to the persistent possibility of human error underscored the premise that the safest blood would be the patient's own [23]. Utilizing the patient's own blood can be achieved through preoperative autologous blood donation (PABD), perioperative hemodilution, intraoperative salvage and reuse of blood from the operative field, or postoperative reinfusion of drained blood [24]. Owing to the elective nature of non-traumatic orthopedic procedures with increased blood loss, PABD gained significant momentum and established itself as the standard alternative to allogeneic transfusions in orthopedic surgery [25]. A blood unit is drawn every 5–7 days, with the last one at least 3 days prior to the surgery [4]. In children, the volume of each donation must be lower than 13 % of their circulating blood volume, unless simultaneous volume replacement is performed [26]. The optimal range for donation is 4–6 weeks prior to surgery with iron supplementation to ensure adequate compensatory erythropoietic response. 325 mg ferrous sulfate or ferrous fumarate three times daily are the most common iron supplements. The blood is then stored at the hospital's blood bank for later intraoperative or postoperative transfusions. According to the National Heart, Lung, and Blood Expert Institute Panel on the Use of Autologous Blood, autologous blood donation is possible in most patients who are healthy enough to undergo elective surgery and constitutes a safer alternative than allogeneic blood. The panel defines appropriate patients as (1) those undergoing elective surgery that can be scheduled at least 7 weeks in advance, (2) undergoing a surgical procedure-for which blood is usually crossmatched, (3) having a hemoglobin $>$ 11 g/dl (hematocrit, 33), and (4) no contraindications to autologous blood donation [23]. The absolute contraindication due to concerns of reinfection during transfusion is bacteremia or conditions predisposing to bacteremia such as urinary or cutaneous catheters. Other contraindications include pregnancy, severe pulmonary disease, unstable angina, myocardial infarction within the previous 3 months, congestive heart failure, and significant aortic valve stenosis with an A-a gradient $>$ 70 mmHg [27].

The widespread recognition and appeal of PABD as a blood saving modality stem from three major benefits:

1. Safety from viral infection, graft-versus-host disease, alloimmunization, and Rh sensitization.
2. "Preemptive" early stimulation of the reticulocytosis preoperatively, thus overriding the intraoperative blood loss as a trigger for the erythropoietic response [28].
3. The reduction of effective RBC mass by diluting the blood, resulting in a lower RBC loss during surgery [29].

In addition to that, PABD has been reported to reduce the risk of postoperative deep venous thrombosis in patients undergoing total knee and total hip replacement procedures [30, 31]. It also provides a psychological benefit to the patient.

With the established safety of autologous blood donation, its efficacy in reducing or even preventing exposure to allogeneic blood comes into question. Extensive studies conducted in the last two decades concluded that PABD effectively decreases the risk of allogeneic transfusion but increases overall transfusion rates. A Cochrane review studying preoperative donation in surgery including orthopedic estimated a 68 % reduction in exposure to allogeneic blood in the PABD group, at the expense of a 24 % higher risk of receiving any transfusion (allogeneic and/or autologous). The latter risk of exposure to any transfusion was attributed

donation-induced anemia, as well as a tendency to more liberal transfusion of autologous blood [32].

On the basis of the current literature, PABD appears effective in reducing exposure to allogeneic blood in spine surgery (scoliosis surgery and vertebral fusion) [33]. Similarly in total joint arthroplasty, PABD significantly reduced allogeneic blood transfusion rates in a meta-analysis of 950 patients in three randomized trials (RR 0.16, 95 % CI), as well as 18 observational controlled studies covering 19,239 patients (RR 0.29, 95 % CI) [34]. Similar results were reported by the Orthopedic Surgery Transfusion Hemoglobin European Overview (OSTHEO) study of 3,996 patients [35], as well as a multicenter center study of 9,482 patients from 330 TJA surgeons in the United States. However, these studies also shed light on the inefficiency of the collection and use of autologous blood [36].

Critical evaluation of this intervention has raised a number of concerns with PABD, including high cost, increased transfusion rates, and high incidence of wasted blood. PABD is not associated with an increase in either the morbidity or mortality rates or the length of hospital stay [26]. However, the high percentage of wasted blood units (up to 50 %) [36] as well as the potential risks of transfusion reactions, vasovagal episodes, circulatory volume overload, bacterial contamination, and clerical errors, undermine the universal acceptance of autologous predonation. The logistically difficult procedure requires a setup in place to adequately handle the blood units. It is also time-consuming and costly for the patients. The endogenous erythropoietin response in patients with mild anemia might be insufficient, exacerbating the preoperative anemia, and increasing the likelihood of a transfusion [14].

In addition to that, PABD seems to have less impact when integrated in a transfusion protocol. Its combination with rHuEPO proved more effective in reducing allogeneic blood transfusion rate than any of them alone [37]. The administration of rHuEPO to adults, children, and adolescents has been found to enhance the effectiveness of PABD [38].

Preoperative hemoglobin level plays an important role in balancing risk and benefit. Patients with hemoglobin above 13 g/dl have a five times lower transfusion risk than those in the 11–13 g/dl range. Preoperative hemoglobin levels of >13 g/dl are associated with the highest percentage of wasted autologous blood, up to 90 % reported in shoulder arthroplasty [39]. Predonation of autologous blood may not be indicated when Hgb levels are greater than 15 g/dl or between 13 and 15 g/dl in those who are less than 65 years old undergoing primary TJA. In THA for instance, PABD failed to show benefit for nonanemic (Hb > 12.5 g/dl) patients [40].

A rationale approach to determining transfusion risk would be stratifying of patients based on preoperative hemoglobin levels and estimated blood loss of each procedure (unilateral vs. bilateral, primary vs. revision) [14]. One of the main disadvantages of preoperative donation remains its cost. Cost-effectiveness is compromised when at least one unit of allogeneic blood must be transfused, or when more than 15 % of the donated blood must be discarded [27]. Insurance coverage of autologous donation is questionable, sometimes reflecting a direct cost on the patient as well as the hospital.

However, when used on selected patients with high transfusion probabilities, PABD is clinically beneficial and effective. It should be offered to the patient whenever the probability of a blood transfusion is at least 10 % in the absence of contraindications [24], such as Hg < 11 g/dl, infections, or increased cardiac risk [41].

## Supplements

Baseline hemoglobin at or exceeding 13 g/dl has been deemed essential for reducing exposure to blood products, improving postsurgical recovery, reducing complications, and optimizing patient status at discharge [36]. In light of the role of starting RBC stock in dictating transfusion needs, pharmacological enhancement of erythropoiesis can be achieved by supplementing iron and folic acid, with or without recombinant erythropoietin. Preoperative iron has been advocated as a potential adjunct in both anemic and nonanemic patients [42, 43]. As the release of iron from its ferritin stores is a slow process, iron supplementation is advised even with normal ferritin levels [44]. Iron can be administered orally and parenterally, but intravenous administration is five times more effective in inducing the erythropoietic response after significant blood loss [45].

Coupled to a restrictive transfusion protocol, oral iron was shown to reduce transfusion requirements in total knee arthroplasty patients [46]. Similarly, perioperative administration of intravenous (IV) iron, with or without single doses of erythropoietin, in knee replacement or hip fracture showed a reduced number and volume of transfusions [47, 48].

Chronic anemia from inflammation, infections, and malignancies is often mild to moderate, but is probably one of the most common forms of anemia after iron deficiency [49]. These patients are important to distinguish from the patients with iron-deficiency anemia, because iron supplementary has no therapeutic benefits. As opposed to iron deficiency, anemia of chronic inflammation is associated with high serum hepcidin levels. Hepcidin impairs the absorption of orally administrated iron and increases the sequestration of iron in macrophages by inducing the

internalization of ferroportin in enteric cells and macrophages [50]. In such patients intravenous iron is able to overcome this effect [44], and they may require higher doses of erythropoietin to trigger sustained erythropoiesis [51].

Cobalamine (vitamin B12) and folate deficiency are responsible for 5–10 % of anemias in the elderly population and must be supplemented in cases of macrocytic anemia [52].

### Safety

Although iron therapy has been found to be generally safe and effective, especially high molecular weight iron, dextran has the disadvantage of potentially life-threatening dextran-associated anaphylactic reactions [53]. While no clinically relevant adverse reaction to iron administration was observed in studies, the administration of IV iron should be avoided in patients with pre-treatment ferritin values $>$ 500 ng/ml or with ongoing bacteremia [42]. Oral iron is available in four preparations: ferrous sulfate, ferrous gluconate, ferrous fumarate, and iron polysaccharide. Gastrointestinal side effects may limit these preparations' tolerability. Iron supplements with a high elemental value will require fewer pills and fewer doses, reducing the risk and frequency of side effects. Intravenous (IV) iron preparations including iron sucrose and iron gluconate exhibit greater safety than past formulations infamous for anaphylactic reactions. The effect on hemoglobin levels usually occurs starting at 1 week, with the maximum effect achieved at 2 weeks [54]. Hypotension, arthralgia, abdominal discomfort, and back pain are potential side effects of IV iron. Intravenous iron presents a safer alternative to blood transfusion and is associated with a lower risk of death (0.4 per million vs. 4 per million, respectively) as well as life-threatening adverse events (4 per million vs. 10 per million, respectively) according to the Network for Advancement of Transfusion Alternatives [42].

## Erythropoietin

The process of erythropoiesis is greatly dependent on erythropoietin (EPO), a glycoprotein hormone synthesized in the kidney and secreted by renal cortical interstitial cells. Released in response to tissue hypoxia, EPO acts on erythrocyte colony-forming units in the bone marrow and stimulates RBC production. In the United States, recombinant human erythropoietin has been approved for use in the treatment of anemia in patients with chronic renal failure, human immunodeficiency virus, and people receiving chemotherapy [55]. Through subcutaneous or intravenous administration, erythropoiesis-stimulating agents such as epoetin alfa and darbepoetin boost hemoglobin level and decrease or eliminate transfusion needs in chronic renal patients [54]. This effect was explored in patients undergoing elective procedures such as cardiovascular and orthopedic surgeries. Extensive studies established the effectiveness of perioperative EPO in stimulating erythropoiesis (Table 27.1). It was found to increase preoperative hemoglobin concentration, hematocrit, reticulocyte count, and autologous blood units donated. In addition, such agents significantly reduce the rate of allogeneic transfusion (AOR 0.63; 95 % CI) [56–58].

The erythropoietic response depends on the dose of EPO and the availability of iron [87]. It is physiologically triggered by acute blood loss in surgery, showing evidence of erythroid hyperplasia after 3–6 days and maximal response in 7–10 days [88]. However, the erythropoietic response is often impaired in older patients with medical comorbidities [89]. This contributes to a delayed postoperative recovery of hemoglobin levels even after allogeneic blood transfusion. The anticipated benefit of erythropoietin is creating a period of magnified erythropoietic response. Reticulocyte levels have been shown to normalize 2 weeks after discontinuation of erythropoietin [90]. In patients with preoperative hemoglobin levels of 10–13 g/dl, erythropoietin significantly reduces transfusion risk to 16 % from 45 %. The results directly reflected on readiness to resume daily activities and muscle strength measured as postoperative vigor and functional ability. This reduces the length of hospital stays and facilitates postoperative rehabilitation [14]. In light of the diminished postoperative intestinal absorption of iron, administration of IV iron with erythropoietin reduces the delay to recover baseline hemoglobin levels [47].

### Safety

Despite FDA approval for elective surgery, the risk of erythropoietin came under scrutiny in 2007, fueled by concerns over perioperative thromboembolic events. The Food and Drug Administration alerted to the preliminary results of a 681 patient randomized study of recombinant erythropoietin (4 $\times$ 40,000 IU) in patients undergoing elective spine surgery. While all patients did not receive anticoagulation, those treated with erythropoietin experienced twice the frequency of deep venous thrombosis relative to the control group (4.7 % vs. 2.1 %) (FDA alert 16 November 2006, updated 16 February 2007 and 9 March 2007).

Other studies have shown erythropoietin to be safe and effective in treating anemia and decreasing patient exposure to allogeneic blood transfusion. However, it is important to note that the available agents are prothrombotic especially in the absence of pharmacologic DVT prophylaxis. As hemoglobin levels may exceed normal levels, a higher risk of thromboembolic events are the results of an increased blood viscosity and platelet concentration. EPO is contraindicated for patients with comorbidities that may predispose to adverse side effects, such as uncontrolled

**Table 27.1** Efficacy of epoetin alpha in major orthopedic procedures

| Study (year) | No. of patients | Procedure | Treatment, dose | Key findings with epoetin alpha |
|---|---|---|---|---|
| Moonen et al. (2008) [59] | 100 | Total joint arthroplasty | Epoetin alfa, 40,000 IU × 4/week for 3 weeks preop subcutaneously + iron PO (orally) versus postoperative retransfusion of shed blood | Lower allogeneic transfusion rate in epoetin group versus retransfusion group (4 % vs. 28 %) |
| Vitale et al. (2007) [60] | 61 | Scoliosis surgery | Epoetin alpha, 10,000 IU or 300 IU/kg 21, 14, and 7 days preop and on the day of surgery subcutaneously + iron PO | Higher mean preoperative and discharge hematocrit level |
| Weber et al. European Epoetin Alfa Surgery Trial (EEST) (2005) [57] | 695 | Orthopedic | Epoetin alfa, 40,000 IU/week or placebo subcutaneously × 3 week preop and on the day of surgery + iron PO | Higher Hb values from the day of surgery until discharge and lower transfusion rates (12 % vs. 46 %) |
| Rosencher et al. (2005) [61] | 93 | Orthopedic | Epoetin alfa, 40,000 IU/week subcutaneously preop until they reached a maximal Hct of 40 % versus PABD only group | Increased RBC production, higher hematocrit on days 1 and 3 postop and at discharge; better energy score; 2 EPO injections were sufficient to reach a Ht of 40 % in the majority of patients |
| Franchini et al. (2004) [62] | 51 | Scoliosis surgery | Epoetin alpha, 10,000 IU × 2/week subcutaneously for 3 weeks preop + iron PO | Increase predonation of blood units and hemoglobin levels; all of the patients completed the PABD program; decreased allogeneic blood requirements |
| Colomina et al. (2004) [63] | 250 | Spine surgery | Epoetin alfa 40,000 IU × 2/week subcutaneously + PABD starting approximately 2 months preop versus PABD only + iron PO | Higher hemoglobin and hematocrit values at time of surgery; more predonated units retrieved per patient; reduced allogeneic transfusion requirements |
| Lee et al. (2003) [64] | 53 | 2-stage reimplantation hip arthroplasty | Epoetin alfa, 40,000 IU subcutaneously at intervals of 21, 14, and 7 days before reimplantation + iron PO vs. controls | Increased preop hemoglobin levels and decreased rate of allogeneic transfusion |
| Wurnig et al. (2001) [65] | 194 | Orthopedic or cardiovascular | Epoetin beta, 125 or 250 IU/kg/week subcutaneously or no therapy for 3–4 weeks before surgery + iron PO | Increased preop hemoglobin levels and decreased rate of allogeneic transfusion |
| Tamir et al. (2000) [66] | 56 | Total joint arthroplasty | Epoetin alfa, 100 IU/kg/day for those with hemoglobin (Hb) > 13 g/dl, 300 IU/kg/day for Hb < 13 during the 10 days prior to surgery and the 4 days following the operation + iron PO | Decreased allogeneic transfusion rates vs. controls |
| Stowell et al. (1999) [67] | 490 | Total joint arthroplasty | Epoetin alfa, 600 IU/kg/week × 4 weekly doses subcutaneously or PABD | Higher hemoglobin pre- and postoperatively and at discharge versus PABD patients; lower transfusion rate than PABD group |
| Mercuriali et al. (1998) [68] | 40 | Hip arthroplasty | Epoetin alfa, 300, 150, or 75 IU/kg, or placebo × 2/week + iron intravenously | Dose-dependent increases in PAD (4.3 units, 300 IU/kg; 3.4 units, 150 IU/kg; 3.0 units, 75 IU/kg; 2.1 units, placebo) |
| Vitale et al. (1998) [69] | 178 | Scoliosis surgery | Epoetin alpha, 10,000 IU/week for 3 weeks or 300 IU/kg/week for 3 weeks subcutaneously + iron PO | Higher hematocrit levels overall, decreased hospital stay and lower transfusion rates in idiopathic scoliosis group |
| Cazenave et al. (1997) [70] | 80 | Orthopedic or cardiovascular | Epoetin alfa, 600 or 300 IU/kg or placebo × 3/week for 1 week starting 18–21 days preop intravenously + iron PO | Increased predonation of >4 units of blood; dose-related increase in red blood cell volume |
| Tryba et al. (1996) [71] | 125 | Orthopedic | Epoetin alfa, 150, 100, or 50 IU/kg of body weight or placebo × 2/week for 3 weeks beginning 18–21 days preop intravenously + iron intravenously | Increased reticulocyte count; increased predonation blood; reduced risk of exposure to allogeneic blood |

(continued)

**Table 27.1** (continued)

| Study (year) | No. of patients | Procedure | Treatment, dose | Key findings with epoetin alpha |
|---|---|---|---|---|
| de Andrade et al. (1996) [72] | 290 | Hip and knee arthroplasty | Epoetin alfa, 300 or 100 IU/kg or placebo daily for 15 days beginning 10 days preop subcutaneously + iron PO | Dose-related increase in reticulocyte count and hematocrit; reduced risk of exposure to allogeneic blood |
| Faris et al. (1996) [55] | 185 | Hip and knee arthroplasty | Epoetin alfa, 300 or 100 IU/kg or placebo daily for 15 days beginning 10 days preop subcutaneously + iron PO | Dose-related increase in reticulocyte count, hemoglobin, and hematocrit; reduced risk of exposure to allogeneic blood |
| Goldberg et al. (1996) [73] | 140 | Hip and knee arthroplasty | Epoetin alfa, 600 IU/kg subcutaneously for 4 doses beginning 21 days preop or 300 IU/kg intravenously daily for 15 days beginning 10 days preop + iron PO | Increased hemoglobin concentration; weekly subcutaneous regimen equivalent to daily intravenous regimen |
| Goodnough et al. (1994) [74] | 116 | Orthopedic | Epoetin alfa, 600, 300, or 150 IU/kg or placebo × 2/week for 3 weeks intravenously + iron PO | Increased reticulocyte count and red blood cell volume |
| Schlaeppi et al. (1994) [75] | 62 | Orthopedic | Epoetin alfa, 100 or 200 IU/kg/week or placebo × 4 week subcutaneously + iron PO | No allogeneic transfusions in epoetin group |
| Mercuriali et al. (1994) [76] | 23 | Hip arthroplasty | Epoetin alfa, 300 IU/kg or placebo intravenously × 2/week for 3 weeks + iron intravenously | Increased predonation of >2 units of blood; reduced risk of exposure to allogeneic blood |
| Beris et al. (1993) [77] | 101 | Orthopedic | Epoetin alfa, 150–180 IU/kg × 6 in 3 weeks or placebo subcutaneously + iron PO | Increased reticulocyte count; reduced drop in hemoglobin |
| Canadian Orthopedic Perioperative Erythropoietin Study Group (1993) [78] | 198 | Hip arthroplasty | Epoetin alfa, 300 IU/kg daily for 14 days beginning 10 days preop; placebo for 5 days, beginning 10 days preop, and then Epoetin alfa, 300 IU/kg of body weight, for next 9 days; or placebo | Dose-related increase in reticulocyte count and hemoglobin concentration; reduced risk of exposure to allogeneic blood |
| Biesma et al. (1993) [79] | 40 | Hip arthroplasty | Epoetin alfa, 500 IU/kg or placebo × 2/week for 3 weeks preop subcutaneously + iron PO | Sixfold increase in reticulocyte count, recovery of baseline hemoglobin after PABD |
| Mercuriali et al. (1993) [80] | 50 | Hip arthroplasty | Epoetin alfa, 600 or 300 IU/kg or placebo × 2/week for 3 weeks intravenously + iron PO and intravenously | Increased predonation of blood; reduced risk of exposure to allogeneic blood |
| Goodnough et al. (1992) [81] | 44 | Orthopedic | Epoetin alfa, 600 IU/kg or placebo × 2/week for 3 weeks intravenously + iron PO | Increased predonation of blood; increased red blood cell production |
| Hochreiter et al. (1992) [82] | 82 | Hip arthroplasty | Epoetin alfa, 200 or 100 IU/kg or placebo × 2/week for 3 weeks intravenously + iron PO | Increased predonation of blood by mildly anemic patients |
| Tasaki et al. (1992) [83] | 25 | Orthopedic | Epoetin alfa, 9,000, 6,000, or 3,000 IU × 2/week for 3 weeks intravenously + iron PO and intravenously | Dose-related increase in red blood cell volume |
| von Bormann et al. (1991) [84] | 10 | Hip arthroplasty | Epoetin alfa, 200 IU/kg or placebo × 7 doses subcutaneously + iron PO | Increase in reticulocytes, maintenance of hemoglobin levels during PABD |
| Graf et al. (1990) [85] | 10 | Hip arthroplasty | Epoetin alfa, 150–200 IU/kg × 3/week for 2–6 weeks (6–18 doses) intravenously + iron PO | Predonation of a mean of 4.4 units of blood; no allogeneic transfusions |
| Goodnough et al. (1989) [86] | 47 | Orthopedic | Epoetin alfa, 600 IU/kg or placebo × 2/week for 3 weeks intravenously + iron PO | Minimized drop in hematocrit; increased red blood cell volume |

arterial hypertension, previous acute myocardial infarction or stroke, unstable angina, and severe carotid stenosis. The FDA subsequently required a warning to be added to the package inserts to specify the increased risk of DVT in surgical patients not receiving prophylactic anticoagulation. The warning urges to consider the use of DVT prophylaxis in surgical patients receiving erythropoietin [54]. Monitoring hemoglobin and hematocrit levels in all patients treated with EPO is indicated. The more common side effects, though still rare, include local skin irritation at the injection site, increased blood pressure, and headaches [22].

The reversibility of erythropoietin's effect on the bone marrow has come into question, possibly as a form of withdrawal or antibody-mediated mechanism. However, pure red cell aplasia occurring after EPO administration has not been reported in orthopedic surgery patients. Therefore, this does not seem to be an issue with short-term use of EPO [24, 26].

### Dose

The high cost of this intervention has led to different regimens in an attempt to achieve optimal cost efficiency. The initially suggested regimen involved daily administration of 300 IU/kg body weight for 15 days, starting 10 days before surgery. Alternatively, 600 IU/kg of subcutaneous EPO weekly on preoperative days 21, 14, and 7 and on the day of surgery is now recommended. In adults with a mean weight of around 65 kg, 40,000 IU once weekly is authorized as a preoperative treatment dosage. In conjunction with a PABD protocol, the recommended dose is 600 IU/kg (or a 40,000 IU vial), twice a week throughout the period of blood donation. In both cases, the use of EPO is discontinued if hemoglobin levels reach 15 g/dl [55, 86, 91–95]. Blood levels of ferritin, folic acid, and vitamin B12 should be checked and corrected before initiating therapy. Iron supplementation is necessary with both protocols [73].

## Intraoperative Period

### Pharmacologic

#### Antifibrinolytics

Secondary hemostasis depends on cleavage of fibrinogen to fibrin by thrombin. This process is regulated by different mechanisms, namely the degradation of fibrin by plasmin. Synthesized in the liver, circulating plasminogen is proteolytically cleaved in lysine-rich areas by endothelium-produced tissue plasminogen activator. The resulting plasmin promotes degradation of fibrin. Antifibrinolytics such as tranexamic acid (TXA), aprotinin, and ε-aminocaproic acid (EACA) have been shown to prevent dissolution of blood clots and stop bleeding [4]. They have come into use in dental extraction, tonsillectomy, prostate surgery, heavy menstrual bleeding, cardiac surgery, and patients with hemophilia. These products allow pharmacologic manipulation of the coagulation cascade through different mechanisms that inhibit fibrinolysis or promote coagulation. An extensive review of their application in over 25,000 surgical patients including orthopedics highlighted significant reductions in blood loss and allogeneic red cell transfusion [96]. Even though slightly less effective than aprotinin, the lysine analogues effectively reduce blood loss during and after surgery with a superior safety profile and cost efficiency [96].

#### Lysine Analogues: Epsilon-Aminocaproic Acid and Tranexamic Acid

Lysine analogues are synthetic amino acids that block the lysine binding sites on plasminogen molecules. They effectively displace plasminogen and plasmin from fibrinogen, inhibiting fibrinolysis. This category encompasses EACA and TXA, the latter exhibiting stronger binding and thus around ten times more potency than the former [97–99]. The benefits of both EACA and TXA have been evaluated in various clinical scenarios including cardiac surgery, prostrate surgery, liver transplantation, and subarachnoid hemorrhage. The fibrinolytic system is activated transiently after any surgery, especially in tissues with high tissue plasminogen activator content [100]. In orthopedic surgery, this is particularly applicable to total knee arthroplasty. Employing a pneumatic tourniquet to create a bloodless field results in increased fibrinolytic activity, contributing to early postoperative blood loss [101] (see Fig. 27.1).

#### Aprotinin

Aprotinin is considered an antifibrinolytic agent with a different mechanism of action than EACA and TXA, as it is not a lysine analogue. This nonspecific serine protease inhibitor occurs naturally and was first isolated from bovine lungs [102]. Much of the current knowledge about aprotinin and its inherent antifibrinolytic properties stems from the experience with cardiac surgery, specifically cardiopulmonary bypass (CPB) surgeries. It has been rationalized that the negatively charged surface of the bypass circuit activates factor XII, converting prekallikrein to kallikrein. Kallikrein, a peptidase enzyme, acts in a positive feedback loop, activating factor XII and converting plasminogen into plasmin [103]. While the exact mechanism of action remains unclear, it is thought that aprotinin functions to inhibit several serine proteases, including trypsin, plasmin, plasma- and tissue-kallikrein. This indirectly inhibits the contact phase of coagulation and decreases thrombin production. By protecting membrane-bound GPIb platelet receptors, aprotinin has been theorized to prevent postoperative platelet hyporeactivity [4, 103, 104]. In a large meta-analysis of 45 trials involving 5,805 patients, aprotinin clearly

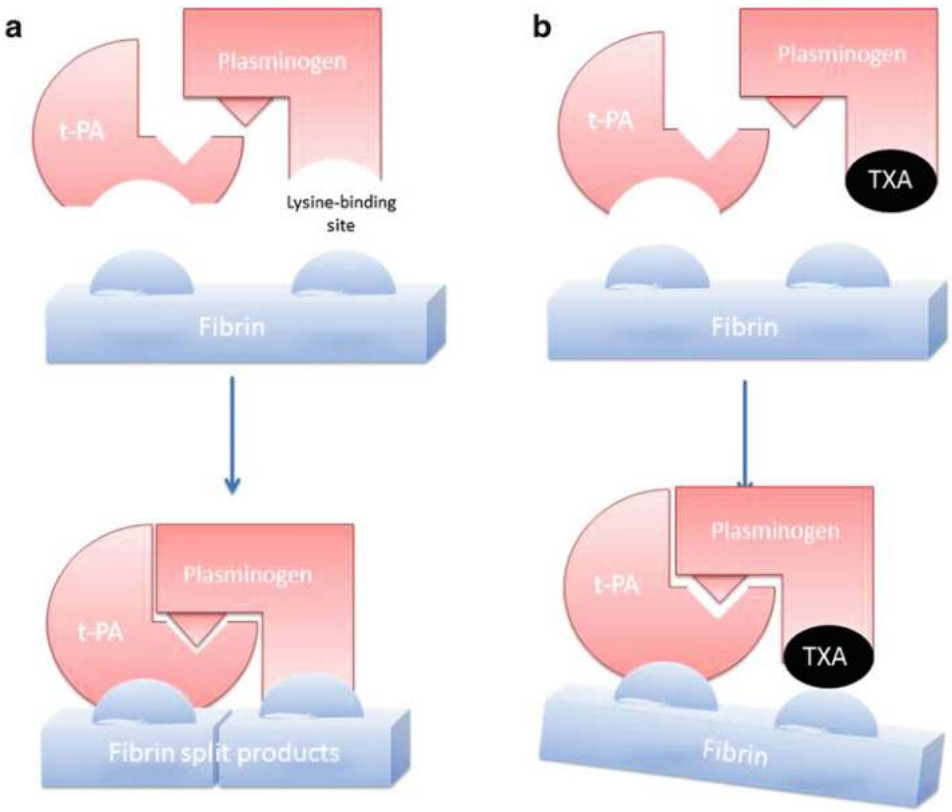


**Fig. 27.1** Inhibition of fibrinolysis by tranexamic acid. (**a**) Activation of fibrinolysis. (**b**) Tranexamic acid (TXA)-mediated inhibition of fibrinolysis by competitive binding to lysine-binding site on fibrinogen. *T-PA* tissue plasminogen activator

demonstrated reduction in blood loss and allogeneic transfusion rates [105, 106].

## Efficacy

As an inhibitor of fibrinolysis, TXA was found to decrease postoperative blood loss after conventional TKA [107–109] as well as minimally invasive TKA with one intraoperative injection [110]. In primary total hip arthroplasty, TXA led to a significant reduction in the proportion of patients requiring allogeneic blood transfusion with no significant differences in deep-vein thrombosis, pulmonary embolism, infection rates, or other complications [111]. Studies on antifibrinolytics in major orthopedic procedures compared to controls evaluated allogeneic transfusion requirements according to a transfusion protocol. The resulting level I evidence supported the efficacy of both aprotinin (OR, 0.42) and TXA (OR, 0.18) [112]. Capdevila et al. demonstrated beneficial effects of aprotinin in patients undergoing surgery of the hip, femur, or pelvis for infectious or malignant diseases [113]. A Cochrane review on the use of aprotinin in 655 orthopedic patients versus 491 controls revealed a relative 32 % reduction in the need for allogeneic blood transfusion. The study also covered 1,381 orthopedic patients of whom 722 were randomized to TXA and 659 were randomized to a control group, revealing a 51 % reduction in relative risk for transfusion. While EACA proved effective overall in surgery, it lacks effectiveness in orthopedic patients [102].

In spinal surgery, both lysine analogues proved effective at reducing intraoperative blood loss and transfusion requirements [114, 115]. TXA exhibited dose-dependent efficacy in elective posterior thoracic or lumbar spine fusions in adults [116]. While results were conflicting for EACA [117, 118], TXA reduced blood loss by up to 49 % and transfusions by 80 % compared to controls in both adult and pediatric spine procedures [2, 119–121]. Aprotinin effectively reduced the total blood loss (intra-operative and first 24 h postoperatively), transfusion requirements, and percentage of transfused patients per treatment group in adult patients undergoing spine reconstruction surgery [122]. Its efficacy was established in cases of neuromuscular scoliosis [123] as well as in children and adolescents [124]. EACA, TXA, and aprotinin have been suggested to be equally effective in reducing blood loss and transfusion requirements in the pediatric population undergoing posterior spinal fusion for scoliosis [125].

The widespread use of these pharmacological hemostatic agents has been challenged by some contradictory results

that failed to prove significant benefit of TXA and/or aprotinin in total joint arthroplasty [126, 127]. This could be attributed to small intraoperative and postoperative blood losses not exceeding 1 L, whereas the benefit of these agents comes into play with higher volumes [99]. Another possible reason for the discrepancy could be due to variations in timing and dosing. For instance, studies involving TXA in hip arthroplasty proved unsuccessful when used late during the procedure, whereas most of the studies in which it was administered preoperatively had good results [128].

### Dose

EACA is given at an intravenous loading dose of 100–150 mg/kg followed by an infusion of 10–15 mg/kg/h. 90 % is excreted in the urine within 4–6 h of administration. TXA may be used at lower doses, loading with an intravenous dose of 10 mg/kg followed by a second dose 3 hours postoperative or an infusion of 1 mg/kg/h until a few hours after operation, because its half-life in the plasma is short [4]. Both topical TXA before capsule closure and oral administration of TXA before and up to 18 h after TKR have also proven effective [129]. 90 % of TXA is excreted in the urine after approximately 24 h [4].

Aprotinin is administered intravenously in doses expressed as kallikrein-inhibitory units (KIU). Various dosing regimens have been used in the literature, which generally are considered high-dose (6 million units), intermediate-dose (2–6 million units), and low-dose regimens (2 million units). Continuous infusion or repeated boluses might be needed due to aprotinin's rapid redistribution into the extracellular fluid and rapid renal degradation [4].

### Safety

Although a majority of studies on antifibrinolytics failed to report adverse events or increased morbidity and mortality, it is important to note that such trials were primarily designed to assess efficacy. Small sample sizes are not sufficient to detect relatively infrequent but clinically serious events such as pulmonary emboli, renal failure, or rhabdomyolysis [102]. The fact that these agents may promote a hypercoagulable state remains a concern. However, current evidence is limited to case reports of thrombosis, acute renal failure, and coronary graft occlusion with TXA as well as thrombosis of pulmonary artery catheters in patients receiving EACA. These agents should therefore be avoided in patients with known hypercoagulability or history of myocardial infarction, stroke, or thrombosis [130]. Both EACA and TXA may be associated with orthostatic hypotension during rapid intravenous administration, as well as nausea and diarrhea [99].

Aprotinin was associated with a higher risk of myocardial infarction, renal dysfunction, and anaphylactic reactions as reported by some trials involving cardiac surgery [106, 131]. Even though a Cochrane review of aprotinin use with more than 6,000 patients reported no increased risk of myocardial infarction [96], concerns regarding its safety were raised by the Canadian Blood Conservation Using Antifibrinolytics in a Randomized Trial (BART). While comparing the antifibrinolytics agents in cardiovascular surgery, the study reported a 30-day mortality rate of 6 % in the aprotinin arm, as compared with 4 % in the TXA and aminocaproic acid groups. This amounts to a 1.53 relative risk of death associated with aprotinin. The study was subsequently terminated and aprotinin was withdrawn from the market in 2007 [132].

In addition to that, an IgG reaction to aprotinin is possible in patients upon repeated exposure, resulting in anaphylactic reactions and even shock in 6–9 % of cases [133]. The incidence drops to 1 % 6 months after exposure, compared to less than 0.1 % with no history of prior exposure [134]. Neither EACA nor TXA have been linked to anaphylactic reactions [102]. Decreased glomerular filtration rate and electrolyte excretion has also been attributed to aprotinin. Such an effect might be secondary to its affinity for renal tissue and rapid accumulation in proximal tubular epithelial cells or to inhibition of kallikrein and decreased prostaglandin synthesis [4].

## DDAVP

Desamino-8-D-arginine vasopressin (desmopressin or DDAVP) is a synthetic vasopressin-analogue with V2 vasopressin receptor agonism and little or no activity at the V1 vasopressin receptor. DDAVP has been used for treatment of diabetes insipidus and nocturnal enuresis. Its hemostatic potential is observed in patients with coagulation disorders such as von Willebrand disease, factor VIII deficiency (hemophilia A), thrombocytopenia, and platelet dysfunction secondary to uremia [135]. Stimulating the V1A vasopressin receptor is believed to trigger the release of vWF from endothelial storage sites complexed to factor VIII, thus activating factor X and the coagulation cascade.

Varying reports compare the benefit of desmopressin in cardiac surgery, but its role in orthopedic procedures has yet to be established. DDAVP reduces blood loss by 32.5 % and transfusion rate by 25.6 % in patients undergoing posterior spinal fusion and is also effective in scoliosis surgery [136]. However, its benefit has been challenged in hematologically normal patients undergoing spine surgery [137] as well as elective joint arthroplasty [138]. Several studies including a Cochrane review established the lack of evidence supporting desmopressin as a successful intervention to reduce allogeneic blood transfusion in orthopedic surgery patients who do not have congenital bleeding disorders [139].

### Dose

DDAVP is available for subcutaneous, intranasal, or intravenous administration. The recommended dose of DDAVP is 0.15–0.3 g/kg administered intravenously over 20–30 min prior to the start of the surgical procedure to spare the patient systemic hypotension.

### Safety

Rapid administration of DDAVP could cause systemic vasodilation, possibly due to endothelial cell release of prostacyclin. While the selectivity for V2 receptor spares smooth muscle, antidiuretic hormone activity might result in decreased free water clearance and hyponatremia with excessive preoperative administration of free water [140]. Despite scattered reports of arterial thrombosis, this has not been confirmed in prospective studies comparing CABG patients who received DDAVP and control groups [141, 142].

## Recombinant Factor 7

Local hemostasis is triggered by the interaction of tissue factor (TF) exposed at the site of vascular injury with activated factor VII (FVIIa) circulating in the blood. The resulting complex initiates the extrinsic pathway by activating factor X on the TF bearing cell, in turn generating thrombin (FIIa) from prothrombin (FII). Consequently, thrombin activates factor VIII, V, XI, fibrin stabilizing factor XIII and platelets and promotes the conversion of fibrinogen to fibrin [143]. The sustainability and stability of the fibrin plug and its resistance to fibrinolysis is a function of the rate and amount of thrombin generated. Activated factor VII serves as a general hemostatic agent, developed to control bleeding episodes and surgical blood loss in hemophilia patients with inhibitors or auto-antibodies against FVIII or FIX (acquired hemophilia) [144]. It was first used in 1988 in a knee surgery patient who suffered from hemophilia with antibodies to factor VIII. Factor VII promotes hemostasis by enhancing thrombin formation on activated platelets [4]. This led to question its potential use to control acute bleeding in nonhemophiliac patients with coagulopathies of various etiologies, as well as qualitative or quantitative platelet abnormalities. Furthermore, rFVIIa has been used to control life-threatening hemorrhage when other modalities such as FFPs have failed and has proved beneficial in controlling massive surgical or traumatic bleeding in hemophilic patients [4, 145].

The off-label use of factor VII was explored in different surgical specialties, including trauma, urology, and neurosurgery. Its perceived benefit in the nonhemophiliac surgical patient is based on the premise that a preoperative bolus would provide a high thrombin burst to cover the operative as well as the postoperative period [3]. The prophylactic administration of rFVII reduced perioperative blood loss but not transfusion requirements in patients undergoing major pelvic fracture surgery [146] as well as spinal fusions [147, 148]. However, the efficacy of factor VII in orthopedic surgery remains unclear in light of the lack of randomized controlled trials [26]. The current recommended dose is about 70–90 mg/kg and could be repeated after 4–6 h. With the cost of a single dose of 90 mg/kg reaching over $5,000 [33] and high rates of thromboembolic events that increase with age [149], the use of rFVIIa is currently not supported in orthopedic procedures. It may, however, be considered in cases of persistent bleeding when the coagulopathy does not respond to FFP or when practical, timing, or religious concerns preclude the use of blood products [4].

## Fibrin Sealants

A variety of topical agents have been developed to promote platelet aggregation (primary hemostasis) or the coagulation cascade (secondary hemostasis). These interventions can be stratified as either passive or active. Passive agents act through providing a physical structure for contact activation and promotion of platelet aggregation [150]. Examples include collagen-based products such as gelatin sponges, gelatin matrices, and microfibrillar collagen, or plant-based compounds containing cellulose, both of which activate the intrinsic pathway of coagulation. Active agents possess intrinsic biological activity and rely on the interplay of fibrinogen with thrombin in the presence of calcium to bypass much of the coagulation cascade and generate a fibrin clot. Their hemostatic action is less susceptible to coagulopathies caused by clotting-factor deficiencies or platelet dysfunction [33].

First-generation sealants contained animal-derived products and have fallen out of favor fueled by concerns about their potential for disease transmission and alloimmunization. Second-generation sealants are derived from humans and have an improved safety profile. Autologous platelet-rich plasma (PRP) sprays and fibrin sealants derived from the patient's own blood are currently available [138].

Fibrinogen and thrombin are the active components of all fibrin sealants [138]. When sprayed onto the wound, the activation of fibrinogen by thrombin leads to the formation of a semirigid clot. In the context of orthopedic surgery, the efficacy of fibrin sealant treatment in reducing postoperative blood loss has been substantiated in a Cochrane meta-analysis as well as in multiple trials. Fibrin sealants reduced the risk of exposure to allogeneic RBC transfusion by 32 % and postoperative bleeding by half [151] in patients undergoing total joint arthroplasty [152, 153].

The fact that fibrin sealants are derivative from human blood products remains a theoretic concern, although there has never been a reported case of infection transmission. While bovine-derived preparations entail a risk of transmission of CJD or inducing immunogenicity, commercial preparations are theoretically free of that risk. However, there is no guarantee of a "zero" risk even with the use of autologous preparations, as operators and equipment are always potential sources of contamination [154]. So far, fibrin sealants have not shown to increase the risk of transmitted infections, wound infections, duration of hospital stay, or mortality [130].

## Non-pharmacologic

### Electrocautery

High-frequency coagulation, or electrocautery, is a common hemostatic instrument in the orthopedic surgical field. It does so by heating the tissue to the point of denaturation and coagulation of blood vessels. However, as temperatures exceed 300 °C, standard electrocautery leads to circumscriptive damage of the tissue and deep conical eschars. Postoperative breakage or detachment of such clots would result in postoperative blood loss. Bipolar sealing devices such as the Aquamantys System (Salient Surgical Technologies, Portsmouth, NH) have been suggested as blood-saving alternatives to standard cautery. The system is designed to seal blood vessels in soft tissue and bone through a bipolar generator that delivers radiofrequency energy coupled to a saline pump. The saline functions as coolant as well as a conductive medium to promote even distribution of energy into the tissue. By keeping the surface temperature under 100 °C, this method limits tissue damage while effectively denaturing and shrinking collagen in arterial walls [155].

Trials exploring the efficacy of such systems in total joint arthroplasty and spine surgery have shown reduction in blood loss by up to 40 %, as well as in transfusion requirements and operating time [156–158]. On the other hand, a randomized trial conducted on patients undergoing total hip arthroplasty failed to show significant benefits of bipolar sealing devices [159]. While this could be in part caused by the application technique, further studies are needed to ultimately confirm its efficacy.

### Hypotensive Anesthesia

The concept of controlled hypotension was first described in 1917. It entails dropping a patient's systolic blood pressure to 80 or 90 mmHg and mean arterial pressure (MAP) to 50–65 mmHg. In pediatrics, the procedure aims for a 30 % reduction of baseline MAP. The technique was first achieved with phlebotomy and evolved with the advent of ganglionic blockade [4]. A lower arterial blood pressure during surgery is believed to decrease blood extravasation and local wound blood flow, thus limiting blood loss and improving surgical field visibility. Its application during joint arthroplasty as well as spine surgery reported up to 50 % reduction in intraoperative blood loss [160–162] and 40 % lower transfusion rates [163]. An overview of controlled trials in the last two decades covering 636 patients revealed that deliberate hypotension to the MAP range of 48–78 mmHg reduces blood loss most effectively for total hip arthroplasty (503 ml reduction), followed by spine fusion (318 ml reduction) [164].

The main concern with this technique is the risk of tissue hypoxia by reducing end-organ perfusion. The autoregulatory function of the arteriolar bed in end-organ tissues is responsible to maintain perfusion and blood flow over the autoregulatory limits of the tissue during the drop in MAP [165]. It has been established that the relative reduction in pressure and not cardiac output is the primary determinant of intraoperative blood loss [166]. The controversy remains as to which of the many available agents is optimal for inducing the drop in blood pressure hypotension. The effect can be achieved with spinal or epidural anesthesia, inhalational anesthetic agents, nitrovasodilators, and others such as calcium channel blockers or adrenergic antagonists. The degree of hypotension with the best risk–benefit ratio has come into question as well. A comparison between MAP levels of 60 and 50 mmHg failed to demonstrate any reduction in transfusion requirements, postoperative hematocrit, or the duration of surgery, even though lower pressures were associated with less intraoperative blood loss. Lower MAPs may be useful in cemented arthroplasty, as less blood improves the interdigitation at the cement–bone interface [167].

### Safety

Hypotensive anesthesia has been associated with a morbidity rate of 2.5 % and mortality between 0.02 % and 0.60 %. The most common complications are delayed wakening, blurred vision, and delayed bleeding [168]. Given the risk of organ hypoperfusion, it is advised to use this method with caution in patients with known cardiac, cerebral, peripheral vascular disease, or severe anemia. It should not be used in combination with other hypotension-inducing approaches such as hemodilution.

## Hemodilution

Acute normovolemic hemodilution (ANH) involves the extraction and anticoagulation of a predicted blood volume from the patient and its simultaneous exchange for a

cell-free crystalloid or colloid solution to maintain normovolemia. If colloid is used for the replacement fluid, 1 ml of colloid solution is infused for each milliliter of blood drawn; if crystalloids are used, 2–3 ml of crystalloid solution are infused for each milliliter of blood drawn [169, 170]. The volume of blood that can be extracted is estimated by the formula [170]:

$$V = \frac{\text{EBV} \times (H_i - H_f)}{H_{av}}$$

where $V$ = volume of blood to be removed; EBV = estimated blood volume (body weight in kg × 70 ml/kg for an adult), $H_i$ = the patient's initial hematocrit level prior to the onset of hemodilution; $H_f$ = the patient's desired hematocrit level at the end of hemodilution; $H_{av}$ = the patient's average hematocrit level during hemodilution (average of $H_i$ + $H_f$). Infusion of crystalloid solution without phlebotomy or hypervolemic hemodilution, bears similar theoretical advantages and limitations [171].

The proposed advantage of such a procedure lies in diluting the blood lost during surgery and preserving higher concentrated autologous blood for reinfusion. The activity of coagulation factors and platelets is maintained in the blood as it is only stored for a short period of time [4]. Furthermore, with virtually no risk of bacterial contamination or administrative error, this procedure does not require testing or screening. It is therefore less costly and more practical than PABD [172]. The induced state of anemia is countered by increased venous return, peripheral vasodilation, increased cardiac output, and rightward shift of the hemoglobin dissociation curve. These compensatory physiological mechanisms preserve oxygen delivery and optimize oxygen extraction at the tissue level [4]. As long as normovolemia is preserved during the process, stroke volume and cardiac output increase with no change in heart rate [173].

While some studies support the finding that ANH is equivalent to PABD in both total hip [174] and total knee [175] arthroplasty as well as spinal fusion and instrumentation [176], others including two meta-analyses revealed a modest efficacy in reducing allogeneic transfusions [34, 177, 178] or none at all [179–181]. The meta-analyses failed to support the widespread adoption of this intervention [178] due to lack of properly randomized controlled trials and reduced efficacy of hemodilution when integrated in a transfusion protocol [34]. As the cost of ANH runs at approximately 50–75 % less than PABD [174, 175], it may be of value to procedures with more than 1,000 ml of blood loss, especially in combination with other blood sparing measures [182] such as intraoperative blood salvage or preoperative erythropoietin administration, known as "augmented ANH" [4].

### Safety

ANH has not been reported to increase rate of morbidity, infection, hospital stay, or mortality [34]. It is contraindicated in patients with coronary, renal, pulmonary, or severe hepatic disease [183, 184].

## Tourniquet

The widespread use of pneumatic tourniquets in elective surgery stems from the belief that they serve to decrease intraoperative blood and create a bloodless surgical field. They are inflated above systemic pressure to optimize exposure and cementing in total knee arthroplasty [185, 186] and in foot and ankle surgery [187]. While it may in fact facilitate the procedure and reduce operating time, the efficacy of tourniquets as a blood saving measure is not widely accepted [188].

In a meta-analysis of 1,040 TKRs in 991 patients, employing a tourniquet decreased intraoperative blood loss, but failed to affect postoperative drain output, or overall transfusion rates [189, 190]. This suggests that patients with a tourniquet have more hidden blood loss after the operation [191]. The inefficiency of this intervention is attributed to reactive hyperemia which peaks within 5 min after the tourniquet is released [192]. In addition to that, a certain degree of reperfusion injury and edema ensues after tourniquet. Reports of increased risk of nerve palsy, vascular injury, muscle damage, postoperative swelling, and stiffness are abundant in the literature [193–196]. Perioperative hypoxia and reduced postoperative tissue perfusion might undermine immune function and wound healing, risking early postoperative infection [197, 198]. Applying a tourniquet during TKA could cause fibrinolysis, platelet dysfunction, venous stasis, and blood vessel wall damage [199]. The combination of these factors might increase the rate of deep vein thrombosis (DVT) and pulmonary thromboembolism (PE) in total knee arthroplasty [200, 201].

The impact of timing on tourniquet release is equally controversial. While deflation of the cuff before closure of the wound has been advocated to optimize hemostasis, it has been found to increase blood loss [202]. On the other hand, tourniquet release after wound closure can increase the risk of postoperative hematoma [203, 204].

No clear consensus has been reached on this topic and tourniquet use is guided by personal preference.

## Intraoperative/Postoperative Blood Reinfusion

Intraoperative blood salvage involves the collection of drainage or suction blood and its reinfusion [205]. This

technique offers recovery of up to 60 % of the blood loss using filtered or unfiltered cell savers [28, 206].

As with other interventions targeting autologous blood, the efficacy of perioperative cell salvage depends on the overall blood loss. Approximately 750 ml of drainage blood are required to recover the equivalent of 1 unit of packed red blood cells [34]. The use of washed and unwashed cell salvage in orthopedic surgery showed very similar results in reduction of the relative risk of exposure to red cell transfusion (52 % vs. 53 %) [207–209]. However, the safety of perioperative reinfusion remains controversial [93] as it has been associated with adverse events such as febrile reactions possibly due to increased cytokine concentrations in the transfused drainage blood [210]. Complications of unwashed reinfusion included hypertension, hyperthermia, upper airway edema, coagulopathy, febrile reaction, and even death [211, 212].

### Safety

No association with increased mortality or morbidity was reported in two meta-analyses of randomized trials and observational studies of either intraoperative or postoperative cell salvage [34, 213]. Contraindications to the use of blood recovery include the potential for aspiration of malignant cells, the presence of infection, and contaminants [214].

## Postoperative Period

### Drains

Postoperative wound drains aim at avoiding postoperative hematoma formation. By increasing tension and decreasing perfusion, a hematoma impairs wound healing and provides a medium for bacterial growth [215]. Inefficient drainage might cause pain and stiffness resulting in delayed rehabilitation and extended hospital stay [216]. Conversely, drains may provide a conduit for the entry of bacteria and compromise resistance to infection [217, 218]. 90 % of the blood is collected within the first 24 h after which the risk of retrograde infection surpasses any proposed benefit, and the drain should be discontinued [219].

A Cochrane meta-analysis failed to note any significant difference in the incidence of wound infection, hematoma, dehiscence or reoperations between drained and undrained wounds in orthopedic patients [220]. Whereas more blood transfusions were associated with the use of drains, increased bruising and more frequent dressing reinforcement were reported in the control group. The review concluded that there was insufficient evidence to support the routine use of closed suction drainage in orthopedic surgery [14, 215, 216, 220].

### Transfusion Trigger

The World Health Organization defines anemia by a hemoglobin level less than 13 g/dl in men and less than 12 g/dl in women [221]. According to current guidelines from the American Society of Anesthesiologists, RBC transfusions are recommended if the hemoglobin concentration drops below 6–10 g/dl. While transfusions in patients with a hemoglobin over 10 g/dl are rarely indicated, there is little debate that patients with a hemoglobin below 6 g/dl should be transfused [222]. Hemoglobin levels below 6.4 g/dl have been associated with impaired cognitive function and below 4.8 g/dl with a mortality of 50 % [223].

Lower transfusion triggers have also been shown to be safe and effective for patients undergoing cardiac surgery [224] and critically ill patients [225]. Thus, transfusion trigger might be lowered for younger patients (Hb $\leq$ 70 g/dl) and should be raised (Hb $\leq$ 80 g/dl) for older patients and those with comorbidities [26].

In 1988, the Health Consensus Development Conference advocated a hemoglobin level of 8 g/dl as the indication for transfusion and recommended that decisions regarding transfusion should include an assessment of clinical needs and symptoms rather than depend on laboratory values. Setting a transfusion trigger is ultimately the function of:

1. The underlying health of the patient
2. The change in the level of hemoglobin
3. The absolute level of hemoglobin
4. The development of cardiovascular symptoms

## Combination of Techniques/Algorithm

Many of the techniques and concepts discussed in this chapter can be combined. The Conference of Experts on the Rational Use of Drugs, convened by the World Health Organization states that “the rational use of medicines requires that patients receive medications appropriate to their clinical needs, in doses that meet their own individual requirements, for an adequate period of time, and at the lowest cost to them and their community” [26]. Such individualized approaches to blood management lead the way to blood-less orthopedic surgery. “The determination of whether intermediate hemoglobin concentrations justify or require red blood cell transfusion should be based on any ongoing indication of organ ischemia, potential or actual ongoing bleeding (rate and magnitude), the patient’s intravascular volume status, and risk factors for complications of inadequate oxygenation” [222].

## Summary

Elective orthopedic procedures such as total joint arthroplasty involve significant blood loss. Despite the evolution of safer transfusion practices, transmission of infection remains a potentially devastating complication to any patient. The development of various blood management interventions highlights the need to reduce allogeneic transfusions in various surgical disciplines. Individual preoperative assessment of transfusion risk is crucial to identify the best-suited modalities to minimize blood requirements. Bloodless procedures can only be achieved through patient-tailored protocols that employ the best-suited modalities for each case, maximizing efficacy while reducing cost and adverse effects.

**Summary Bullet Points**

- Major orthopedic procedures entail significant blood loss in patient groups with high prevalence of anemia.
- The vital role of allogeneic blood is widely established in managing life-threatening blood loss. However, the safety profile of such transfusions is still far from perfect.
- Various perioperative modalities have proven capable of minimizing or even eliminating transfusion requirements in elective orthopedic procedures.
- Perioperative blood management is a multimodal planned approach to patient care. It should be regarded as the standard of care in elective orthopedic procedures.

## Case Study

A case study for this chapter is included in Appendix P at the end of this book.

## References

1. McManus KT, Velchik MG, Alavi A, Lotke PA. Non-invasive assessment of post-operative bleeding in TKA patients with Tc-99m RBCs. J Nucl Med. 1987;28:565.
2. Shapiro F, Zurakowski D, Sethna NF. Tranexamic acid diminishes intraoperative blood loss and transfusion in spinal fusions for duchenne muscular dystrophy scoliosis. Spine (Phila Pa 1976). 2007;32(20):2278–83.
3. Goodnough LT, Shander A, Brecher ME. Transfusion medicine: looking to the future. Lancet. 2003;361(9352):161–9.
4. Tobias JD. Strategies for minimizing blood loss in orthopedic surgery. Semin Hematol. 2004;41(1 Suppl 1):145–56.
5. Eder AF, et al. The American Red Cross Hemovigilance Program: advancing the safety of blood donation and transfusion. Immunohematology. 2009;25(4):179–85.
6. Blajchman MA. Transfusion immunomodulation or TRIM: what does it mean clinically? Hematology. 2005; 10 Suppl 1:208–14.
7. Triulzi DJ, et al. A clinical and immunologic study of blood transfusion and postoperative bacterial infection in spinal surgery. Transfusion. 1992;32(6):517–24.
8. Fernandez MC, Gottlieb M, Menitove JE. Blood transfusion and postoperative infection in orthopedic patients. Transfusion. 1992;32(4):318–22.
9. Adams RC, Lundy JS. Anesthesia in cases of poor surgical risk. Some suggestions for decreasing the risk. Surg Gynecol Obstet. 1942;74:1011–9.
10. McLean E, et al. Worldwide prevalence of anaemia, WHO Vitamin and Mineral Nutrition Information System, 1993–2005. Public Health Nutr. 2009;12(4):444–54.
11. Spahn DR. Anemia and patient blood management in hip and knee surgery: a systematic review of the literature. Anesthesiology. 2010;113(2):482–95.
12. Callaghan JJ, Rosenberg AG, Rubash HE. The adult hip. Philadelphia, PA: Lippincott Williams & Wilkins; 2007.
13. Pola E, et al. Clinical factors associated with an increased risk of perioperative blood transfusion in nonanemic patients undergoing total hip arthroplasty. J Bone Joint Surg Am. 2004;86-A(1):57–61.
14. Callaghan JJ, Spitzer AI. Blood management and patient specific transfusion options in total joint replacement surgery. Iowa Orthop J. 2000;20:36–45.
15. Clemens J, Spivak JL. Serum immunoreactive erythropoietin during the perioperative period. Surgery. 1994;115(4):510–5.
16. van Iperen CE, et al. Iron metabolism and erythropoiesis after surgery. Br J Surg. 1998;85(1):41–5.
17. Rosencher N, et al. Blood conservation approaches in orthopedic surgery. Transfus Clin Biol. 2008;15(5):294–302.
18. Keating EM. Preoperative evaluation and methods to reduce blood use in orthopedic surgery. Anesthesiol Clin North America. 2005;23(2):305–13. vi–vii.
19. Chassot PG, Delabays A, Spahn DR. Perioperative use of antiplatelet drugs. Best Pract Res Clin Anaesthesiol. 2007;21 (2):241–56.
20. Bong MR, et al. Risks associated with blood transfusion after total knee arthroplasty. J Arthroplasty. 2004;19(3):281–7.
21. Carson JL, et al. Effect of anaemia and cardiovascular disease on surgical mortality and morbidity. Lancet. 1996;348 (9034):1055–60.
22. Glassner PJ, et al. Blood, bugs, and motion—what do we really know in regard to total joint arthroplasty? Bull NYU Hosp Jt Dis. 2011;69(1):73–80.
23. Transfusion alert: use of autologous blood. National Heart, Lung, and Blood Institute Expert Panel on the use of Autologous Blood. Transfusion. 1995;35(8):703–11.
24. Karger R, Kretschmer V. Modern concepts of autologous haemotherapy. Transfus Apher Sci. 2005;32(2):185–96.
25. Garcia-Erce JA, et al. Predeposit autologous donation in spinal surgery: a multicentre study. Eur Spine J. 2004;13 Suppl 1:S34–9.
26. Munoz M, et al. Blood conservation strategies in major orthopaedic surgery: efficacy, safety and European regulations. Vox Sang. 2009;96(1):1–13.
27. Kleinert K, et al. Alternative procedures for reducing allogeneic blood transfusion in elective orthopedic surgery. HSS J. 2010;6 (2):190–8.
28. Sculco TP. Global blood management in orthopaedic surgery. Clin Orthop Relat Res. 1998;357:43–9.
29. Stanisavljevic S, Walker RH, Bartman CR. Autologous blood transfusion in total joint arthroplasty. J Arthroplasty. 1986;1 (3):207–9.

30. Bae H, et al. The effect of preoperative donation of autologous blood on deep-vein thrombosis after total hip arthroplasty. J Bone Joint Surg Br. 2001;83(5):676–9.
31. Anders MJ, et al. Effect of preoperative donation of autologous blood on deep-vein thrombosis following total joint arthroplasty of the hip or knee. J Bone Joint Surg Am. 1996;78(4):574–80.
32. Henry DA, et al. Pre-operative autologous donation for minimising perioperative allogeneic blood transfusion. Cochrane Database Syst Rev. 2002(2):CD003602.
33. Tse EY, et al. Reducing perioperative blood loss and allogeneic blood transfusion in patients undergoing major spine surgery. J Bone Joint Surg Am. 2011;93(13):1268–77.
34. Carless P, et al. Autologous transfusion techniques: a systematic review of their efficacy. Transfus Med. 2004;14(2):123–44.
35. Rosencher N, et al. Orthopedic Surgery Transfusion Hemoglobin European Overview (OSTHEO) study: blood management in elective knee and hip arthroplasty in Europe. Transfusion. 2003;43(4):459–69.
36. Bierbaum BE, et al. An analysis of blood management in patients having a total hip or knee arthroplasty. J Bone Joint Surg Am. 1999;81(1):2–10.
37. Bezwada HP, et al. Preoperative use of recombinant human erythropoietin before total joint arthroplasty. J Bone Joint Surg Am. 2003;85-A(9):1795–800.
38. Garcia-Erce JA, et al. Recombinant human erythropoietin facilitates autologous blood donation in children undergoing corrective spinal surgery. Transfusion. 2005;45(5):820–1. author reply 821–2.
39. Millett PJ, et al. Analysis of transfusion predictors in shoulder arthroplasty. J Bone Joint Surg Am. 2006;88(6):1223–30.
40. Boettner F, et al. Nonanemic patients do not benefit from autologous blood donation before total hip replacement. HSS J. 2010;6 (1):66–70.
41. Karger R, Kretschmer V. Pre-operative autologous blood and plasma donation and retransfusion. Baillieres Clin Anaesthesiol. 2005;11:319–33.
42. Beris P, et al. Perioperative anaemia management: consensus statement on the role of intravenous iron. Br J Anaesth. 2008;100(5):599–604.
43. Andrews CM, Lane DW, Bradley JG. Iron pre-load for major joint replacement. Transfus Med. 1997;7(4):281–6.
44. Auerbach M, Coyne D, Ballard H. Intravenous iron: from anathema to standard of care. Am J Hematol. 2008;83(7):580–8.
45. Weiss G, Goodnough LT. Anemia of chronic disease. N Engl J Med. 2005;352(10):1011–23.
46. Cuenca J, et al. Preoperative haematinics and transfusion protocol reduce the need for transfusion after total knee replacement. Int J Surg. 2007;5(2):89–94.
47. Garcia-Erce JA, et al. Perioperative intravenous iron preserves iron stores and may hasten the recovery from post-operative anaemia after knee replacement surgery. Transfus Med. 2006;16 (5):335–41.
48. Garcia-Erce JA, et al. Perioperative stimulation of erythropoiesis with intravenous iron and erythropoietin reduces transfusion requirements in patients with hip fracture. A prospective observational study. Vox Sang. 2005;88(4):235–43.
49. Salerno SM, et al. Impact of perioperative cardiac assessment guidelines on management of orthopedic surgery patients. Am J Med. 2007;120(2):185.e1–6.
50. Ganz T. Hepcidin, a key regulator of iron metabolism and mediator of anemia of inflammation. Blood. 2003;102(3):783–8.
51. van der Putten K, et al. Mechanisms of disease: erythropoietin resistance in patients with both heart and kidney failure. Nat Clin Pract Nephrol. 2008;4(1):47–57.
52. Fotland SS, et al. Does the preoperative iron status predict transfusion requirement of orthopedic patients? Transfus Apher Sci. 2009;40(3):213–7.
53. Chertow GM, et al. Update on adverse drug events associated with parenteral iron. Nephrol Dial Transplant. 2006;21(2):378–82.
54. Kumar A. Perioperative management of anemia: limits of blood transfusion and alternatives to it. Cleve Clin J Med. 2009;76 Suppl 4:S112–8.
55. Faris PM, Ritter MA, Abels RI. The effects of recombinant human erythropoietin on perioperative transfusion requirements in patients having a major orthopaedic operation. The American Erythropoietin Study Group. J Bone Joint Surg Am. 1996;78(1):62–72.
56. Feagan BG, et al. Erythropoietin with iron supplementation to prevent allogeneic blood transfusion in total hip joint arthroplasty. A randomized, controlled trial. Ann Intern Med. 2000;133 (11):845–54.
57. Weber EW, et al. Effects of epoetin alfa on blood transfusions and postoperative recovery in orthopaedic surgery: the European Epoetin Alfa Surgery Trial (EEST). Eur J Anaesthesiol. 2005;22 (4):249–57.
58. Fauci A, Braunwald E, Kasper D, Hauser S, Longo D, Jameson J, et al. Harrison's principles of internal medicine. 17th ed. New York: McGraw-Hill; 2008.
59. Moonen AF, et al. Pre-operative injections of epoetin-alpha versus post-operative retransfusion of autologous shed blood in total hip and knee replacement: a prospective randomised clinical trial. J Bone Joint Surg Br. 2008;90(8):1079–83.
60. Vitale MG, et al. Efficacy of preoperative erythropoietin administration in pediatric neuromuscular scoliosis patients. Spine (Phila Pa 1976). 2007;32(24):2662–7.
61. Rosencher N, et al. Two injections of erythropoietin correct moderate anemia in most patients awaiting orthopedic surgery. Can J Anaesth. 2005;52(2):160–5.
62. Regis D, et al. Recombinant human erythropoietin in pediatric patients: efficacy in facilitating autologous blood donation in spinal deformity surgery. Chir Organi Mov. 2004;89(4):299–303.
63. Colomina MJ, et al. Preoperative erythropoietin in spine surgery. Eur Spine J. 2004;13 Suppl 1:S40–9.
64. Lee GC, et al. Use of erythropoietin in two-stage reimplantation total hip arthroplasty. Clin Orthop Relat Res. 2003;414:49–54.
65. Wurnig C, et al. Subcutaneous low-dose epoetin beta for the avoidance of transfusion in patients scheduled for elective surgery not eligible for autologous blood donation. Eur Surg Res. 2001;33 (5–6):303–10.
66. Tamir L, et al. Recombinant human erythropoietin reduces allogeneic blood transfusion requirements in patients undergoing major orthopedic surgery. Haematologia (Budap). 2000;30 (3):193–201.
67. Stowell CP, et al. An open-label, randomized study to compare the safety and efficacy of perioperative epoetin alfa with preoperative autologous blood donation in total joint arthroplasty. Orthopedics. 1999;22(1 Suppl):s105–12.
68. Mercuriali F, et al. Epoetin alfa in low hematocrit patients to facilitate autologous blood donation in total hip replacement: a randomized, double-blind, placebo-controlled, dose-ranging study. Acta Haematol. 1998;100(2):69–76.
69. Vitale MG, et al. The effectiveness of preoperative erythropoietin in averting allogenic blood transfusion among children undergoing scoliosis surgery. J Pediatr Orthop B. 1998;7(3):203–9.
70. Cazenave JP, et al. Epoetin alfa facilitates presurgical autologous blood donation in non-anaemic patients scheduled for orthopaedic or cardiovascular surgery. Eur J Anaesthesiol. 1997;14(4):432–42.
71. Tryba M. Epoetin alfa plus autologous blood donation in patients with a low hematocrit scheduled to undergo orthopedic surgery. Semin Hematol. 1996;33(2 Suppl 2):22–4. discussion 25–6.

72. de Andrade JR, et al. Baseline hemoglobin as a predictor of risk of transfusion and response to Epoetin alfa in orthopedic surgery patients. Am J Orthop (Belle Mead NJ). 1996;25(8):533–42.
73. Goldberg MA, et al. A safety and efficacy comparison study of two dosing regimens of epoetin alfa in patients undergoing major orthopedic surgery. Am J Orthop (Belle Mead NJ). 1996;25 (8):544–52.
74. Goodnough LT, et al. A phase III trial of recombinant human erythropoietin therapy in nonanemic orthopedic patients subjected to aggressive removal of blood for autologous use: dose, response, toxicity, and efficacy. Transfusion. 1994;34(1):66–71.
75. Schlaeppi B, Gunter P, Nydegger UE. Enhancing the efficacy of preoperative autologous blood donation by erythropoietin. Transfus Sci. 1994;15(2):171–7.
76. Mercuriali F, et al. Use of recombinant human erythropoietin to assist autologous blood donation by anemic rheumatoid arthritis patients undergoing major orthopedic surgery. Transfusion. 1994;34(6):501–6.
77. Beris P, et al. Recombinant human erythropoietin as adjuvant treatment for autologous blood donation. A prospective study. Vox Sang. 1993;65(3):212–8.
78. Laupacis A, Feagan B, Wong C. Effectiveness of perioperative recombinant human erythropoietin in elective hip replacement. COPES Study Group. Lancet. 1993;342(8867):378.
79. Biesma DH, et al. The efficacy of subcutaneous recombinant human erythropoietin in the correction of phlebotomy-induced anemia in autologous blood donors. Transfusion. 1993;33 (10):825–9.
80. Mercuriali F, et al. Use of erythropoietin to increase the volume of autologous blood donated by orthopedic patients. Transfusion. 1993;33(1):55–60.
81. Goodnough LT, et al. Preoperative red cell production in patients undergoing aggressive autologous blood phlebotomy with and without erythropoietin therapy. Transfusion. 1992;32(5):441–5.
82. Hochreiter J, et al. Preoperative autologous blood collection under erythropoietin stimulation. Preliminary results in patient selection, erythropoietin dosage and administration. Z Orthop Ihre Grenzgeb. 1992;130(6):519–23.
83. Tasaki T, et al. Recombinant human erythropoietin for autologous blood donation: effects on perioperative red-blood-cell and serum erythropoietin production. Lancet. 1992;339(8796):773–5.
84. von Bormann B, et al. Recombinant erythropoietin in autologous blood donation. Anaesthesist. 1991;40(7):386–90.
85. Graf H, et al. Recombinant human erythropoietin as adjuvant treatment for autologous blood donation. BMJ. 1990;300 (6740):1627–8.
86. Goodnough LT, et al. Increased preoperative collection of autologous blood with recombinant human erythropoietin therapy. N Engl J Med. 1989;321(17):1163–8.
87. Eschbach JW. Iron requirements in erythropoietin therapy. Best Pract Res Clin Haematol. 2005;18(2):347–61.
88. Fauci AS. Harrison's principles of internal medicine: companion handbook. 14th ed. New York: McGraw-Hill, Health Professions Division; 1998.
89. Lemaire R. Strategies for blood management in orthopaedic and trauma surgery. J Bone Joint Surg Br. 2008;90(9):1128–36.
90. Kourtzis N, Pafilas D, Kasimatis G. Blood saving protocol in elective total knee arthroplasty. Am J Surg. 2004;187(2):261–7.
91. Cheung W, Minton N, Gunawardena K. Pharmacokinetics and pharmacodynamics of epoetin alfa once weekly and three times weekly. Eur J Clin Pharmacol. 2001;57(5):411–8.
92. Cheung WK, et al. Comparative pharmacokinetics, safety, and tolerability after subcutaneous administration of recombinant human erythropoietin formulated with different stabilizers. Biopharm Drug Dispos. 2000;21(6):211–9.
93. Faris PM, et al. Unwashed filtered shed blood collected after knee and hip arthroplasties. A source of autologous red blood cells. J Bone Joint Surg Am. 1991;73(8):1169–78.
94. Goodnough LT, Monk TG, Andriole GL. Erythropoietin therapy. N Engl J Med. 1997;336(13):933–8.
95. Rosencher N, et al. Preoperative strategy for homologous blood salvage and peri-operative erythropoietin. Transfus Clin Biol. 1999;6(6):370–9.
96. Henry DA, et al. Anti-fibrinolytic use for minimising perioperative allogeneic blood transfusion. Cochrane Database Syst Rev. 2007(4): CD001886.
97. Faught C, et al. Adverse effects of methods for minimizing perioperative allogeneic transfusion: a critical review of the literature. Transfus Med Rev. 1998;12(3):206–25.
98. Mannucci PM. Hemostatic drugs. N Engl J Med. 1998;339 (4):245–53.
99. Eubanks JD. Antifibrinolytics in major orthopaedic surgery. J Am Acad Orthop Surg. 2010;18(3):132–8.
100. Risberg B. The response of the fibrinolytic system in trauma. Acta Chir Scand Suppl. 1985;522:245–71.
101. Ellis MH, et al. The effect of tourniquet application, tranexamic acid, and desmopressin on the procoagulant and fibrinolytic systems during total knee replacement. J Clin Anesth. 2001;13 (7):509–13.
102. Henry DA, et al. Anti-fibrinolytic use for minimising perioperative allogeneic blood transfusion. Cochrane Database Syst Rev. 2001(1): CD001886.
103. Smith CR. Management of bleeding complications in redo cardiac operations. Ann Thorac Surg. 1998;65(4 Suppl):S2–8. discussion S27–8.
104. Royston D. Aprotinin versus lysine analogues: the debate continues. Ann Thorac Surg. 1998;65(4 Suppl):S9–19. discussion S27–8.
105. Wells PS. Safety and efficacy of methods for reducing perioperative allogeneic transfusion: a critical review of the literature. Am J Ther. 2002;9(5):377–88.
106. Laupacis A, Fergusson D. Drugs to minimize perioperative blood loss in cardiac surgery: meta-analyses using perioperative blood transfusion as the outcome. The International Study of Peri-operative Transfusion (ISPOT) Investigators. Anesth Analg. 1997;85(6):1258–67.
107. Benoni G, Fredin H. Fibrinolytic inhibition with tranexamic acid reduces blood loss and blood transfusion after knee arthroplasty: a prospective, randomised, double-blind study of 86 patients. J Bone Joint Surg Br. 1996;78(3):434–40.
108. Orpen NM, et al. Tranexamic acid reduces early post-operative blood loss after total knee arthroplasty: a prospective randomised controlled trial of 29 patients. Knee. 2006;13(2):106–10.
109. Hiippala S, et al. Tranexamic acid (Cyklokapron) reduces perioperative blood loss associated with total knee arthroplasty. Br J Anaesth. 1995;74(5):534–7.
110. Lin PC, et al. Does tranexamic acid save blood in minimally invasive total knee arthroplasty? Clin Orthop Relat Res. 2011;469(7):1995–2002.
111. Sukeik M, et al. Systematic review and meta-analysis of the use of tranexamic acid in total hip replacement. J Bone Joint Surg Br. 2011;93(1):39–46.
112. Gehrig LM. Orthopedic surgery. Am J Surg. 2011;202(3):364–8.
113. Capdevila X, et al. Aprotinin decreases blood loss and homologous transfusions in patients undergoing major orthopedic surgery. Anesthesiology. 1998;88(1):50–7.
114. Florentino-Pineda I, et al. The effect of epsilon-aminocaproic acid on perioperative blood loss in patients with idiopathic scoliosis undergoing posterior spinal fusion: a preliminary prospective study. Spine (Phila Pa 1976). 2001;26(10):1147–51.

115. Neilipovitz DT, et al. A randomized trial of tranexamic acid to reduce blood transfusion for scoliosis surgery. Anesth Analg. 2001;93(1):82–7.
116. Grant JA, et al. Perioperative blood transfusion requirements in pediatric scoliosis surgery: the efficacy of tranexamic acid. J Pediatr Orthop. 2009;29(3):300–4.
117. Amar D, et al. Antifibrinolytic therapy and perioperative blood loss in cancer patients undergoing major orthopedic surgery. Anesthesiology. 2003;98(2):337–42.
118. Kovesi T, Royston D. Pharmacological approaches to reducing allogeneic blood exposure. Vox Sang. 2003;84(1):2–10.
119. Elwatidy S, et al. Efficacy and safety of prophylactic large dose of tranexamic acid in spine surgery: a prospective, randomized, double-blind, placebo-controlled study. Spine (Phila Pa 1976). 2008;33(24):2577–80.
120. Tsutsumimoto T, et al. Tranexamic acid reduces perioperative blood loss in cervical laminoplasty: a prospective randomized study. Spine (Phila Pa 1976). 2011;36(23):1913–8.
121. Wong J, et al. Tranexamic acid reduces perioperative blood loss in adult patients having spinal fusion surgery. Anesth Analg. 2008;107(5):1479–86.
122. Urban MK, et al. The efficacy of antifibrinolytics in the reduction of blood loss during complex adult reconstructive spine surgery. Spine (Phila Pa 1976). 2001;26(10):1152–6.
123. Kasimian S, et al. Aprotinin in pediatric neuromuscular scoliosis surgery. Eur Spine J. 2008;17(12):1671–5.
124. Cole JW, et al. Aprotinin reduces blood loss during spinal surgery in children. Spine (Phila Pa 1976). 2003;28(21):2482–5.
125. Tzortzopoulou A, et al. Antifibrinolytic agents for reducing blood loss in scoliosis surgery in children. Cochrane Database Syst Rev. 2008(3):CD006883.
126. Engel JM, et al. Regional hemostatic status and blood requirements after total knee arthroplasty with and without tranexamic acid or aprotinin. Anesth Analg. 2001;92(3):775–80.
127. Langdown AJ, et al. Aprotinin (Trasylol) does not reduce bleeding in primary total hip arthroplasty. J Arthroplasty. 2000;15 (8):1009–12.
128. Tanaka N, et al. Timing of the administration of tranexamic acid for maximum reduction in blood loss in arthroplasty of the knee. J Bone Joint Surg Br. 2001;83(5):702–5.
129. Zohar E, et al. The postoperative blood-sparing efficacy of oral versus intravenous tranexamic acid after total knee replacement. Anesth Analg. 2004;99(6):1679–83. table of contents.
130. Carless PA, Henry DA, Anthony DM. Fibrin sealant use for minimising peri-operative allogeneic blood transfusion. Cochrane Database Syst Rev. 2003(2):CD004171.
131. Mangano DT, Tudor IC, Dietzel C. The risk associated with aprotinin in cardiac surgery. N Engl J Med. 2006;354(4):353–65.
132. Fergusson DA, et al. A comparison of aprotinin and lysine analogues in high-risk cardiac surgery. N Engl J Med. 2008;358 (22):2319–31.
133. Slaughter TF, Greenberg CS. Antifibrinolytic drugs and perioperative hemostasis. Am J Hematol. 1997;56(1):32–6.
134. Scheule AM, et al. The significance of preformed aprotinin-specific antibodies in cardiosurgical patients. Anesth Analg. 2000;90(2):262–6.
135. Mannucci PM. Desmopressin: a nontransfusional form of treatment for congenital and acquired bleeding disorders. Blood. 1988;72(5):1449–55.
136. Kobrinsky NL, et al. 1-Desamino-8-D-arginine vasopressin (desmopressin) decreases operative blood loss in patients having Harrington rod spinal fusion surgery. A randomized, double-blinded, controlled trial. Ann Intern Med. 1987;107(4):446–50.
137. Theroux MC, et al. A study of desmopressin and blood loss during spinal fusion for neuromuscular scoliosis: a randomized, controlled, double-blinded study. Anesthesiology. 1997;87(2):260–7.
138. Thoms RJ, Marwin SE. The role of fibrin sealants in orthopaedic surgery. J Am Acad Orthop Surg. 2009;17(12):727–36.
139. Carless PA, et al. Desmopressin for minimising perioperative allogeneic blood transfusion. Cochrane Database Syst Rev. 2004 (1):CD001884.
140. Shepherd LL, et al. Hyponatremia and seizures after intravenous administration of desmopressin acetate for surgical hemostasis. J Pediatr. 1989;114(3):470–2.
141. Marquez J, et al. Repeated dose administration of desmopressin acetate in uncomplicated cardiac surgery: a prospective, blinded, randomized study. J Cardiothorac Vasc Anesth. 1992;6(6):674–6.
142. Brown MR, et al. Desmopressin acetate following cardiopulmonary bypass: evaluation of coagulation parameters. J Cardiothorac Anesth. 1989;3(6):726–9.
143. Roberts HR, Monroe DM, Hoffman M. Molecular biology and biochemistry of the coagulation factors and pathways of hemostasis. In: Lichtman MA, Beutler E, Coller BS, Kipps TJ, Seligsohn U, editors. Williams hematology. New York: McGraw-Hill; 2011. p. 1409–34.
144. Hedner U, Lee CA. First 20 years with recombinant FVIIa (NovoSeven). Haemophilia. 2011;17(1):e172–82.
145. Mariani G, et al. Recombinant, activated factor VII for surgery in factor VII deficiency: a prospective evaluation—the surgical STER. Br J Haematol. 2011;152(3):340–6.
146. Raobaikady R, et al. Use of activated recombinant coagulation factor VII in patients undergoing reconstruction surgery for traumatic fracture of pelvis or pelvis and acetabulum: a double-blind, randomized, placebo-controlled trial. Br J Anaesth. 2005;94 (5):586–91.
147. Kolban M, Balachowska-Kosciolek I, Chmielnicki M. Recombinant coagulation factor VIIa—a novel haemostatic agent in scoliosis surgery? Eur Spine J. 2006;15(6):944–52.
148. Sachs B, et al. Recombinant activated factor VII in spinal surgery: a multicenter, randomized, double-blind, placebo-controlled, dose-escalation trial. Spine (Phila Pa 1976). 2007;32 (21):2285–93.
149. Levi M, et al. Safety of recombinant activated factor VII in randomized clinical trials. N Engl J Med. 2010;363 (19):1791–800.
150. Schonauer C, et al. The use of local agents: bone wax, gelatin, collagen, oxidized cellulose. Eur Spine J. 2004;13 Suppl 1: S89–96.
151. Wang GJ, et al. Use of fibrin sealant to reduce bloody drainage and hemoglobin loss after total knee arthroplasty: a brief note on a randomized prospective trial. J Bone Joint Surg Am. 2001;83-A (10):1503–5.
152. Levy O, et al. The use of fibrin tissue adhesive to reduce blood loss and the need for blood transfusion after total knee arthroplasty. A prospective, randomized, multicenter study. J Bone Joint Surg Am. 1999;81(11):1580–8.
153. Wang GJ, et al. Fibrin sealant reduces perioperative blood loss in total hip replacement. J Long Term Eff Med Implants. 2003;13 (5):399–411.
154. Radosevich M, Goubran HI, Burnouf T. Fibrin sealant: scientific rationale, production methods, properties, and current clinical use. Vox Sang. 1997;72(3):133–43.
155. Zeh A, et al. The Aquamantys system—an alternative to reduce blood loss in primary total hip arthroplasty? J Arthroplasty. 2010;25(7):1072–7.
156. Marulanda GA, et al. Hemostasis using a bipolar sealer in primary unilateral total knee arthroplasty. Am J Orthop (Belle Mead NJ). 2009;38(12):E179–83.
157. Marulanda GA, et al. Reductions in blood loss with a bipolar sealer in total hip arthroplasty. Expert Rev Med Devices. 2008;5 (2):125–31.

158. Marulanda GA, et al. Reductions in blood loss with use of a bipolar sealer for hemostasis in primary total knee arthroplasty. Surg Technol Int. 2005;14:281–6.
159. Krebs VE, et al. Blood management in joint replacement surgery: what's in and what's out. Orthopedics. 2006;29(9):801–3.
160. Sollevi A. Hypotensive anesthesia and blood loss. Acta Anaesthesiol Scand Suppl. 1988;89:39–43.
161. Niemi TT, et al. Comparison of hypotensive epidural anaesthesia and spinal anaesthesia on blood loss and coagulation during and after total hip arthroplasty. Acta Anaesthesiol Scand. 2000;44 (4):457–64.
162. Juelsgaard P, et al. Hypotensive epidural anesthesia in total knee replacement without tourniquet: reduced blood loss and transfusion. Reg Anesth Pain Med. 2001;26(2):105–10.
163. Tenholder M, Cushner FD. Intraoperative blood management in joint replacement surgery. Orthopedics. 2004;27(6 Suppl):s663–8.
164. Paul JE, et al. Deliberate hypotension in orthopedic surgery reduces blood loss and transfusion requirements: a meta-analysis of randomized controlled trials. Can J Anaesth. 2007;54 (10):799–810.
165. Fukusaki M, et al. Effects of controlled hypotension with sevoflurane anaesthesia on hepatic function of surgical patients. Eur J Anaesthesiol. 1999;16(2):111–6.
166. Sivarajan M, et al. Blood pressure, not cardiac output, determines blood loss during induced hypotension. Anesth Analg. 1980;59 (3):203–6.
167. Sharrock NE, et al. The effect of two levels of hypotension on intraoperative blood loss during total hip arthroplasty performed under lumbar epidural anesthesia. Anesth Analg. 1993;76 (3):580–4.
168. Little Jr DM. Induced hypotension during anesthesia and surgery. Anesthesiology. 1955;16(3):320–32.
169. JD, G. Hemodilution: physiology and limits of anemia. In: MR Lake CL, editors. Blood: hemostasis, transfusion, and alternatives in the perioperative period. New York: Raven Press; 1995. p. 345–80.
170. Lake CL, Moore RA. Blood: hemostasis, transfusion, and alternatives in the perioperative period. New York: Raven Press; 1995.
171. Kumar R, Chakraborty I, Sehgal R. A prospective randomized study comparing two techniques of perioperative blood conservation: isovolemic hemodilution and hypervolemic hemodilution. Anesth Analg. 2002;95(5):1154–61. table of contents.
172. Bryson GL, Laupacis A, Wells GA. Does acute normovolemic hemodilution reduce perioperative allogeneic transfusion? A meta-analysis. The International Study of Perioperative Transfusion. Anesth Analg. 1998;86(1):9–15.
173. Kreimeier U, Messmer K. Hemodilution in clinical surgery: state of the art 1996. World J Surg. 1996;20(9):1208–17.
174. Goodnough LT, et al. A randomized trial comparing acute normovolemic hemodilution and preoperative autologous blood donation in total hip arthroplasty. Transfusion. 2000;40(9):1054–7.
175. Goodnough LT, et al. A randomized trial of acute normovolemic hemodilution compared to preoperative autologous blood donation in total knee arthroplasty. Vox Sang. 1999;77(1):11–6.
176. Epstein NE, et al. Impact of intraoperative normovolemic hemodilution on transfusion requirements for 68 patients undergoing lumbar laminectomies with instrumented posterolateral fusion. Spine (Phila Pa 1976). 2006;31(19):2227–30. discussion 2231.
177. Karakaya D, et al. Acute normovolemic hemodilution and nitroglycerin-induced hypotension: comparative effects on tissue oxygenation and allogeneic blood transfusion requirement in total hip arthroplasty. J Clin Anesth. 1999;11(5):368–74.
178. Segal JB, et al. Preoperative acute normovolemic hemodilution: a meta-analysis. Transfusion. 2004;44(5):632–44.
179. Bennett SR. Perioperative autologous blood transfusion in elective total hip prosthesis operations. Ann R Coll Surg Engl. 1994;76 (2):95–8.
180. Van der Linden P, et al. Cardiovascular effects of moderate normovolaemic haemodilution during enflurane-nitrous oxide anaesthesia in man. Acta Anaesthesiol Scand. 1994;38(5):490–8.
181. Gombotz H, et al. Preoperative treatment with recombinant human erythropoietin or predeposit of autologous blood in women undergoing primary hip replacement. Acta Anaesthesiol Scand. 2000;44(6):737–42.
182. Murphy MF, et al. Guidelines for the clinical use of red cell transfusions. Br J Haematol. 2001;113(1):24–31.
183. Keating EM. Current options and approaches for blood management in orthopaedic surgery. Instr Course Lect. 1999;48:655–65.
184. Messmer K. Hemodilution—possibilities and safety aspects. Acta Anaesthesiol Scand Suppl. 1988;89:49–53.
185. Fukuda A, et al. Effect of tourniquet application on deep vein thrombosis after total knee arthroplasty. Arch Orthop Trauma Surg. 2007;127(8):671–5.
186. Wakankar HM, et al. The tourniquet in total knee arthroplasty. A prospective, randomised study. J Bone Joint Surg Br. 1999;81 (1):30–3.
187. Smith TO, Hing CB. The efficacy of the tourniquet in foot and ankle surgery? A systematic review and meta-analysis. Foot Ankle Surg. 2010;16(1):3–8.
188. Rama KR, et al. Timing of tourniquet release in knee arthroplasty. Meta-analysis of randomized, controlled trials. J Bone Joint Surg Am. 2007;89(4):699–705.
189. Smith TO, Hing CB. Is a tourniquet beneficial in total knee replacement surgery? A meta-analysis and systematic review. Knee. 2010;17(2):141–7.
190. Tai TW, et al. Tourniquet use in total knee arthroplasty: a meta-analysis. Knee Surg Sports Traumatol Arthrosc. 2011;19 (7):1121–30.
191. Li B, et al. The effect of tourniquet use on hidden blood loss in total knee arthroplasty. Int Orthop. 2009;33(5):1263–8.
192. Larsson J, et al. Early biochemical and hemodynamic changes after operation in a bloodless field. Eur Surg Res. 1977;9 (5):311–20.
193. Abdel-Salam A, Eyres KS. Effects of tourniquet during total knee arthroplasty. A prospective randomised study. J Bone Joint Surg Br. 1995;77(2):250–3.
194. Noordin S, et al. Surgical tourniquets in orthopaedics. J Bone Joint Surg Am. 2009;91(12):2958–67.
195. Palmer SH, Graham G. Tourniquet-induced rhabdomyolysis after total knee replacement. Ann R Coll Surg Engl. 1994;76(6):416–7.
196. Barr L, et al. Tourniquet failure during total knee replacement due to arterial calcification: case report and review of the literature. J Perioper Pract. 2010;20(2):55–8.
197. Bengtson S, Knutson K. The infected knee arthroplasty. A 6-year follow-up of 357 cases. Acta Orthop Scand. 1991;62(4):301–11.
198. Lundgren CE, Zederfeldt BH. Influence of low oxygen pressure on wound healing. Acta Chir Scand. 1969;135(7):555–8.
199. Reikeras O, Clementsen T. Time course of thrombosis and fibrinolysis in total knee arthroplasty with tourniquet application. Local versus systemic activations. J Thromb Thrombolysis. 2009;28(4):425–8.
200. Berman AT, et al. Emboli observed with use of transesophageal echocardiography immediately after tourniquet release during total knee arthroplasty with cement. J Bone Joint Surg Am. 1998;80(3):389–96.
201. Kato N, et al. Abnormal echogenic findings detected by transesophageal echocardiography and cardiorespiratory impairment during total knee arthroplasty with tourniquet. Anesthesiology. 2002;97(5):1123–8.

202. Hersekli MA, et al. The timing of tourniquet release and its influence on blood loss after total knee arthroplasty. Int Orthop. 2004;28(3):138–41.
203. Yavarikia A, Amjad GG, Davoudpour K. The influence of tourniquet use and timing of its release on blood loss in total knee arthroplasty. Pak J Biol Sci. 2010;13(5):249–52.
204. Lotke PA, et al. Blood loss after total knee replacement. Effects of tourniquet release and continuous passive motion. J Bone Joint Surg Am. 1991;73(7):1037–40.
205. Moonen AF, Neal TD, Pilot P. Peri-operative blood management in elective orthopaedic surgery. A critical review of the literature. Injury. 2006;37 Suppl 5:S11–6.
206. Flynn JC, Metzger CR, Csencsitz TA. Intraoperative autotransfusion (IAT) in spinal surgery. Spine (Phila Pa 1976). 1982;7 (5):432–5.
207. Huet C, et al. A meta-analysis of the effectiveness of cell salvage to minimize perioperative allogeneic blood transfusion in cardiac and orthopedic surgery. International Study of Perioperative Transfusion (ISPOT) Investigators. Anesth Analg. 1999;89(4):861–9.
208. Carless PA, et al. Cell salvage for minimising perioperative allogeneic blood transfusion. Cochrane Database Syst Rev. 2010(4): CD001888.
209. Woolson ST, Wall WW. Autologous blood transfusion after total knee arthroplasty: a randomized, prospective study comparing predonated and postoperative salvage blood. J Arthroplasty. 2003;18(3):243–9.
210. Handel M, et al. Increased interleukin-6 in collected drainage blood after total knee arthroplasty: an association with febrile reactions during retransfusion. Acta Orthop Scand. 2001;72 (3):270–2.
211. Southern EP, et al. Unwashed wound drainage blood. What are we giving our patients? Clin Orthop Relat Res. 1995(320):235–46.
212. Tate Jr DE, Friedman RJ. Blood conservation in spinal surgery. Review of current techniques. Spine (Phila Pa 1976). 1992;17 (12):1450–6.
213. Hansen E, Hansen MP. Reasons against the retransfusion of unwashed wound blood. Transfusion. 2004;44(12 Suppl):45S–53.
214. Goodnough LT, et al. Transfusion medicine. Second of two parts–blood conservation. N Engl J Med. 1999;340(7):525–33.
215. Alexander JW, Korelitz J, Alexander NS. Prevention of wound infections. A case for closed suction drainage to remove wound fluids deficient in opsonic proteins. Am J Surg. 1976;132(1):59–63.
216. Waugh TR, Stinchfield FE. Suction drainage of orthopaedic wounds. J Bone Joint Surg Am. 1961;43-A:939–46.
217. Casey BH. Bacterial spread in polyethylene tubing. A possible source of surgical wound contamination. Med J Aust. 1971;2 (14):718–9.
218. Willett KM, Simmons CD, Bentley G. The effect of suction drains after total hip replacement. J Bone Joint Surg Br. 1988;70 (4):607–10.
219. Drinkwater CJ, Neil MJ. Optimal timing of wound drain removal following total joint arthroplasty. J Arthroplasty. 1995;10 (2):185–9.
220. Parker MJ, et al. Closed suction surgical wound drainage after orthopaedic surgery. Cochrane Database Syst Rev. 2007(3): CD001825.
221. Nutritional anaemias. Report of a WHO scientific group. World Health Organ Tech Rep Ser. 1968;405:5–37.
222. Adams EB. Nutritional anaemias. Br J Clin Pract. 1968;22 (12):501–4.
223. Weiskopf RB, et al. Acute isovolemic anemia does not impair peripheral or central nerve conduction. Anesthesiology. 2003;99 (3):546–51.
224. Bracey AW, et al. Lowering the hemoglobin threshold for transfusion in coronary artery bypass procedures: effect on patient outcome. Transfusion. 1999;39(10):1070–7.
225. Hebert PC, et al. A multicenter, randomized, controlled clinical trial of transfusion requirements in critical care. Transfusion Requirements in Critical Care Investigators, Canadian Critical Care Trials Group. N Engl J Med. 1999;340(6):409–17.

# Part V

# Role of Allied Services

# Professional Nursing Practice in the Orthopedic Care Setting

28

Stephanie Goldberg and Patricia Quinlan

**Objectives**

- To describe the Magnet Model for Nursing Excellence as paradigm for profession nursing practice in the context of orthopedic surgery.
- To detail three key care delivery processes, namely, nursing assessment, coordination care, and patient education.
- To describe nursing practice in three commonly encountered orthopedic surgical complication scenarios: compartment syndrome, thromboembolism, and surgical site infection.

**Key Points**

The Magnet Model for Nursing Excellence® provides a conceptual framework to guide orthopedic nursing practice:

- Assessment is the cornerstone of patient care delivery.
- Communication is a key factor of effective care coordination.
- Nurses coach and support patients and families through multiple care transitions.
- Knowledge and self-care competency is achieved through patient and family education.

## Introduction

The American Nurses Credentialing Center's Magnet Model for Nursing Excellence provides a framework for nurses to practice in the acute care setting. The Magnet paradigm supports nursing excellence with an emphasis on safety and satisfaction [1]. The aim of this chapter is to describe how, through application of the Magnet Model, nurses provide care to patients in the setting of orthopedic surgery. The chapter begins with a brief description of the ANCC Magnet Program. Three key care delivery processes within the exemplary practice component of the Magnet Model: nursing assessment, care coordination and patient teaching will be detailed. These elements of practice will be further articulated through discussion of three orthopedic surgical complications, specifically compartment syndrome, thromboembolism, and surgical site infection.

## Magnet Recognition Program

Through its prestigious Magnet Recognition Program®, the American Nurses Credentialing Center (ANCC) a subsidiary of the American Nurses Association, recognizes and endorses health-care organizations that demonstrate nursing excellence. The Magnet Model is an organizational paradigm to facilitate best practice. The model has four essential components: (a) transformational leadership; (b) structural empowerment, (c) exemplary professional practice, as well as (d) new knowledge, innovation and improvement. These components are interdependent within a global health-care backdrop to support positive empirical outcomes [1].

According to the Magnet Model, care delivery is an essential element of exemplary practice demonstrated through continuous, accountable assessment, care coordination and patient teaching. Nurses are vital stewards of these processes. They support patient healing and recovery toward primary goals of independent mobility as well as the absence or

S. Goldberg (✉) • P. Quinlan
Department of Nursing Administration, Hospital for Special Surgery, 535 E 70th Street, New York, NY 10021, USA
e-mail: goldbergs@hss.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_28, © Springer New York 2014

reduction of pain. Nurses regularly assess patients before, during, and after surgery. They make clinical judgements about readiness for surgery, pain control, mobility and wound healing. Nurses monitor and report signs and symptoms of postoperative complications. They coordinate the interdisciplinary treatment plan and serve as patient advocates and teachers to support transitions along the patient care trajectory. The next section of this chapter will describe in more detail one of the most important processes within care delivery, patient assessment.

## Patient Assessment

Assessment is the cornerstone of nursing practice. Nurses need to be proficient in this clinical competency in order to identify physical and psychosocial issues that may influence care before and after surgery. Before surgery, nurses conduct a comprehensive assessment that begins with an extensive review of the patient's health history. Nurses physically examine the patient, documenting important data to inform medical and surgical treatment plans. Identified concerns are communicated to the operating room team to anticipate required patient care adjustments that meet individual needs or preferences. For example, nurses activate special care protocols for preexisting clinical conditions such as sleep apnea to assure adequate respiratory support during surgical recovery. Head-to-toe examination may also identify a skin lesion unrelated to the planned surgery that requires further evaluation and preoperative treatment so as not to introduce the risk of postoperative infection.

Nurses in the operating room work with the surgical team to assess patient response to the surgical procedure and to conduct multiple safety checks that minimize the risk of medical errors. Nurses activate universal safety protocols such as time-out procedures and assess the operative site before surgical incision to avert wrong-side surgery. They implement safety checklists that include prosthesis verification as well as instrument and sponge count procedures to minimize risks for medical errors. Nurses carefully position and assess patients at regular intervals to minimize risk for peripheral nerve and skin injury.

Patient assessment continues once the patient leaves the operating room. Nurses evaluate the patient's response to the operative procedure and monitor anesthesia recovery. They review the perioperative sequence of events and initiate physician orders and/or appropriate protocols. Comprehensive nursing assessment includes evaluation of central and peripheral neurological status as well as the patient's cardiorespiratory status. Nurses read and interpret cardiac monitoring to identify arrhythmias. They monitor pulse and blood pressure and report significant deviations that might indicate inadequate hemodynamic functioning. Nurses assess the condition of surgical dressings, casts and traction to ensure proper functionality and body alignment. Skin integrity is evaluated at vulnerable pressure points and patients are repositioned to prevent injury. Nurses assess fluid balance through careful tracking of intravenous and oral intake as well as urinary output. The presence and function of wound drains are frequently checked to evaluate fluid status and blood loss. Devices used to prevent venous thrombosis are inspected to be sure that they are correctly placed on the patient and are in continuous working order. Gastro intestinal (GI) motility is monitored, for example, listening for bowel sounds to determine and readiness for oral intake. Nutritional and GI status is reevaluated as the patient's diet is advanced.

Nurses use assessment skills to continuously evaluate the patient's response to standardized, surgery specific protocols. They work with patients to determine response to standardized pain control treatment using the Pain Numeric Rating Scale [2]. These data combined with information gleaned from direct observation of signs such as facial expressions are used to determine pain status. Progression with mobility is another important clinical assessment. Nurses assess the patient's response to the rehabilitation treatment plan and work with rehabilitation therapists to progress patients through therapeutic milestones toward independent mobility.

Nurses assess the patient's cognitive function and rational decision-making at each step along the orthopedic surgical care trajectory. Baseline assessment data drive the nurse's approach to patient education, an integral element of care provision aimed toward building self-care competencies and participation in the treatment plan. In recent years, the assessment of health literacy has come to be recognized as an important learning factor [3].

Nurses assess learning barriers such as low health literacy, to construct teaching plans that will help patients better understand their treatment and to assure that they are able to carry out self-care instructions. Accessibility and commitment of family caregivers or significant others must also be determined to augment patient support as well as to reinforce accurate and consistent self-care information.

## Care Coordination

Data collected by nurses while caring for patients are shared with appropriate members of the multidisciplinary care team to estimate clinical progress along standard, surgery specific, pathways. Patient progress is discussed at interdisciplinary rounds that include all members of the care delivery team. Nurses provide information at these rounds specific to patient activity and response to treatment during the previous 24 hours. The interdisciplinary team comprised of nurses, prescribers, rehabilitation therapists, case managers and registered dieticians analyze patient data and adjust the plan of care accordingly. Smaller groups of nurses and prescribers convene patient care huddles during evenings and nights

hours to discuss the condition of complex patients to anticipate related problems and the need for care plan alterations. Failures of patients to progress as expected generate plan modifications, delivered by nurses who closely monitor the clinical responses to these changes. Complications or concerns that require immediate attention are communicated directly to prescribers by nurses as they occur.

Communication is a key factor in effective coordination of care. Nurses channel information to all members of the health-care team and during multiple patient care transitions. Several best practices used by nurses to facilitate communication include face-to-face "patient hand-offs." Nurses from the inpatient units personally go to the Post Anesthesia Care Unit (PACU) to meet patients who will be transferred to their care. The PACU nurse provides a face-to-face report with the inpatient nurse who then transports the patient to the inpatient unit. These in-person exchanges allow for the validation of patient data and application of treatment plan elements such as intravenous fluid, assistive device settings as well as socialization to the change in care setting. Nurses orient patients to their new surroundings to instill confidence and familiarity about unit routines, personnel and how to access help when needed.

Nurses work with patients to communicate and adapt to ongoing changes in their treatment. A best practice to further improve this communication is the use of individualized "White Boards." Erasable boards are mounted near patients' beds with standard information specific to their care, for example, the name of the nurse caring for the patient and the last time that pain medication was administered.

Nurses conduct multiple patient interventions based upon the interdisciplinary treatment plan and continual reassessment. Rest and activity are balanced. Nurses check on their patients hourly to assess pain. Adjuvant measures such as repositioning and ice therapy augment carefully administered pain medication. Consistent hourly checks also serve as a means for influencing patient safety. Such rounds can preempt patient misjudgment about going to the bathroom unassisted and thereby reduce risk for falling. Moreover, patients who are regularly visited by their nurse report greater satisfaction with care provided [4].

## Patient Education

Nurses play a key role during transitions in care. Nurses are responsible to help patients and their caregivers build the knowledge necessary to participate in the treatment plan and to competently follow self-care instruction. Self-care competency is important during all care transitions but particularly after discharge. The process of building self-care knowledge and competency is accomplished through patient education. Education is initiated before, during and after admission. Before surgery, preoperative patient education classes are a resource for patients and their caregivers to work with nurses towards mutual health-care goals.

### Preoperative Education

The preoperative classroom setting affords an opportunity to develop a quality nurse-patient relationship that will continue to grow throughout the hospital experience. Nurse driven classroom education sessions are multimodal in content, combining written materials, multimedia presentations, and hands-on demonstration. Realistic patient and family expectations are emphasized with particular focus on participation in care management. The major educational topics addressed during the preoperative class include pain management, mobility, discharge planning, and prevention of surgical complications (i.e., wound infection and venous thrombosis). Expectations are clearly described in a sequential format beginning with the admission and ending with the discharge process. Patients and families are encouraged to ask questions throughout the session. Nurses' contact information is provided should patients need clarification about class content or ask additional questions once they return home.

Nurses use technology to provide easy access and as an alternate means for patient education. Electronic access to information has improved dramatically with rapidly advancing technology. Nurses work with media specialists to supply Web based instruction via physician practice portals or webinar classes through the Internet. This alternative to traditional classroom learning is especially useful for younger patients who are to undergo minimally invasive surgery. An important advantage of this approach is the elimination of the need for patients to travel long distances to attend preoperative classes. Disadvantages include the inability of the nurse educator to visually assess patients for indications that they may be having difficulty understanding the material. This format is generally reserved for patients who can navigate electronic media and are used to processing information that is Web based.

### Postoperative Education

Once the patient is admitted to the hospital, the patient receives one-on-one education on a daily basis. As previously stated, nurses continuously educate patients to the treatment they receive and progressively introduce information that patients need once they leave the hospital. One-on-one teaching is essential for patients to learn how to use equipment such as mechanical devices that provide cold therapy or compression boots to prevent deep vein thrombosis. Devices that assist with ambulation such as crutches require meticulous step-by-step instruction and return demonstration. Similarly, medications such as inhalers or injections need hands on demonstration with return presentation to assure self-care

competency. Each time patients receive medication, these medications are reviewed with the patient as to purpose and function. As the patient progresses toward discharge, the nurse reinforces medication information and expands on previous instruction to include side effects, the importance of taking the medication according to the prescribed dosage and frequency as well as when to call the provider with questions.

The "teach-back" method is a way to confirm that information explained to the patient is done so in a manner that the patient can understand [5]. Open-ended questions are asked that require the patient to draw from his/her memory and apply the information learned. A sample question is: "What are you going to do when you get home?" Another example could be: "I want to be sure that I explained your medication correctly. Can you tell me how you are going to take this medicine?" If patients cannot remember the information or accurately repeat instructions, information or instructions are clarified and patients are asked to teach it back again. The teach-back process is repeated until the patient is able to correctly describe what they are going to do in their own words. Understanding is validated when patients and/or caregivers explain information back to the clinician. The teach-back technique can also help familiarize clinicians with individual, patient learning preferences.

### Follow-up After Discharge

Telephone contact by a nurse after discharge is considered a best-practice for exchanging information with patients about their progress, verify adherence to treatment and to provide additional health education [6]. Firsthand experience at our organization has demonstrated that patients appreciate post discharge phone calls from nurses. Surveyed patients who receive postoperative telephone calls report greater overall satisfaction than patients who do not receive calls [4]. Such telephone calls complete the orthopedic care delivery cycle and should be should be made by nurses who are familiar with the patient's hospital experience and plan of care. The telephone exchange offers yet another opportunity for a teach-back exchange to elicit continued understanding of treatment. It is also a chance to ask the patients about healing, mobility, signs of infection, medication management, and physician follow-up.

## Identification and Management of Postoperative Orthopedic Complications

The next section of this chapter will focus on care delivery specific to the identification and management of orthopedic complications. Nursing management of three orthopedic complications will be described: (1) compartment syndrome, (2) thromboembolism, that is, deep vein thrombosis and pulmonary embolism, and (3) surgical wound infection. Though these are only three of a longer list of potential postoperative complications, they provide an opportunity to clearly describe nursing care delivery in the orthopedic surgical setting.

### Compartment Syndrome

Compartment syndrome is a complication caused by increased pressure within a confined myofascial space resulting in circulatory compromise, ischemia and if not treated, tissue necrosis [7]. Subsequent tissue damage may result in permanent neurologic injury and necrosis of muscle. Increased internal pressure within a compartment may be caused by swelling, bleeding or increased capillary permeability, while external compartment pressure is caused by peripheral compression such as tight casts or dressings.

Nurses can detect compartment syndrome by frequent and reliable assessment. Pain beyond what is expected, which is not responsive to narcotics and intensified by passive stretching and elevation, may be indicative of compartment syndrome. Inspection of the skin may note shininess related to increased internal pressure. Skin color may progress from bright pink during the initial inflammatory phase to a pale and dusky color with increased arterial compression. The skin becomes cold to touch and capillary refill is usually less than 3 seconds. Paresthesia related to nerve compression implies decreased neurovascular function and pain is likely to decrease with progressive injury. Serious injury is imminent when pulses are not palpable due or the patient shows signs of limb paralysis [8].

Communication of compartment pressures and patient symptoms to the surgeon and medical team is paramount. Ongoing pain management is also crucial and medication may be needed to treat anxiety, which may compound the vasoconstriction. Surgical treatment consists of relieving pressure, achieved through fasciotomy for internal compression or in the case of excessive external pressure, a bivalve cast. Nurses carry out prescribed wound care, monitor and report red and white blood counts as well as administer antibiotics to avert or mitigate infection. Nurses also provide teaching to explain to patients and caregivers why vigilant monitoring is necessary. Emotional support may also offset some of the anxiety and discomfort.

### Thromboembolism

Thromboembolism is a widely acknowledged complication of orthopedic surgery and includes both deep vein thrombosis and pulmonary embolism. Three factors that contribute to thromboembolism are venous stasis, blood coagulability,

and vessel wall damage. Arthroplasty and spinal surgery patients are among those at high risk for thromboembolism. Other factors commonly seen in the orthopedic patient population include: (a) obesity, (b) lack of mobility, (c) smoking, (d) chronic heart disease, and (e) hormone replacement [8].

Nursing care for these patients consists of an assessment of signs and symptoms as well as administering and monitoring prophylaxis regimes. For venous thromboembolism, signs and symptoms are dependent on the size of the clot. Symptoms include erythema, pain, and tenderness in the clot location as well as thigh and/or calf swelling [8]. Signs and symptoms of pulmonary embolus include dyspnea or tachypnea, lower arterial pressure, cough with hemoptysis, anxiety and restlessness, chest pain, and tachycardia [9].

Nurses administer prescribed chemical and mechanical prophylaxis and continually evaluate and report the effects thereof. Management of anticoagulants such as low molecular weight Heparin and Warfarin requires careful dosing, contingent on findings of physical assessment and laboratory analysis. Nurses report deviations in clinical results to prescribers for ongoing anticoagulation adjustment. They teach patients and their caregivers about these drugs, which they will need to manage once discharged. Nurses review the purpose, dose, frequency, side effects of the medications and in what circumstances their provider should be contacted.

Therapeutic devices such as intermittent pneumatic compression stockings and venous foot pumps are useful to prevent venous stasis [10]. Nurses assure application as well as evaluate proper fit and function of these assistive devices. Patients are encouraged to dorsiflex and plantar flex ankles and toes. Nurses support early mobilization to promote lower extremity venous return. Mobility is encouraged throughout hospitalization through discharge transition. Nurses contact patients after discharge to assess self-management and effects of chemical and mechanical anticoagulation.

## Nosocomial Surgical Site Infection

Postoperative wound infection is a particularly serious complication as it poses the threat of joint prostheses compromise notwithstanding the consequences associated with prolonged hospitalizations, treatments, and propensity for readmission. The Center for Disease Control and Prevention, guideline for prevention of surgical site infection describes conditions that place patients at risk for postoperative infection [11]. Risk factors include: (a) age, (b) obesity, (c) uncontrolled diabetes, (d) smoking, (e) obesity, (f) colonization of microorganisms, (g) preexisting infection, (h) compromised immune system, (i) preoperative anemia, and (j) increased hospital stay.

Nurses work with multidisciplinary colleagues before the surgical event to identify comorbid vulnerabilities and adjust the treatment plan to prevent and/or minimize the possibility of surgical site infection. The role of the nurse in the prevention of surgical site infections consists of preoperative assessment followed by communication of risk, timely administration of antibiotic prophylaxis, careful surgical skin preparation, and competent aseptic technique in the operating room as well as meticulous and frequent evaluation of the wound postoperatively [11].

As mentioned earlier in the chapter, nurses assess patients as they ready them for surgery. Unexpected findings that impose infection risk such as a shingles or an upper respiratory infection are communicated to the surgical team and may result in postponement of the operation. A past history of methicillin-resistant *Staphylococcus aureus* (MRSA) likewise prompts a nurse to activate special protocols that minimize risk to the individual and other patients who enter the operating room. While readying the patient for surgery, hair removal is done by clipping rather than shaving and nurses use products such as Chlorhexidine antiseptic to prepare the skin for incision. In the operating room, nurses reduce infection risk through meticulous surgical scrub and personal hygiene of their hands. Hand hygiene continues to be of paramount importance during the postoperative period where nurses evaluate surgical dressings and wounds for healing. Signs and symptoms of infection such as pain, redness, swelling drainage, odor, and fever are promptly communicated to the prescriber for further analysis and treatment.

During the postoperative period, the nurse teaches the patient and caregiver about how to protect the wound, inspect it for healing, signs and symptoms of infection, how to do a dressing change if necessary and how to contact their provider with concerns. Evaluation of patient understanding determines if home care referral may be necessary to supervise self-management particularly if wound care is complex. Nurses contact patients after discharge to determine competency and evaluate adherence to the treatment plan.

## Summary

The aim of this chapter is to describe how nurses provide care to orthopedic surgical patients. Nurses deliver continuous and accountable patient care that is unique to a specialized body of knowledge. Patient assessment, care coordination, and teaching are important facets of care delivered by nurses. Through these processes, nurses support patient healing and recovery toward primary goals of independent mobility as well as the absence or reduction of pain. Nurses monitor and report signs and symptoms of postoperative complications. They coordinate the interdisciplinary treatment plan and serve as patient advocates and teachers to support transitions along the episode of care. Nurses provide meaning to conceptual models of nursing excellence by delivering the very best care to the patients they serve.

**Summary Bullet Points**

- The Magnet Model for Nursing Excellence provides a paradigm for a work environment that supports optimum nursing practice demonstrated through continuous accountable assessment, care coordination, and patient teaching.
- Patient assessment is a key aspect of nursing practice. In the context of orthopedic care, nurses continuously evaluate the patient to align the plan of care to individual needs and establish effectiveness of the treatment plan.
- Nurse involvement is vital to care coordination to ensure a holistic approach to care transitions. Accurate and complete communication of patient information across transitions is essential for safe, patient-centered care.
- Nurses help patients and their caregivers develop self-care competency through education and coaching. Education should be provided during all phases of the surgical episode of care to achieve independence with health-care goals.
- Complications of orthopedic surgery can be devastating. Signs and symptoms of circulation impairment and infection must be continuously monitored and reported to the prescriber to facilitate prompt and appropriate treatment. Nurses support patients both clinically and emotionally through discomfort and treatment.

## References


1. ANCC Commission on Magnet Recognition. Application manual magnet recognition program. 2008.
2. McCaffery M, Beebe A. Pain: clinical manual for nursing practice. Baltimore: V.V. Mosby; 1993.
3. Institute of Medicine, Committee on Health Literacy, Academy for Educational Development. Health literacy. 2004.
4. Press Ganey Associates. Custom patient satisfaction report. http://www.pressganey.com. Updated 2012.
5. Schillinger D, Piette J, Grumbach K, et al. Closing the loop: physician communication with diabetic patients who have low health literacy. Arch Intern Med. 2003;163(1):83–90.
6. Beckie T. A supportive-educative telephone program: impact on knowledge and anxiety after coronary artery bypass graft surgery. Heart Lung. 1989;18(1):46–55.
7. Bae D, Kadyala K, Waters P. Acute compartment syndrome in children: contemporary diagnosis, treatment and outcome. 2001 (37 (4)):559–62.
8. Morris N. Complications associated with orthopedic conditions and surgery. In: Mosher C, editor. An introduction to orthopedic nursing. 4th ed. Chicago: National Association of Orthopedic Nurses; 2010. p. 129–30.
9. Kim H, Walcott-Sapp S, Leggett K, Bass A, Adler R, Pavlov H, Westrich GH. The use of spiral computed tomography scans for detection of pulmonary embolism. J Arthroplasty. 2008;23(S1):31–5.
10. Kaboli P, Henderson M, White R. DVT prophylaxis and anticoagulation in the surgical patient. Med Clin North Am. 2003; 87:77–110.
11. Mandgram A, Horan T, Pearson M, Silver S, Jarvis W. Guideline for prevention of surgical site infection. Infect Control Hosp Epidemiol. 1999;20(4):247–78.

# The Approach to Physical Therapy Following Orthopedic Reconstructive Surgery

29

Janet B. Cahill and Jeme Cioppa Mosca

**Objectives**

- To understand the goals of preoperative education
- To understand the importance of aggressive pain management and early mobilization to optimize rehabilitation progression for patients undergoing total joint and spine surgeries at Hospital for Special Surgery
- To understand the importance of a functional tracking tool
- To understand key therapeutic principles in acute care phase of rehabilitation

**Key Points**

- Rehabilitation is an integral component after orthopedic surgery. At Hospital for Special Surgery (HSS), our Rehabilitation Therapists have created specific postoperative guidelines to enhance mobility immediately after joint replacement and spinal surgeries.
- Early mobilization allows patients to achieve a higher level of function following joint replacement and spine surgeries.
- The interdisciplinary care team at Hospital for Special Surgery has integrated rehabilitation guidelines into Clinical Pathways for joint replacement and spine procedures to ensure critical steps are implemented in order for patients to achieve specific outcomes.
- Preoperative education is essential in order to enhance the patient experience, decrease anxiety, and meet the patients' expectations in the postoperative phase.

## Introduction

Hospital for Special Surgery is an elective orthopedic specialty hospital. This structure allows the health care team to ensure the optimal surgical candidate is presented to the operating room. Being an elective surgery hospital allows the team to preplan for all patients both surgically and postoperatively. From a rehabilitation perspective, it also allows for early identification of an atypical patient that either requires discharge planning needs other than home disposition or patients requiring additional equipment needs or physical assistance. If appropriate, patients may be referred by their surgeon for preoperative physical therapy. This allows the therapist to frontload the patient education, the surgical experience and address impairments in order to establish realistic patient expectations. In addition, therapeutic exercises, activity expectations and/or modifications are instructed. This interaction between therapist and patient assists with alleviating patient anxiety which may hinder rehabilitation progress and assists with fostering trust between the clinician and patient.

At Hospital for Special Surgery, our interdisciplinary team has recognized the impact of reducing postoperative pain. A comprehensive pain management program is of utmost importance to reduce pain while maximizing mobility throughout the continuum of care. Our clinical pathways have been based on our experience of reducing postoperative pain while reducing length of stay (LOS) and progressing patients to a higher level of function.

J.B. Cahill (✉) • J.C. Mosca
Department of Rehabilitation, Hospital for Special Surgery,
535 E 70th St, New York, NY 10021, USA
e-mail: cahillj@hss.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_29, © Springer New York 2014

Initiating mobilization on the day of surgery has fostered an earlier and higher achievement of a patient's functional mobility. It was imperative that the Acute Pain Service (APS) and the rehabilitation team discuss important considerations that are required for safe postoperative mobility. To consider early mobilization on the day of surgery, the effects of anesthesia need to be minimized. The effects of orthostatic hypotension, nausea, and pain with the full return of motor and sensory function can be a challenging balance. Our institution optimized the anesthetic management which has maximized our functional outcomes.

Lastly, tracking data is essential to evaluate success and to identify variations and opportunities for improvement. The HSS functional milestone database is the largest rehabilitation acute care arthroplasty database in the United States [1]. HSS has tracked joint replacement functional progress for more than 20 years. The information collected and evaluated from the HSS functional milestone form has allowed our department and institution to modify our clinical pathways to meet the patient's accelerated progress.

## Preoperative Education

Patient education is a key component to a successful orthopedic surgery [2]. Over 13 patient education classes are provided weekly by the interdisciplinary team including; nursing, rehabilitation and case management. Our goal is to provide a comprehensive program to keep the patient well informed on their upcoming surgery. A 1½ hour preoperative education class is provided to all patients undergoing Total Hip Arthroplasty (THA), Total Knee Arthroplasty (TKA), and spinal surgeries. In addition, the HSS team has the opportunity to establish an expected discharge plan in order to adequately prepare our patients for after surgery. During this time, our team can also identify high risk patients or those with special needs. These requests may include an interpreter, bed extender, c-pap machine or specific rehabilitation equipment or an alternative plan to home. Early identification of potential issues allows for adequate preplanning prior to the patient's hospitalization.

In addition, some patients may be undergoing outpatient preoperative physical therapy. Outpatient physical therapy allows the therapist to evaluate and fully implement a program to enhance a patient's mobility after surgery. Objective measures such as range of motion (ROM), manual muscle testing, gait deviations and functional deficits can be evaluated, in addition to, identifying the patient's potential postoperatively. Subjective questionnaires, objective scales, and functional tests such as the Timed Up and Go (TUG), Functional Reach, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), or single leg balance can be completed which will allow a comparison for preoperative and postoperative function.

## Functional Milestones

The Hospital for Special Surgery Rehabilitation team has developed a valid and reliable tool to track the functional progression of Total Joint Arthroplasty (TJA) patients in the acute care phase [1] (Fig. 29.1). Key information is recorded and daily functional progress tracked. The HSS Functional Milestone Database has over 20 years of information based on patient's functional mobility, anesthesia type, preoperative level of function, attendance of preoperative class, and component type along with the medical comorbidities. Information from this database is an integral part of our research projects and has allowed our team to modify clinical pathways based on the accelerated progress of patient's recovery and function. Patient databases are essential in monitoring the patient progress, as well as, providing a baseline of statistics which can be modified based on current trends and advances in orthopedic and anesthesia and technology.

## Postoperative Rehabilitation Following Orthopedic Surgery

A common goal following joint replacement and spine surgeries is independent function while minimizing patient impairments in the acute phase. Our functional goals for patients that have a discharge disposition to home, regardless of the surgery, is independent transfers in and out of bed, independent ambulation with the appropriate assistive device, independence with therapeutic exercises/range of motion (if indicated) and independence with postoperative precautions. For patients that are weight bearing as tolerated (WBAT), our goal is to progress the patient to the assistive device which normalizes their gait pattern and minimizes gait deviations. Each case is individualized, rather than protocol based, which provides the patient the ability to progress to the highest level of function for home management. The general HSS philosophy for all surgical procedures is to gradually increase the activity level of the patient. Increased activity immediately after surgery and keeping the operated limb in a dependent position for prolonged periods of time may enhance swelling and pain. The patient's progression plan may have to be modified based on their response to activity and subjective complaints. In most cases, patients at HSS use a rolling walker to initiate ambulation after surgery. This device assists with normalizing a patient's gait pattern. Our clinical

## HSS TOTAL KNEE ARTHROPLASTY – FUNCTIONAL MILESTONES FORM

**REHABLITATION DEPARTMENT**

PT Initials: _____

**Diagnosis:** _____ **Age**:_____

Left / Right / Bilateral Initial / Revision / Reimplant

Unicondylar Staged Rapid Recovery

WBAT PWB TTWB NWB

**Height**_____(in) **Weight** _____(lbs)

**Day of Surgery:** Su M T W Th F Sa

**Anesthesia:** EPI GEN

**PCA:** EPI IV

**Femoral Nerve Block:** YES NO

**Sciatic Nerve Block:** YES NO

**Other:**_____

**Pre-op Class:** YES NO

**Pre-op Amb:** w/c bound <1 1-5 6-10 >10 Blocks

**Pre-op Assistive Device:** Cane / Crutches / Walker / None

**Need to negotiate stairs:** YES NO

**Pre-op Lives Alone:** YES NO

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BID | | | | | | | | | | | | | | | | |
| Discharge | | | | | | | | | | | | | | | | |
| Stairs Unassisted | | | | | | | | | | | | | | | | |
| Stairs Assisted | | | | | | | | | | | | | | | | |
| Cane Unassisted | | | | | | | | | | | | | | | | |
| Cane Assisted | | | | | | | | | | | | | | | | |
| Walker Unassisted | | | | | | | | | | | | | | | | |
| Walker Assisted | | | | | | | | | | | | | | | | |
| Stand Only | | | | | | | | | | | | | | | | |
| Transfer Unassisted | | | | | | | | | | | | | | | | |
| Transfer Assisted | | | | | | | | | | | | | | | | |
| Dangle Unsupported | | | | | | | | | | | | | | | | |
| Dangle Supported | | | | | | | | | | | | | | | | |
| CPM | | | | | | | | | | | | | | | | |
| Active Ext R | | | | | | | | | | | | | | | | |
| Active Flex R | | | | | | | | | | | | | | | | |
| Active Ext L | | | | | | | | | | | | | | | | |
| Active Flex L | | | | | | | | | | | | | | | | |
| Pain Level | | | | | | | | | | | | | | | | |
| Date of Surgery _____ | | | | | | | | | | | | | | | | |
| P.O.D | RR | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |

**Discharge To:** Home Rehab SNF

**If D/C Home:** Home PT Outpatient PT No PT

**If D/c home, with:** Friends/Family/Other Alone

**Complications/PT Held:** _____

_____

_____

## PERTINENT PAST MEDICAL HISTORY

**Please circle all that apply**

**Cardiovascular**
1.A-fib/arrythmia
2. Angina
3. CAD
4. ↑ Cholesterol
5. HTN
6. MI
7. Tachycardia
8. Valve Disease

**Circulatory**
9. Cellulitis
10. DVT
11. PVD
12. Phlebitis
13. PE

**Endocrine**
14. DM
15. Hyperthyroidism
16. Hypothyroidism
17. Renal disease

**Hearing/Vision**
18. Blind
19. Glaucoma
20. Cataracts
21. HOH
22. Deaf
102. Cataract

**Immunological/Infectious Disease**
23. Chronic Infection
24. HIV
25. Hepatitis

**Musculoskeletal**
26. AVN
27. DDD
Fractures
28. -Femur
29. -Pelvis
30. -Spine
31. -Humerus
32. -Wrist
33. -Other
34. HO
35. HNP
36. LBackP
37. OA
38. OP
39. Rotator Cuff Tear
40. Sciatica
41. Scoliosis
42. Spinal Stenosis
104. Gout

**Neurological**
43.Alzheimers/ Dementia
44. CP
45. CVA/TIA
46. MS
47. Parkinsons
48. Paraparesis
49. Paraplegia
50. Polio
51. RSD
52. Seizures
101. Carpal Tunnel

**Oncology**
Cancer
53. -Breast
54. -Colon
55. -Leukemia
56. -Lung
57. -Lymphoma
58. -Prostate
59. -Other malignant
_____

**Psychological**
60. Anxiety/Panic
61. Bipolar disorder
62. Depression
63. Schizophrenia

**Pulmonary**
64. Asthma
65. CHF
66. COPD/Emphysema
67. Pneumonia
68. SOB

**Rheumatological**
69. Fibromyalgia
70. JRA
71. SLE
72. Psoriatic Arthritis
73. RA

**Other**
74. Drug/substance abuse
75. Mental Retardation
76. Obesity
77. Ulcer Disease/Gastric
105. Incontinence
106. Sleep Apnea

**Other PMH**:
78. _____
_____
_____
_____
_____
_____

## PAST SURGICAL HISTORY

79. TKR
80. TKR revision
81. THR
82. THR revision
83. TSR
84. Spine
85. Arthroscopy -LE
86. Arthroscopy -UE
87. Amputee UE
88. Amputee LE
89. ORIF UE
90. ORIF LE
91. Ligament/joint reconstruction
92. CABG
93. Pacemaker
94. Valve replacement
95. Recent Major Abdominal Surgery (within last 6 months)
100. Cardiac Cath
103. Carpal Tunnel Repair (CTR)

**Other PSH**:
96. _____
_____
_____
_____

**Fig. 29.1** Total hip replacement functional milestone form

pathways for each of the following surgeries, provides a guideline for each surgical procedure. The following information is broken down to highlight critical components of Total Knee, Total Hip and Spine surgery.

## Postoperative Rehabilitation Following Total Knee Arthroplasty

Physical therapy is initiated within 4 hour after a Total Knee Arthroplasty or as soon as it is medically appropriate. At our institution, TKA patients may utilize a variety of postoperative pain management techniques based on surgeon preference. These include epidural Patient Controlled Analgesia (PCA) pumps, with or without a concomitant femoral nerve block (FNB) or an oral analgesic course. Quadriceps strength is closely and consistently evaluated by the physical therapist to determine the effects of the nerve block and the appropriate amount of weight bearing during the first 24–36 hour after surgery. Active knee extension may be used in sitting to quickly assess quadriceps strength or possible impairments from the FNB, as well as, a straight leg with or without a lag. Weight bearing may be minimized if decreased quadriceps strength is noted and a knee immobilizer may be utilized for safety to minimize buckling unless clinically determined by the therapist that it is not required.

Quadriceps inhibition is inherent after TKA arthroplasty. However, the therapist needs to determine the impact of the nerve block. If the patient cannot actively perform knee extension, the PT can passively extend the knee and determine if the patient can use any volitional strength to maintain knee extension. This will assist the therapist in providing verbal feedback to the patient when weight bearing. Walking is initiated with a rolling walker and progressed as tolerated to a cane or crutch for discharge home. A heel toe gait pattern is emphasized to restore a normal gait as early as possible.

Knee ROM is critical to achieve within 6–8 weeks after surgery. Preoperative ROM is the primary indicator of postoperative ROM [3]. Ideal extension after surgery is 0° and minimum target flexion ROM by 6 weeks is 120° to allow patients to participate in functional activities. Activities such as tying shoes requires 106° of knee flexion, while squatting and lifting an object off the floor requires 117° of knee flexion [4]. Our main goal in the immediate postoperative phase is to emphasize full knee extension. When supine, patients are encouraged to lie in passive extension. The principles of low load prolonged stretch are implemented and the patient is supine with a towel roll under the ankle. The principles of low load prolong stretch has been studied and found to be the most effective technique to successfully achieve elongation of tissue and restoration of ROM [5, 6]. It is critical to maintain neutral hip rotation during passive extension as patient's have a tendency to externally rotate at the hip and flex at the knee for comfort. In addition, it is important to maintain flexibility at the gastrocnemius and hamstrings if deficits are present. "Aggressive Flexion ROM" can adversely affect gains in ROM. Aggressive ROM often leads to muscle guarding and increased pain which can hinder the patient's progress. Consistent ROM sessions are encouraged in a position that is optimal for the patient. Moderate discomfort may be experienced during ROM sessions and should NOT be severe. Prone quadricep stretching is not recommended in the early phases as a tight rectus femoris may limit knee joint ROM.

In 2008, the HSS Clinical Pathway for TKA patient population was revised to a 4 day length of stay (LOS) goal. On average, patients undergo approximately six to eight physical therapy sessions during their hospitalizations with an additional walking sessions during every nursing shift. Ideally patients participate in at least one physical therapy session on the day of surgery and two physical therapy sessions on subsequent days until their functional goals are achieved. Physical Therapy during the hospitalization includes basic home exercise program:

- Including ankle pumps
- Active range of motion knee flexion
- Quadriceps sets
- Active assistive knee flexion
- Gluteal sets
- Stair stretch (if tolerable)
- Passive extension
- Straight leg raise (SLR)

The Continuous Passive Motion Machine (CPM) continues to be a controversial device after TKA [7]. The CPM machine is not part of our clinical pathway but must be ordered specifically by the surgeon. Many doctors continue to use the machine although the long term benefits are refuted. Simplistically, the CPM machine keeps the knee joint in motion, alleviates patient anxiety, and may play a role in pain control.

Cryotherapy is extremely important particularly after TKA. Cryotherapy is effective in reducing swelling and as an adjunct to pain management. There are many options for cryotherapy devices including commercial devices or simplistic options such as a gel pack or crushed ice. Frequent icing for at least 15–30 min with minimal compression is easily reproducible for patients at home and as effective as compared to commercial devices [8]. Preoperative discussions can educate patients on cryotherapy options.

Within 3–4 days after surgery, most patients have achieved independence with bed mobility, transfers and ambulation with an appropriate device on level surfaces and stairs, which will allow the patient to be safely discharged home with visiting nurse services, if needed.

When functionally appropriate, outpatient physical therapy services may be initiated to allow the patient to return to a higher level of function. During the outpatient phase, the goal is to continue to emphasize end ROM and flexibility and to minimize gait impairments. In addition, lower extremity strength and balance deficits are addressed to allow a patient to negotiate stairs reciprocally and perform functional activities, such as getting out of a chair without compensatory movements. Subjective questionnaires are a means to assess patient's reported progress, in addition to, objective measures and functional scales to measure functional progress.

## Postoperative Rehabilitation Following Total Hip Arthroplasty

Patients undergoing Total Hip Arthroplasty (THA) most often are able to ambulate with less pain and functional impairments as compared to their preoperative level of function. For the majority of patients at HSS, surgeons use a posterior/lateral approach in which three precautions are adhered to for 6–8 weeks until their follow-up with their surgeon.

The posterior lateral precautions include:

- No hip flexion greater than 90°
- No internal rotation past neutral
- No adduction

In 2007, HSS modified our postoperative clinical pathways for THA to initiate mobilization hours after surgery. Similarly to TKA, a variety of postoperative pain management pathway options can be utilized based on surgeon preference. Shortly after implementing an early mobilization pathway, our data indicated that most patients can achieve independence with a cane by POD # 3 following the posterolateral approach. In 2012, the THA pathway was modified again to a consolidated 51 hour pathway. Patients are seen twice a day by physical therapists until independence with functional goals for discharge home is achieved.

In evaluating our patient statistics, you must consider the large patient volume. At HSS, we have more than 25 orthopedic surgeon performing THA's on a diverse range of patients with varying preoperative functional levels. Our data reflect averages for all patients undergoing primary THA. Specific surgeon's statistics may differ, as well as specific controlled variables.

Data in Table 29.1 demonstrate improvement in achievement of functional milestones since implementing 51 hour THA Pathway to Recovery [8].

The most difficult functional activity for THA patients is transferring in and out of bed. This maneuver is reiterated in preoperative class so the patient has the opportunity to practice prior to surgery. In our experience, we have found patients have an easier time transferring in and out on the surgical side, although any modification may be made as long as the patient can adhere to the precautions during the transfer. In addition, a detailed THA video is provided to patients which reviews all functional activities, ADL training with equipment and therapeutic exercises post surgery. An occupational therapy consult is ordered for all patients that are discharged home to allow intensive ADL and equipment training and home preparation and planning.

**Table 29.1** Improvement in achievement of functional milestones since implementing 51 THA pathway to recovery

| Day mobility initiated | 2007 72 h pathway | 2012 51 h pathway |
|---|---|---|
| | Day achieved | Day achieved |
| | Independence with Cane | Independence with Cane |
| Day of surgery | 3.25 | 2.41 |
| POD # 1 | 3.78 | 2.55 |

Accessed from Hospital for Special Surgery, Rehabilitation Department, Functional Milestone Database 2012.

The majority of patients undergoing primary THA regardless of being cemented or uncemented are allowed progressive weight bearing as tolerated (WBAT). All patients initiate ambulation with a rolling walker and progress to a standard cane as tolerated. Physical Therapy Exercises during the hospitalization includes basic and an advanced home exercise program including:

- Ankle pumps
- Standing hip extension
- Quadriceps sets
- Standing hip abduction
- Gluteal sets
- Standing knee flexion with 0° hip flexion
- Sitting hip flexion <90°
- Sitting knee extension
- Heel slide supine <45°

Straight leg raise (SLR) is an advanced exercise and usually instructed 4–6 weeks after surgery due to the increased joint reaction force across the hip joint [9].

Patients are instructed in a home exercises while adhering to the posterolateral hip precautions. After the precautions are lifted at 6 weeks, patients are instructed in an exercise program to include lower extremity strengthening, balance and specific exercises which will allow the individual to gain hip flexion and external rotation to perform functional activities.

Patient should begin outpatient physical therapy when THA precautions are lifted to optimize their function. The goals for outpatient physical therapy is to minimize gait impairments, restore balance and ROM and allow the patient to return to functional activities without adaptive equipment. The most challenging tasks for most patients after surgery are putting on socks, shoes and cutting toenails. Typical hip

ROM demands for tying shoes is 120° hip flexion, whereas functional stair training only requires 36° of hip flexion to descend a step and 67° of hip flexion for ascending a step [10]. Progressive stretching and ROM is emphasized to allow the patient to be independent in these functional activities. Hip Abductor strengthening is critical to improve normal pelvic alignment during gait and stair negotiation. Gluteus medius strength can be weak after surgery for up to 2 years. Hip abductor strengthening can be done in a position of comfort for the patient and is more functional in a weight bearing position without increasing strain or activation of the gluteus medius [11]. In addition, bilateral balance activities progressing to single leg balance exercises are initiated. A series of objective tests, including functional reach and timed up and go, have been determined valid and reliable with normative values that will enable the clinician to compare postoperative joint replacements to older/normal individuals [12, 13].

## Rehabilitation Following Spine Surgery

Spine surgery can often vary from a microdiscectomy to a multilevel fusion. Due to patients receiving general anesthesia there are no delays of motor and sensory return and these patients may be mobilized within 2 hour of surgery if medically cleared and dependent on the complexity of the surgery. Our goal is to promote frequent and gradual increase in mobility with this patient population. Since each patient's pain and functional level may fluctuate, each patient's baseline of postoperative progression will vary.

Bracing is often surgeon specific and recommended for those individuals who may not adhere to proper body mechanics following surgery. Bracing is typically recommended during movement activities. Normally, sitting time is limited to 15–30 min to minimize soreness and compression on the spine [14] (Fig. 29.2). An occupational therapy consult may be recommended for ADL training, if the patient presents with functional impairments and ADL deficits.

Patients are instructed in safe and proper body mechanics after any type of spine surgery. Log rolling is typically instructed for cervical, thoracic and spine procedures to minimize any undue rotational stress on the spine. In addition, patients are instructed in modifications to bending, lifting and twisting. Patients may be instructed, depending on the surgery, on how to bend at the hips and knees for dressing and to minimize excessive trunk flexion. Patients are instructed to minimize lifting and unnecessary weight, in addition to, minimizing torque at any level of the spine. Our goal is to progress the patients to a functional level of independence for ADLs but they may require assistance or the use of adaptive equipment if limited with functional tasks.

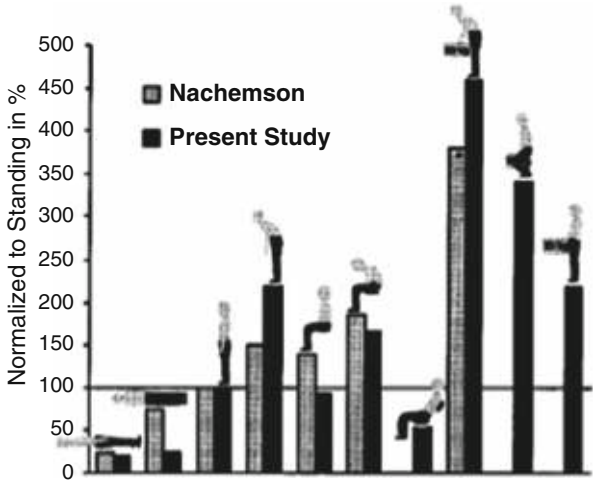


**Fig. 29.2** A comparison between data of Nachemson* and those of the Wilke study (see source line) (both for 70-kg individuals) regarding intradiscal pressure in common postures and activities, normalized to standing. Lifting weight = 20 kg in the current study; *lifting weight = 10 kg in Nachemson study. (*See Simmonds MJ, Olson SL, Jones S et al. Psychometric characteristics and clinical usefulness of physical performance tests in patients with low back pain. Spine 1998; 23: 2412–2421.) (Figure used with permission from Wilke HJ, Neef P, Caimi M, Hoogland T, Claes LE. New in vivo measurements of pressures in the intervertebral disc in daily life. Spine. 1999 Apr 15;24(8):755–62)

Depending on the spine surgery, assistive devices for ambulation typically coincides with the complexity of the surgery, deviations, support required, comfort level and prior level of function. One level microdiscectomy or laminectomy surgeries may not require any device, whereas multilevel fusions may require rolling walkers for in hospital and home use.

Postoperative outpatient physical therapy is surgeon and surgery specific. Overall, all patients may benefit from a core stabilization program while protecting the spine. Our goals for outpatient therapy are to emphasize activity modification and minimize repetitive loading of the spine while improving core strength in a static and then dynamic positions.

## Summary

A cohesive interdisciplinary team and care plan needs to be established in order to design and implement an effective clinical pathway. Critical factors that delay LOS need to be identified and modified in order to design a pathway in order to progress patients to the highest level of function safely and expeditiously.

Preoperative planning and preoperative education are essential steps that will allow the organization to

individualize the clinical care plan for each patient. Formalized education programs will allow the education material to consistent and comprehensive and will prepare the patient for the upcoming surgery, answer questions, and reduce anxiety.

It is imperative that the interdisciplinary team, particularly the surgeons, anesthesiologist and the rehabilitation specialists, discuss rehabilitation goals in the acute phase while concomitantly reducing pain and side effects of opioids. Once this is achieved, early mobilization is imperative to enhance the patient's recovery. As seen since the inception of the revised HSS THA Clinical Pathway in 2007 and again in 2012, patients are achieving independence with a cane earlier as we continue to increase mobilization while minimizing pain.

Lastly, tracking data is critical to evaluate the effectiveness of the pathway and identify variables and opportunities for improvement. The HSS functional milestone tool is a valid and reliable tool which has be utilized in modification of clinical pathways as surgical and anesthesia trends have evolved.

**Summary Bullet Points**

- Preoperative education is essential to establish realistic patient expectations.
- Early mobilization after surgery allows the patient to achieve functional milestones earlier.
- Communication with the interdisciplinary team is crucial to ensure the patient is following critical steps in the Rehabilitation Guideline.
- A functional tracking tool will enable you to evaluate outcomes and make appropriate modifications to your plan of care.
- Rehabilitation therapists need to execute specific therapeutic principles to address functional deficits of the patient.

## References


1. Kroll M, Ganz S, Backus S, Benick R, MacKenzie C, Harris L. A tool for measuring functional outcomes after total hip arthroplasty. Arthritis Care Res. 1994;7(2):78–84.
2. Dunbar C. Making cents—what patient education can do. Nurs Spectr. 2002;14A(15):5.
3. Ritter M, Stringer EA. Predictive range of motion after total knee arthroplasty. Clin Orthop. 1979;143:115–9.
4. Laubenthal KN, Schmidt GL, Kettlekamp DB. A quantitative analysis of knee motion during activities of daily living. Phys Ther. 1972;52:34–42.
5. Warren CG, Lehmann JF, Koblanski JN. Heat and stretch procedures: an evaluation using rat tail tendon. Arch Phys Med Rehabil. 1976;57(3):122–6.
6. Light KE, Nuzik S, Personius W, Barstrom A. Stretch in treating knee contractures low-load prolonged stretch vs. high-load brief. Phys Ther. 1984;64:330–3.
7. Lachiewicz PF. The role of the continuous passive motion after total knee arthroplasty. Clin Orthop. 2000(380):144–50.
8. Su EP, Perna M, Boettner F, Mayman DJ, Gerlinger T, Barsoum W, et al. A prospective, multi-center, randomised trial to evaluate the efficacy of a cryopneumatic device on total knee arthroplasty recovery. J Bone Joint Surg Br. 2012;94(11 Suppl A):153–6.
9. Davy DT, Kotzar GM, Brown RH, Heiple KG, Goldberg VM, Heiple Jr KG, et al. Telemetric force measurements across the hip after total arthroplasty. J Bone Joint Surg Am. 1988;70(1):45–50.
10. Magee DJ. Orthopedic physical assessment. Philadelphia: W.B. Saunders Company; 1992.
11. Jacobs CA, Lewis M, Bolgla LA, Christensen CP, Nitz AJ, Uhl TL. Electromyographic analysis of hip abductor exercises performed by a sample of total hip arthroplasty patients. J Arthroplasty. 2009;24(7):1130–6.
12. Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc. 1991;39(2):142–8.
13. Isles RC, Low Choy NL, Steer M, Nitz JC. Normal values of balance tests in women aged 20–80. J Am Geriatr Soc. 2004;52(8):1367–72.
14. Wilke HJ, Neef P, Caimi M, Hoogland T, Claes LE. New in vivo measurements of pressures in the intervertebral disc in daily life. Spine. 1999;24(8):755–62.

# Quality Improvement in the Perioperative Orthopedic Setting

30

Michelle Horváth and Steven K. Magid

**Objectives**

- To understand the historical and philosophical underpinning of the quality–safety movement
- To impart an appreciation of the relevance of these issues to the perioperative orthopedic setting
- To review the concepts of "never events" and "a culture of safety"
- To discuss how quality is measured

**Key Points**

- The definition of quality care is complex and incorporates the viewpoint of perspectives including the patient, the provider, the institution where care is conducted, and the insurer.
- Safety is only one aspect of quality and is a concept that is patient centered and subsumes a number of considerations including effectiveness, timeliness, efficiency, and equity.
- Never events are errors for which the system should have zero tolerance. In the surgical setting they include wrong-site surgery (WSS) and retained foreign objects.
- A culture of safety strives to minimize errors and other adverse events and requires a commitment by all participants.

Practitioners should be aware of the challenges and opportunities in measuring performance and linking it to payment.

## Introduction

What is quality, and how is it measured? Most of us understand the concept of quality from everyday consumer experience. We know when we have received responsive customer service or when our expectations are not met. We know when the goods we purchase "work" as anticipated or when they fall short of our expectations. In healthcare the definition of quality is more complex. Perspectives may differ between the patient, provider, organization, and insurer. What are the characteristics of quality, and who decides if the patient experience has been one of quality?

Concern for evidence-based clinical care, safety, and articulating a broad set of characteristics in defining quality care is evident in the long history of the movement. In 1847, Dr. Ignaz Semmelweis introduced hand washing standards after discovering that the occurrence of puerperal fever could be prevented by practicing hand disinfection in obstetrical clinics. In 1863, the preface of Florence Nightingale's book, *Notes on Hospitals*, she preached, "It may seem a strange principle to enunciate as a first requirement in a hospital that it should *do the sick no harm*" [1]. Forty-five years ago, Avedis Donabedian, a physician and pioneer in healthcare excellence, published his classic description of the dimensions of quality. In his formulation quality is viewed as an attribute of a system, one requiring a proper *structure* (the capacity to provide high-quality care), a set of organized activities called *process*, and an *outcome* that results from both [2]. In 1990, the Institute of Medicine stated that "quality of care is the degree to which health services for individuals and populations increase the

M. Horváth (✉)
Department of Quality Management, Hospital for Special Surgery, New York, NY, USA
e-mail: horvathm@hss.edu

S.K. Magid
Department of Medicine, Rheumatology, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA
e-mail: magids@hss.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_30, 

likelihood of desired health outcomes and are consistent with current professional knowledge" [3]. This definition is widely accepted and has proven to be a useful reference in the formulation of practical approaches to quality assessment and improvement.

The Institute of Medicine's report *To Err is Human* in 1998 and the subsequent follow-up report *Crossing the Quality Chasm* in 2001 triggered seismic shifts in our attention to healthcare quality [4, 5]. These reports focused attention on the staggering number of deaths resulting from errors in healthcare as well as the unacceptably slow pace of change in protecting patients from such harm.

Patient *safety* rapidly rose to center stage after release of the IOM reports, and it is where this discussion of quality in perioperative care of the orthopedic patient will begin. Safety includes reducing preventable complications with evidence-based practice. Safety also includes highly publicized "never events," those that should never occur in hospitals. Safety, however, is only one aspect of quality. *Crossing the Quality Chasm* outlined other important components [5]:

- Effectiveness—avoiding underuse or overuse of services
- Patient centeredness—providing respectful, empathetic, responsive, individualized care
- Timeliness—reducing waits and harmful delays in care
- Efficiency—avoiding waste of equipment, supplies, ideas and energy, and resources to get the best value for the money spent
- Equity—providing equal care regardless of personal characteristics, gender, ethnicity, geographic location, and socioeconomic status

But what is the best way to *measure* quality? Using measures that have undergone a structured development process with content area experts and which have been endorsed by a national standard-setting body is a good starting point. The National Quality Forum (NQF) is an example of an organization that develops measures in this way. The NQF works with panels of experts who come to consensus on what constitutes "best" practice (based on current knowledge) and develop related standards through a process that includes feedback by healthcare providers, stakeholder groups such as professional organizations, and the public. Following the feedback period draft standards are voted on and, if adopted, field tested for reliability and feasibility of measurement [6]. Many of the quality measures being used in mandated quality measurement programs today were established through the NQF measure development process. The data reflecting compliance to these quality measures may be abstracted from medical records by hospital staff or "pulled" electronically from clinical computer systems and administrative data sets, such as those used for billing purposes.

In the orthopedic patient the role of quality in perioperative care is integral to assuring optimal outcomes. This chapter illustrates continuing challenges in preventing procedural never events and shows how data used to evaluate the processes and outcome of care do not always convey important information about quality accurately. We provide recommendations from the literature, summarize key points, and make recommendations for future priorities and directions for quality.

## Surgical Never Events

### Never Events Overview

The term *never events* references particularly shocking medical errors that simply should never occur [7]. There are now 28 across all sectors of healthcare. In orthopedics these events include surgical objects unintentionally left in the patient (e.g., sponges and instruments) and operations and procedures (e.g., anesthetic blocks of pain procedures) on the wrong patient or on the wrong site (incorrect anatomic site, side, or spinal level). Wrong surgery and unintentionally retained foreign objects (URFOs) are considered *sentinel events* by TJC. Sentinel events are defined as any unanticipated event in a healthcare setting resulting in death or serious physical or psychological injury to a patient or patients. TJC requires that a *root cause analysis* be performed on all sentinel events.

Between the years 2004 and 2013, 7881 sentinel events were reviewed by TJC nationwide, of which 13 % were wrong-patient/site/procedure surgery. URFO's ranked third in frequency, accounting for 875 (11 %) of reviews. TJC reporting is voluntary.

### Unintentionally Retained Foreign Objects

Most of the literature on retained objects after surgery consists of case reports. However, in one case controlled study conducted by Gawande et al. the incidence was estimated at 1 in 8,801–18,760 inpatient surgeries, or 1 per year at a large hospital. A majority were abdominal, pelvic, or vaginal surgeries. The risk increased ninefold during emergency surgery and fourfold if there were unexpected changes in a procedure. In 88 % of cases, the surgical count (the process designed to prevent *URFOs*) was noted to be "correct" [9]. A more recent 3-year review conducted by Cima et al. of a single hospital estimated the frequency of *URFOs* as 1:5,500 surgeries. The surgical count was frequently recorded as correct, and 59 % of objects were found only after routine postoperative X-ray. Unlike the earlier study, most retention occurred during routine surgeries. Breakdowns in communication impacting the surgical

count were most often the contributing factor [10]. Ergova et al. found a rate of retention of 1:7,000 CABG procedures. Count discrepancies identified 77 % and prevented 54 % of *URFOs*. Count discrepancies increased with surgical duration, late-day procedures, increased number of nursing teams, and added additional costs [11, 12].

The lessons learned from these studies are relevant to orthopedic surgery. Retained objects most frequently involve sponges but also include instruments such as retractors, clamps, needles, and other items. Like other never events, the outcome can be devastating and may lead to additional morbidity, mortality, and increased costs.

As noted, surgical counts do not eliminate *URFOs*. Other strategies include using surgical sponges with radio-opaque markers, obtaining intraoperative X-rays in high-risk procedures, and using trays with designated places for certain instruments [10]. Newer technology is becoming available to prevent *URFOs*. Bar-coded inventory systems have been shown to be superior to manual counting and may decrease the opportunity for retention but does not aid in localization of missing items [13]. Radio-frequency identification (RFID) devices are another methodology that enables detection of labeled items at the close of surgery though costly [14]. Currently, a multimodal approach is recommended [9, 12–14].

## Wrong-Site Surgery

Like URFOs, *wrong-procedure*, *wrong-site, wrong-side, wrong-level, and wrong-patient surgery* occur despite practices designed to prevent them. The term *WSS* will be used to reference all these. The occurrence of *WSS* has been attributed to pressures to start or complete surgery, human factors such as fatigue and distraction, emergency procedures, personnel changes, unusual patient anatomy, and incorrect patient preparation including errors in operating room scheduling, site signing, consenting, and failure to review imaging [15–17]. In 126 cases reviewed by TJC almost all involved a breakdown in communication between the surgical team, the patient, and the family [16].

The attention given to *WSS* has resulted in a robust body of literature. In a review of studies conducted between 1990 and 2008 rates of *WSS* ranged from 0.09 to 4.5 % per 10,000 surgeries performed [17]. In a review of malpractice cases from 1985 to 2004, Kwaan et al. estimated the incidence of *WSS* to be 1 in 112,994 surgeries [18]. While WSS occurs across the span of surgical specialties, several studies have demonstrated that most *WSS* occur in orthopedics (including spine) [16, 18, 19]. In a review of 10 years of insurance claims from 1985 to 1995 involving *WSS*, 68 % were related to orthopedic procedures [20]. A review of claims from a different insurer from 1977 to mid-1997 revealed that 36 of 37 claims were from a single outpatient surgical center. The site most commonly associated with error was the knee; arthroscopy was the procedure most frequently associated with error [20]. Data from the National Health Service Litigation Authority from 1995 to 2007 identified trauma and orthopedics as accounting for most *WSS* claims [19]. In a survey of the American Academy of Neurologic Surgeons, 50 % reported that they had done one or more wrong-level surgeries in their career; 15 % of respondents reported that they prepared the incorrect spine level but noticed the mistake before incision [21]. A survey of hand surgeons in 1999 revealed that 21 % reported operating on the wrong site at least once in their careers [22]. A recent case analysis of a surgeon who performed carpal tunnel surgery instead of trigger finger release demonstrates that wrong-hand procedures continue to be a concern today [23]. The Veterans Health Administration (VHA) reported 101 wrong-site events from mid-2006 to 2009 *after* implementation of team safety training. The 13 events reported for orthopedics was half the number prior to team training [15].

The increased incidence of WSS in orthopedics has been attributed to the volume of orthopedic procedures, more opportunity for lateralization errors, cognitive challenges presented by the combination of laterality, patient draping and positioning, and perhaps an increased willingness to report events related to the educational efforts of the American Academy of Orthopedic Surgeons (AAOS) and other safety groups [19, 24]. Unfortunately, because data are self-reported, it is impossible to establish a true prevalence. Fears related to litigation and disclosure hinder reporting.

Spine surgery is particularly challenging. Of 40 cases identified by Kwaan et al. 11 were non-spine orthopedic cases and 15 were spine (wrong vertebral level or wrong-side laminectomy) [18]. Reasons often cited for this challenge are anatomical. Adjacent levels may look identical to each other inside the surgical wound. Congenital or developmental variants may make localization challenging. Obtaining adequate X-ray images may be difficult [17, 25, 26]. Some of these same risks have been documented for spinal pain management procedures [27].

Using an *incorrect implant* in orthopedic surgery is infrequently mentioned in the literature. In the VHA report cited previously, prior to team training, wrong implants accounted for 46 % of orthopedic events. After training they accounted for 23 % of orthopedic events (3 of 13 events) [15]. The New York State Department of Health includes wrong implants in its definition of wrong procedure but has not published data on this category. In addition to the potential need for revision surgery due to pain, decreased motion, and poor function, it is estimated that 36 million dollars a year is wasted when implants are opened, but not used [28]. In a report from Germany, 47 patients had implants which were intended for use in a cemented fashion used in uncemented knee replacement surgery. This error was attributed to erroneous interpretation of English language label packaging and

selection by a company representative [29]. One organization lowered wasted implant rates from 5.7 % to 0.8 % in total knee arthroplasty cases by using a computer based e.Label system that standardized implant labeling and confirmed correct size, site, and compatibility within implant systems. During the 7 month study period, the e.Label and compatibility system also recognized one instance of staff opening a left sided component for a right sided case [30]. The system thus may have potential to decrease the likelihood of actual implanted laterality error.

**Case Study**

A 70-year-old patient underwent bilateral knee arthroplasty. The next day, during implant room inventory, it was discovered that two left femoral components were used. A left femoral component was implanted into a right knee during the second of the simultaneous sequential procedures.

As per routine, the surgeon had ordered the desired implants to be available on the day of the operation. As customary, intraoperatively the surgeon issued a verbal request for the first (left) implant to the circulating nurse who wrote it down and then called the order to the implant room. The implant technician readied the implant and read the implant specifications aloud from the sheet he had prepared from her verbal request. At the implant room the nurse visually scanned the boxes, then signed for the implant, and brought it to the OR. When the surgeon was ready for the component she held up and read the box label to the surgeon who glanced at it and assented but did not read back the measurements and laterality on the box label as per policy. When the request was given for the second (right) implant, the nurse took the implant dispensed to her; however; the implant room technician and the nurse skipped the verification step. The nurse signed the paperwork that indicated that she received a right-sided component although a left-sided component had been dispensed. She brought the components to the OR and verbally communicated to the surgeon a right-sided component and size while holding up the box, which said "left." The surgeon again glanced at it and assented, and the left implant component was opened onto the surgical field and implanted in the right knee.

## Case Study Analysis

One of the first opportunities to prevent this error occurred when the implant technician handed the incorrect box to the nurse, highlighting the importance of an *implant verification*. Because of the fast pace at the implant-dispensing window, a formal read back was not required by policy; instead, the technician reads the specifications aloud, while the nurse visually scans the implant box. Although this process has been effective in the past, it is clear from this case that the process is fallible. Some organizations rely on the expertise of vendor representatives to assist in choosing implants. However, this also has been associated with errors [29].

Implant labels are difficult to read and lack standardization. Label specifications typically include the implant manufacturer, type of prosthesis, brand name, size, and laterality as well as other numerical information such as serial or other identifying numbers. However, the location, size, font, and even presence of this critical information vary among different implants and manufacturers [28]. The choice among a large number of implant components and manufacturers may optimize clinical outcome; however the multiplicity of components and lack of standardization of the labels may increase the likelihood of mistakes. Look-alike packaging has been identified as a root cause of some orthopedic implant-related events [15], and visual-cueing strategies such as color coding for laterality (red = right, green = left) should be considered.

In this case the surgeon's ability to visually verify the implant label was made more difficult by the use of protective "space suits" and the plexiglass barriers of the operating room. A technical solution was found, and magnification boxes are now in the operating rooms.

The *implant time-out* consists of a mandated pause prior to dispensing the implants onto the surgical field to formally verify that the requested implants have been received. The *implant time-out* is a last opportunity to catch critical dispensing errors. It requires a complete stop in activities and full attention. Accountability for the implant time-out was assigned to the circulating nurse. In our case study the circulating nurse was highly experienced, but she was substituting for the regular circulating nurse. She was inserted into a tightly knit and highly functioning surgical team led by a high-profile surgeon. In this setting, she felt uncomfortable asking the surgeon to repeat back the implant specifications while looking at the box.

## Causes of Never Events

While multitasking is common, and perhaps necessary in medicine, it is virtually impossible to perform a committed time-out while attending to other tasks. This is true for an implant time-out and for the anesthesia and procedural time-outs performed to verify patient identity, procedure site, side, and laterality. Distractions and a multitude of other cognitive "biases" or errors have been identified in analyses of never events and other adverse events in healthcare [31]. A few are mentioned next.

### Human (Cognitive) Errors

*Parroting* information during verification or time-outs, without being fully engaged, can be a source of errors. The use of specialized teams which routinely work together may mitigate some types of errors, but they may increase the likelihood of *parroting* because familiarity may contribute to a proclivity to anticipate questions and answers without paying attention to the details. There may also be a greater sense of security with each other which makes them willing to "trust" each other and skip important safety checks. *Inattentional blindness* is another cognitive error that may lead to surgical errors. This may happen when a team member becomes so completely focused on one aspect of the procedure that he or she becomes "blind" to other important information occurring in plain sight. The invisible gorilla awareness test is a dramatic example of inattentional blindness [32]. This cognitive error may contribute to some instances of retained instruments in which attention is so singularly focused on a particular task in the surgical wound that the surgeon does not see that an instrument was left behind in a patient. *Anchoring errors* may also affect surgical outcome; these occur when decisions are made which focus on only one piece of information. A clinician may be so certain about something that he/she reflexively discounts dissonant but potentially important information.

### Fast Pace and Rushing

*Haste* is recognized as a root cause in sentinel events [33]. This may be a function of a high workload but may also be related to wasted energies. The lean improvement methodology has focused on this. For example much time may be lost locating missing instruments. Lean methodology focuses on improving these operational inefficiencies. Other inefficiency examples are inadequate inventory, staff shortages, and wasted steps from poor workflow design.

### Early System Failures

*Lapses* that occur before the patient even enters the operating room also contribute to never events. James Reason described the *Swiss cheese model* of errors [34]. In this construct, an error reaches the patient only after passing through holes in many layers of defense. It is only when all the holes "line up" that the lapses result in an error. Addressing "holes in defenses" as early as possible may prevent error long before the day of surgery. An example of this is *surgical listing errors* that occur in the surgeons' office at the time of booking surgery. It is imperative that the correct patient be identified using more than one identifier and that the correct surgical procedure and laterality be listed. Errors that originate in the surgeon's office may be propagated "downstream." One organization identified 759 surgical listing errors in a single year (1.38 % of surgeries) [35]. Most of these were cases with either incorrect or the absence of laterality.

*Errors of patient identification* form another hole in the layers of cheese. These include choosing the wrong patient name off of an electronic pick-list, choosing the wrong patient because of an identical (or nearly identical) name, and improper electronic merging of information from patients with the same names. Patients may also have look-alike or sound-alike names. Patients often have two or more versions of their name. For example their insurance may be in one name, the patient may be known in daily life as another, and the legal name may be yet another. Rarely, two patients with the exact same name will be scheduled for surgery on the same day. This emphasizes the need for the second unique identifier, such as date of birth, in addition to the name.

*Lack of involved patient participation* may also lead to errors. Patients will sometimes respond to the wrong name, not read their consents with care, and even have undergone wrong-side procedures while awake without calling attention to the issue [27]. Because orthopedic surgery is frequently elective, the last time the surgeon saw the patient may have been weeks earlier. The surgeon may not recognize the patient and be embarrassed to ask the name during the identification process, instead identifying the patient by the room and bed number. Sometimes the provider thinks he/she recognizes the patient, and shortcuts are taken.

## Culture of Safety

The concept of a *culture of safety* originated in studies of "high-reliability" organizations, such as the nuclear, naval, and aviation industries. These organizations strive to minimize errors, and events, despite carrying out complex and intrinsically dangerous work. They maintain a commitment to safety that extends from the front-line workers to the executive suite. There are a number of key elements in a culture of safety:

- Empowerment of individuals to report errors and safety concerns without fear of retribution
- Commitment to improve communications by removing hierarchical barriers such as rank and fostering teamwork
- Determination to achieve consistently safe operations
- Leadership seeks feedback on culture

### Empowerment

A culture of safety encourages the reporting of *near-miss events*. These are events that did not result in injury but had the potential to do so. In the past, safety efforts were typically reactive. After an event occurred which resulted in

patient harm, a drill-down or a root-cause analysis was performed and blame was apportioned. Studying near misses allows organizations to be proactive, preventing "hits" before one happens. A culture of safety establishes a non-punitive atmosphere in which to report them.

To increase reporting of events and near misses, many organizations moved to a "no-blame" culture. They removed the fear of reprimand and used supportive actions such as education and training to address errors except where reckless behavior contributed to the event. These are often appropriate strategies. However, there still needs to be accountability and consequences for staffs that resist adoption of evidence-based safety practices that are generally accepted or have regulatory mandates. The balance between addressing system vulnerabilities and individual accountability is referred to as a *blameworthy or just culture*. In a just culture holding individuals accountable should be predicated on prior education and a discussion of the consequences of not following the guidelines [36].

## Improved Communication and Teamwork

For safe care to be delivered all caregivers must function as a team. The concept of *crew resource management (CRM)* can be traced back to a workshop conducted by NASA in 1979 [37]. Research presented at this meeting demonstrated that human error was involved in the majority of air crashes. Furthermore, these errors were not related to the technical knowledge or skills required to be an aviator. Rather, accidents were the result of failures related to the cognitive and interpersonal skills required to manage a crew or a team. These skills include interpersonal communication, decision making, leadership, situational awareness, and problem solving.

These same factors are also critical in the operating room. Healthcare team training may include communication (e.g., standardized hand-offs, debriefings, assertiveness training), collaboration (e.g., leadership, role clarification, accountability, mutual performance monitoring, and feedback), and situational awareness [38, 39]. The importance of fatigue management to patient safety is recognized in a recent release of a sentinel event alert on healthcare worker fatigue [40].

## Achieving Consistently Safe Operations

Another safety innovation borrowed from aviation is the use of the *checklist*. Investigations of aviation accidents revealed that some accidents occurred because simple steps were omitted in the operation of the aircraft. Flying had become so complex that checklists were needed to ensure compliance with simple but mandatory steps.

The World Health Organization's (WHO) Surgical Safety Checklist [41] is an excellent example of how a checklist can improve safety. In a 2007–2008 study performed in diverse hospitals all over the world, 4,000 patients undergoing non-cardiac surgery were studied before and after implementation of the WHO checklist. Complication rates decreased from 11 to 7 % and mortality decreased from 1.5 to 0.8 % measured 30 days after surgery [42]. In another comparison before and 9 months after introduction of a comprehensive, multidisciplinary surgical checklist, the proportion of patients experiencing one or more complications declined from 15.4 to 10.6 % within 3 months of surgery and in-hospital mortality declined from 1.5 to 0.8 % [43]. In a review of all incidents reported to the United Kingdom's National Reporting and Learning Services database in 2008, it was determined that 14.9 % of near misses and 83.3 % of actual harm events could have been prevented by the use of the WHO checklist [44].

Influenced by such data, TJC mandated a "Universal Protocol" in 2004 (updated in 2010) [45]. There are three components: pre-procedural verification, site marking, and a time-out. TJC is intentionally not prescriptive about how an organization fulfills these requirements [46]. Specialty organizations such as the AAOS and the Association of Perioperative Registered Nurses (AORN) give more specific guidance on implementing safety practices.

The development and use of checklists are not straightforward. Should team members be "forced" to introduce themselves? Should confirming antibiotic administration be included? Should there be an extended debriefing that includes review of postoperative orders? Or should checklists cue only very few critical communications that present the last barrier to a never event? The risk of checklist fatigue and noncompliance may outweigh the benefit of broadening their scope. Organizational culture determines these decisions.

## Leadership Seeks Feedback

Leadership must evaluate the extent to which they have achieved safe operations and use feedback as a baseline for improvements in a culture of safety. An auditing system helps to determine the extent to which crucial safety behaviors have been adopted; however, determining compliance is not easy. Auditing is resource intensive, especially if done by adjunct observers, and may be associated with the "Hawthorne effect" where the presence of an observer improves compliance. Members of a surgical team may not be willing to correct each other or report noncompliance. In the case presented, a process was in place to monitor the implant time-out using surgical staff already in the operating room. These "internal" audits typically demonstrated 100 %

compliance. Following the event cited in the case study, an anonymous electronic survey was sent to all OR staffs which asked if every step in the implant time-out is typically done. The results were far from 100 % compliance. Home-grown electronic surveys coupled with auditing may give a better estimate of compliance to safety behaviors.

"Walk rounds" by senior leadership, using a structured or an unstructured format, is another important tool for getting feedback about staffs' perception of how safe the culture is and visibly demonstrates leadership's commitment to safety. Feedback from rounds prioritizes quality improvement efforts. Annual administration of a safety culture survey by hospitals or physician offices can help track improvement progress and benchmark performance [47].

## Measuring Quality

### The Cost of Healthcare

The cost of healthcare in the United States as a percent of gross domestic product (GDP) has risen steadily from 5.9 % in 1965 to 17.6 % in 2009. It is predicted to be 19.8 % of GDP by 2020. Average annual healthcare spending growth is expected to outpace average annual economy growth by 1.1 % from 2010 to 2020 [48]. Despite the enormous expenditures, spending more on healthcare has not guaranteed better outcomes. A 2009 Dartmouth study found that higher spending regions of the nation demonstrated less adherence to evidence-based care guidelines; had higher mortality rates for acute myocardial infarction, hip fracture, and others; and had more difficulty obtaining inpatient admissions and high-quality specialist referrals [49].

Healthcare costs continue to rise despite attempts to restrain them. Prior to 1983, hospitals were paid for each day the patient stayed and for each procedure or test performed. There was little incentive to limit either. Payment by "diagnosis-related groups" (DRGs) was implemented by CMS in 1983. DRGs placed patients into groups by their diagnoses and paid a fixed rate for the care of patients in each group. The *Health Maintenance Organization* (HMO) Act of 1973 stimulated the development of HMOs as another cost control mechanism. This required primary care physicians to act as gatekeepers to health services. Other forms of *managed care* proliferated in the late 1980s and attempted to control costs by using networks of participating providers with whom fees could be negotiated. HMOs and managed care plans also included review of service utilization by providers and financial incentives for patients (e.g., in the form of lower out-of-pocket payments). These efforts were not overly successful, and there was the widespread perception that quality of care was sacrificed to save money, sometimes by preventing patient access to needed care.

These attempts to control healthcare costs focused on the *quantity* of services offered but not the quality of healthcare. An example of this is that hospitals were still paid for their errors. If a patient had to return to the operating room to remove a retained sponge the hospital was reimbursed for the additional costs incurred. If a patient had a complication due to a medical error, that additional diagnosis was reimbursed. Thus the IOM reports were a lightening rod furthering a rapid shift in focus to controlling rising costs by paying for quality healthcare and not paying for mistakes or poor quality. In order to link payment to quality of care, however, definitions and measures of "quality care" had to be developed.

### Types of Quality Measures

The six domains of quality described by the Institute of Medicine are often used as a framework for quality measures. Quality care should be safe, effective, timely, efficient, patient centered, and equitable. *Indicators* (a term often used interchangeably with *measures*) of quality can be descriptive, prescriptive, or proscriptive. *Descriptive indicators* provide descriptive information on unusual situations, for example, an unplanned return to the operating room within 24 h of elective hip replacement surgery. They are used to cue cases for closer review. *Prescriptive indicators* compare performance with an external standard such as compliance rates with appropriate antibiotic selection in elective knee surgery. *Proscriptive indicators* measure undesirable situations or actions such as medication errors [50, 51].

Another system for categorizing indicators is by whether they measure structure, process, or outcome. *Structural measures* help to evaluate the care environment, i.e., the facility's resources and how it is organized. Examples are implementation of electronic medical records, nursing hours per patient day, and surgical volume. The "how" of caregiving is evaluated by *process measures*: for example, the timely administration of appropriate anticoagulation prophylaxis for a particular surgery. Until recently, structure and process measures have been the main focus of healthcare quality initiatives because measurement is straightforward. *Outcome measures* evaluate the end result of care delivery [2, 50]. They may be more difficult to measure and interpret because any given outcome should be adjusted for the patient's comorbidities and the complexity and risk of a procedure. These adjustments are subject to many methodological concerns. Venous thromboembolism after surgery is an outcome example of a *potentially preventable complication*. Use of evidence-based treatments can reduce these

events although any particular patient can still experience them even with all the "right" care. *Patient experience of care measures* (satisfaction) is also considered as outcome measures.

## Key Quality Organizations

Several organizations form the backbone of the hospital quality movement (Appendix 1 at the end of this chapter). The Joint Commission (TJC), formerly the Joint Commission on the Accreditation of Healthcare Organizations (JCAHO), was established in 1951 as a not-for-profit organization for the voluntary accreditation of hospitals. *The Center for Medicare and Medicaid Services* (CMS) also has its own requirements for quality and safety called *conditions of participation*, although they give TJC the ability to decide if hospitals meet the requirements necessary for being eligible for Medicare reimbursement known as *deeming authority*.

In 1998 TJC implemented its *core measures program*. This program required hospitals by 2002 to report how well they performed on specific evidence-based quality measures. Because all hospitals were collecting information using the same criteria, it allowed TJC to make valid comparisons of care across accredited hospitals. Current core measure sets can be found on http://www.jointcommission.org/core_measure_sets.aspx and include measures for venous thromboembolism, surgical care improvement, and immunization.

The President's Advisory Commission on Consumer Protection and Quality in the Health Care Industry proposed creation of the National Quality Forum (NQF) in 1998. The mission of the NQF is to improve the American healthcare system by working with panels of experts to create evidence-based best practice and standards. Today it has endorsed more than 500 quality measures.

*The Leapfrog Group*, founded in 2000, is composed of corporations and agencies that buy health benefits on behalf of their employees. They are able to leverage their purchasing power to further quality. Their initial measures included three structural initiatives: computerized physician order entry, staffing intensive care units by trained intensivists, and evidence-based referrals for high-risk surgeries.

The *Hospital Quality Alliance* (HQA) was formed in 2002. The HQA is made up of organizations that represent hospitals, physicians, nurses, and others. The HQA has a commitment to making healthcare quality and cost information available to the public. Together with CMS, the HQA launched the Hospital Compare website (www.hospitalcompare.hhs.gov/) to support this goal. Since then many states and agencies have established public websites for the review of hospital quality data. This supports the concept of *transparency* as a way to promote quality. By publishing data on where quality care can be obtained, it is believed that shifts in consumer behavior will lead to better results.

## Linking Quality to Reimbursement

In 2003 CMS partnered with Premier, Inc., to launch the voluntary, incentivized Hospital Quality Improvement Demonstration (HQID) project to prove that linking quality to reimbursement improved quality and had the potential to save lives. Following the success of this program CMS began to require reporting of select hospital quality data. This became known as *pay for reporting*. The first measure sets mandated for reporting were for heart failure, acute myocardial infarction, and pneumonia. Shortly thereafter surgical quality measures in the form of the *Surgical Care Improvement Project* (SCIP) were introduced. They initially consisted of three measures for antibiotic prophylaxis—administration within 60 min of surgical incision, appropriate antibiotic selection, and discontinuance by 24 h after surgery. Hospitals that did not report their data were penalized by losing a percentage of their Medicare *market basket update* or Medicare reimbursement the following year. Soon additional measures were added to the SCIP set such as perioperative beta blocker use and anticoagulation prophylaxis measures. The amount of reimbursement withheld for not reporting has increased, and the number of measures mandated for reporting has increased from 10 measures in 2005 to 55 in 2014 [52]. These programs now include free-standing ambulatory surgery centers.

Since 2011, hospitals are subject to *pay for performance* or *value-based purchasing* (VBP). CMS holds back a percentage of the expected reimbursement for the following fiscal year. Hospitals earn this money back by achieving defined goals or by improving significantly. Given the consistently high level of performance across all measures of care and patient satisfaction required to reach the top level of goal performance, it may not come as a surprise that very few hospitals earn back all of their withheld funds [53].

## Challenges in Measuring Quality

Currently, obtaining quality data is time and resource intensive. Much of the data must be manually abstracted from the medical record. However, other data may be available in electronic systems such as those used for billing. Although organizations can transmit data directly to and from CMS, many use a costly vendor intermediary. This reduces the technical burden while helping quality staffs stay abreast of changing regulations and data transmission deadlines. Data entry or other technical errors can result in six-figure penalties.

These programs have been successful nationwide in improving compliance with evidence-based processes measures. For instance, the SCIP measure for giving prophylactic antibiotic within 60 min of incision to hip and knee replacement patients increased 14.5 % from the inception of the program in 2006 to 2010. The measure for discontinuing prophylactic antibiotics within 24 h after surgery improved 27 % for the same period of time. Prescribing and giving anticoagulation prophylaxis for all types of surgery use have improved 8 % and 10.5 %, respectively, since the inception of these measures from 2007 to 2010 [54].

Although many organizations have improved in these measures, there is a concern that process measures alone may have limited usefulness in telling us about hospital quality. While they may highlight particularly poor performers, statistically they have lost their power to differentiate "good" hospitals from "better" hospitals [55]. Surprisingly, adherence to evidence-based process measures has not always translated into expected outcome improvements such as improved surgical site infection (SSI) rates [56, 57]. There are a number of possible explanations for this. Perhaps hospital adherence to process measures known to prevent infection in SCIP (such as timely antibiotic prophylaxis and selection) has improved to where current high levels of performance no longer have a differentiating effect on SSI rate [55]. Additionally, SSI rate is impacted by many variables beyond SCIP processes such as variation in clinician skill and competency and risk adjustment for procedural complexity especially in orthopedics [58]. Other factors that are not adequately accounted for that may impact SSI rate and other outcomes in orthopedics include patient selection, preoperative planning, anesthesia management, controlled bleeding, and appropriate rehabilitation [55].

## Quality Measures in Orthopedics

The national measures that are most germane to orthopedics include the SCIP process measures (e.g., antibiotic prophylaxis) as well as some of the outcome measures (e.g., venous thromboembolism). Appendix 2 at the end of this chapter summarizes many current measures used in evaluating perioperative quality today and their associated domains.

However, how well do standardized national quality indicators truly measure orthopedic quality? Is the bar set too low, and are the measures specific enough to be meaningful? In orthopedics it may be necessary for individual institutions to develop their own measures after consulting literature specific to the particular orthopedic population. For example how does one measure quality for carpal tunnel syndrome surgery [59]? Or for patients with rheumatoid arthritis undergoing foot surgery—is quality measured by the need for a preoperative vascular consult, assessment of the cervical spine for stability, and the management of postoperative steroids [60]? One organization developed its own metrics to evaluate pain management interventions after joint replacement surgery [61]. Further, in an expert review of 101 potential quality indicators for elective hip and knee replacement 68 were rated as having statistical validity [62]. This article included a more expansive measure menu than the complication and all-cause readmission measures for elective hip and knee surgery currently under development by CMS [63].

In addition, to fully understand orthopedic quality and the outcomes associated with orthopedic surgery a much longer time frame must be used. Prosthetic failure and need for revision surgery typically occur far after the index surgery. For this reason, establishing clinical data registries that follow patient outcomes for years after the surgery are crucial in orthopedics. Return to activities of daily functioning and perceptions of pain relief are measures associated with data registries but are not reflected in current quality measurement programs.

Two important quality issues in the perioperative care of the orthopedic patient are appropriate preoperative risk stratification and optimization of the patient for surgery by managing comorbidities. There are various methods of assessing risk; however, these provide only general guidance and their usefulness in the orthopedic population has not been completely studied. Hospitals may need to use proxy measures such as performing an HbA1c test within 30 days of surgery on diabetic patients or waiting a year before performing elective surgery on patients who have had drug-eluting stents placed [64].

Determining hospital and physician quality is more complex than currently understood by the public. Examples of how confusing this information can be are given next:

- In the first release (2011) of TJC's America's Best Hospitals list, some of the nation's most prominent hospitals, including some of the nation's most renowned hospitals, did not make the list. Responding to confusion created by their ranking and the "best" rankings given to these renown organizations by others, TJC cited flaws in popular ranking systems that rely on reputation and flawed risk adjustment [65].
- There may be an ability to "game the system."
- There are marked differences in the diligence with which "occurrences" are reported. For example in 2009, the New York City Comptroller noted that some hospitals reported occurrences 20 times more often than rates at comparable hospitals. Yet some of these were also recognized as "Centers of Excellence" [66].
- Coding inconstancies and varying interpretation of codes exist between hospitals and result in widely different quality reports.

- Some measures include a wide variety of conditions, making their interpretation difficult. For example hospital-acquired "falls and trauma" include falls resulting in fractures, burns, dislocated joints, and electric shock.
- There is debate as to whether some complications which supposedly reflect quality of care are truly preventable or even clinically significant when they occur. The category "accidental puncture or laceration" is one of several *hospital-acquired conditions* sometimes used to rank hospital quality. This category may or may not, depending on the ranking organization, include accidental lacerations of the dura during spine surgery. In one study a majority of inadvertent dura lacerations were considered unavoidable as a result of scar tissue from prior surgery or surgical complexity [67]. How is the public to know or understand the differences in quality rankings which include or exclude this complication?
- Postoperative pulmonary embolus (PE) is a potentially preventable complication that can result in decreased hospital reimbursement and is also a measure of quality. However, some PEs occur despite complete adherence to recommended prevention guidelines. This may be due to a related comorbidity or a genetic predisposition to clots. Since PEs will *never* be completely preventable should poor care be assumed?
- Documentation problems can result in a hospital with near-perfect performance looking as if it is a poor performer (Fig. 30.1).

Despite these limitations, there is almost always something to be learned from the measures. Many times the data will shine the spotlight on hospital opportunities to improve medical record documentation, to correct coding practices, and, most importantly, to improve performance.

The graph represented in Fig. 30.2 demonstrates the intended value of national measure sets. In an effort to reduce catheter-acquired urinary infections, a measure was promulgated to insure that indwelling Foley catheters be removed within 48 h of surgery (unless contraindicated). At the Hospital for Special Surgery, a quality improvement team was formed in the first quarter of 2010; and after patient and staff education, changes in post op order sets, and the acquisition of bladder scans, a dramatic improvement occurred. This is not only the case at our hospital but the national trend also demonstrates an improvement.

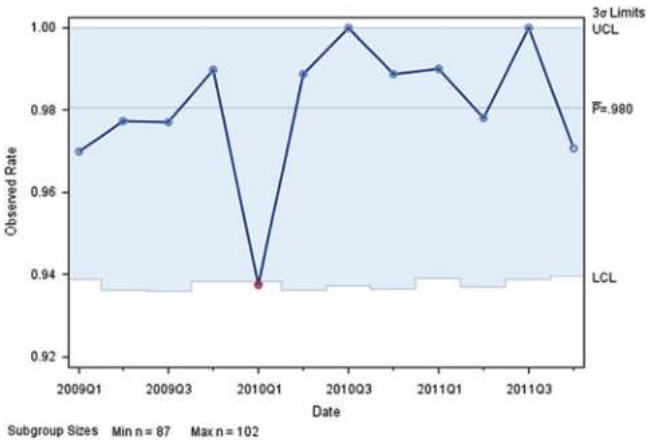


**Fig. 30.1** P Chart for performance improvement. SCIP-Inf-1a: Proph Atbx received within 1 h prior to Surg Incsn: Overall rate. Impact of documentation on "performance." At the Hospital for Special Surgery, the *anesthesia end time* (AET), used to calculate compliance to timely administration of postoperative antibiotics, was used synonymously with *PACU transfer time* and manually documented in the *PACU time* spot on the anesthesia record. Although an AET spot was also available on the record, the *PACU time* had long been used for other reasons to avoid duplicative documenting. When chart abstraction rules changed, disallowing *PACU time* to substitute for AET, documented performance "failed" although actual performance was near perfect, until anesthesiologists routinely started documenting in a new spot on the anesthesia record. The impact of this performance is seen in first quarter 2010 data

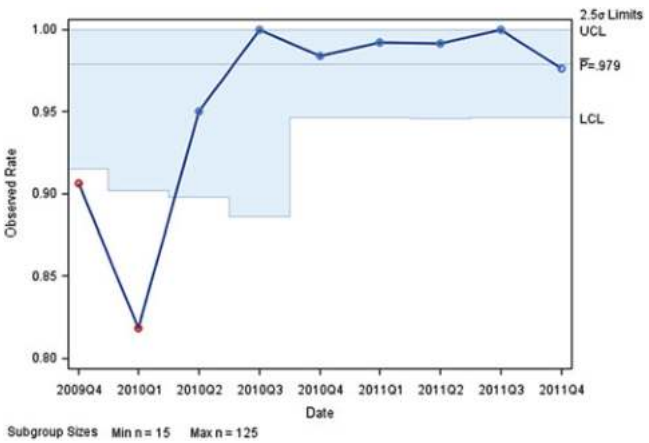


**Fig. 30.2** P Chart for performance improvement. SCIP-Inf-9: Urinary catheter removed on POD 1 or POD 2. Demonstrates the intended value of national measure sets. In an effort to reduce catheter-acquired urinary infections, a measure was promulgated to insure that indwelling Foley catheters are removed within 48 h of surgery (unless contraindicated). At the Hospital for Special Surgery, quality improvement team was formed in the first quarter of 2010; and after patient and staff education, changes in post op order sets, and the acquisition of bladder scans, a dramatic improvement occurred

## Orthopedic Benchmarks

At present, reliable orthopedic specific benchmarks are lacking in many areas. These include readmission rates as well as unplanned return to the operating room. Rates of certain complications, such as venous thromboembolism, are published and used in quality rankings without stratifying by specialty and by procedure performed and without consideration of patient comorbidities that place

patients at greater risk. This may lead to incorrect conclusions about quality as well as inappropriate reductions in reimbursement. Some events are quite rare, and therefore prevalence rates are difficult to ascertain. Tracking days between these events instead of a rate or consulting the literature for other guidance on how to analyze rare events may be more useful [68, 69].

### Socioeconomic Status and Equity

The relationship of socioeconomic factors and patient demographics to outcomes and to equitable access to care needs more investigation. In addition, even while socioeconomic status is known to affect outcomes such as in hip replacement [70] current methodologies do not account for this variable in risk adjustment. Even where equity in access to care is expected, disparities exist. In a study on joint replacement in the United Kingdom, inequities to access were related to age and gender, but not rurality as seen in other studies. Age-related inequity to access was theorized as being related to patient variables (e.g., unwillingness and stoicism) and physician variables (e.g., concern over advanced age leading to poor outcomes [71]). This adds to concern that current methods for measuring and reporting quality could result in "cherry picking," i.e., inappropriately limiting elective procedures to the healthiest of patients in order to avoid, for instance, potentially preventable complications [58, 71]. National data programs and registries are uniquely situated to advance the study of outcomes and disparities in healthcare across race, gender, ethnicity, and socioeconomic groups.

## Future Challenges

### Obtaining Data

Medical knowledge is increasing at a rapid rate. It is estimated that clinical knowledge doubles every 18 months [72]. So too is the amount of medical information generated, collected, and stored. Increasingly this information is stored in electronic format. Access to this information is critical to quality endeavors because access to accurate data is the foundation of measuring quality. Dr. H. James Harrington said: "Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it" [73]. It is clear then that not having *access* to data and information for measurement is tantamount to not having it at all.

At present, healthcare data are likely to reside in different places and in different forms. Medical information may be stored in a patient's home or in a many different clinician's offices. It may be in one or a number of hospitals (in the same city or across the globe), rehabilitation and nursing facilities, and freestanding laboratories or X-ray practices. It will also exist in many different forms. Some of it will be analogue on paper such as a chart, EKG, or X-ray film. Mining charted data to perform quality measurements is fraught with difficulty. It must be manually gathered and then tabulated. Handwriting is difficult to read, and many times information has not been recorded. Transcription errors occur and can be over 10 % in some settings [74, 75].

The electronic health record offers help with many of these problems. The ability of computer physician order entry (CPOE) to prevent transcription errors has been well studied; however, in the United States, we are many years away from having a seamless interconnected electronic medical record. Despite meaningful use (which incentivizes both hospitals and physicians to meaningfully use the EHR), most institutions are not paperless or anywhere near that vision. A recent survey documented only a moderate increase in the number of the US hospitals that have either a basic or a comprehensive EHR from 8.7 % in 2008 to 11.9 % in 2009 [76]. Only 2 % of hospitals are estimated to be able to meet all of the objectives of the first stage of meaningful use, and there is concern over a widening technology gap between larger academic centers and small- and medium-sized, public and rural hospitals that may not be able to meet eligibility criteria. This may widen the gap in regional disparities in quality of care [76].

Even in the most wired hospitals information may live in disparate systems and forms that cannot easily "talk to" each other. This is difficult enough when applied to a single institution; the issue is magnified enormously when the data can only be found elsewhere, such as another hospital, or an outside lab or in a regulatory databases. While data warehouses are commonplace in industries, they are rudimentary in most medical settings if they exist at all. This effort will require large outlays of capital as well as ongoing resources. Yet while the expenses are front loaded, the savings from increased quality and efficiency may be years away. Furthermore the study of the impact of information technology on quality and safety is in its youth. Recognizing that poorly designed and implemented IT systems might actually negatively impact patient safety and quality, in November 2011 the IOM released a report with recommendations for federal agencies and others to maximize the safety of healthcare assisted by IT [77]. The report recognizes the role of clinicians in health IT to be "intimately" involved in outlining the requirements of IT solutions and that opportunities to improve safety include

improving the communication of clinician requirements and their involvement in all phases of testing and deployment to avoid perpetuating system flaws. The future state will require large pools of IT talent that are not yet fully developed and dedicated clinician involvement.

The future of the quality movement is inextricably intertwined with the future of data and information management. Many clinical issues today can be informed by the data already available, given the resources to obtain the data. However, clinicians and quality professionals need to provide their expertise and input to the future of data management by framing those questions that still need to be answered and by helping to design, test, and implement electronic data systems.

## Meaningful Data

There must be a clear-cut relationship between the quality measure and an improved outcome. Without this proven link the measure is useless or, worse, leads to wasted clinician efforts or negatively impacts patient care. Recent well-publicized reports from the VA highlight this issue. In one report increased adherence to the SCIP measures did not lead to improved rates of SSI. And in another, adherence to a bundle of measures was associated with worse outcomes [56, 57]. This highlights the risk of unintended consequences of these measures.

Measures should be clinically relevant, i.e., measure what they say they do, and affect outcomes in the desired way. In addition, they should also be meaningful to the clinician. Current measures tend to focus on short-term outcome measures for orthopedic surgery and do little to inform physicians of the long-term outcome of patients. Some measures set the bar quite low, such as checking for TB before starting a TNF inhibitor or a creatinine before starting a uric acid-lowering drug. Although both are important, are they truly meaningful measures of how we care for RA patients or gout?

Investment in national data registries is essential to advance quality. Although local registries suggest the ability to lower joint revision rates, there are currently no national total joint registries. Although for different reasons e.g. long-term outcomes research versus cost control, clinicians as well as insurers support the registry concept [78].

The future will also be influenced by comparative effectiveness research. Comparative effectiveness research "provides information on the relative strengths and weakness of various medical interventions" [79]. If it can be proven that certain interventions provide better outcomes then guiding clinicians to their use should improve the quality of care that we deliver. The dilemma is that, as with all measures, there will be those patients who should not receive a particular treatment. Clinicians must be as diligent with the exceptions as with the majority and should not feel pressured to treat all patients the same way just to "pass the measure." Furthermore, the regulatory bodies and media should be brought to realize that these exceptions do exist.

## Leading Quality Improvement

Quality is the responsibility of the entire institution, but inculcating it throughout an entire organization is the responsibility of leadership. This requires a committed board of trustees and executive suite.

Legally quality has rested with the board since the court decision of Darling versus Charleston Hospital in 1965. In this orthopedic case a teen athlete had complications following casting of the lower extremity resulting in amputation. The hospital, a charitable entity, contended that it could not be held liable for the decisions of the physician, an independent medical staff contractor. The Darling decision expanded the concept of corporate liability, holding the hospital board responsible for a physician's action within its walls [80]. The Darling decision only set the stage for board involvement in quality. As important as the decision was, real quality will only ensue when the board actually demonstrates involvement in and accountability for quality. Over the past decade a number of organizations have issued guidance to help boards exercise their fiduciary responsibility for quality, as many boards have been much more comfortable with their financial responsibility than oversight of quality. Executive respondents to a 2006 survey of board engagement in quality demonstrated that while a number of practices had been widely adopted, e.g., the boards set strategic goals for quality and reviewed dashboards of quality metrics, only 61 % reported having a board quality committee. Having a board quality committee has been associated with a better performance on process of care measures and mortality outcomes [81].

These efforts must also have the complete and unwavering support of the medical leadership. Frequently appointing a chief quality officer with executive suite presence helps to underline the importance of quality within the institution. It must be made clear that quality is the number one goal of the institution. It must become part of every physician's vocabulary. It is simply the way to do business.

Just as it is up to leadership to be sure that surgical checklists and hand washing are at 100 %, so too must physician leadership insist on the use of evidence-based medicine (EBM) in the form of clinical guidelines or protocols in treating patients. "Although physicians must use their understanding of disease, past clinical experience and knowledge of controlled studies to make appropriate clinical decisions patient by patient, EBM requires applying the best available evidence to improve the quality of care [82]." Physician leaders must make clear that EBM does not

detract from the creativity, skill, and independent thinking that make physicians great. It enhances them. It does not remove the surgeon from being the captain of the ship in the operating room; it makes him or her captain of a team, allowing him or her to cull information from every possible source. EBM and quality improvement methodologies should be inculcated into training programs for physicians and all healthcare professionals. Physicians thrive on accurate, timely, and risk-adjusted data about their individual as well as organizational performance. Coupling continuing medical education (CME) with individual performance auditing and giving feedback on individual compliance to evidence-based practices has been demonstrated to improve adherence to clinical guidelines more than CME alone [82]. The quality department must collaborate with medical staff leadership to collect and disseminate individual performance feedback to evidence-based practices. No professional wants to be an underachiever.

In addition, in order for physicians to become part of the solution to quality problems, they need to be involved in projects as champions, chair committees, and lead clinical and system process redesign. Time is valuable, and physician participation and expertise in quality need to be recompensed in the same way participation in research and clinical education is. Advancing quality requires valuing the science of improvement. Physician expertise in quality should also serve as a basis for academic achievement and promotion [83].

## Summary

Procedural (e.g., surgical, anesthetic, pain) never events are the tip of the iceberg in evaluating orthopedic quality. Patients having orthopedic procedures and the teams caring for them need to appreciate the unique risks that create a higher likelihood of these errors in orthopedics than in any other specialty, even in elective surgery. These include anatomical risks in orthopedics, such as laterality and challenges in localizing spinal levels, and the risks posed by the high-tech, complex, and fast-paced environment of the operating room. While probably under-reported, the rare nature of these events must not undermine their larger significance. These potentially devastating events, perhaps most importantly, point to problems and issues in other domains of quality such as system inefficiencies that result in wasted efforts and increase vulnerability to human cognitive errors, rush, and distraction. A culture of safety recognizes the continuing fallibility of current "protections" such as manual surgical counts and manual verification processes relied on for implant and procedural time-outs and addresses operational barriers to the crucial team communications necessary to keep patients safe. Systematizing communication through checklists, addressing organizational impediments to on-time starts and smooth OR turnaround times, ensuring that policies are workable and spelling out team member accountabilities, and giving (e.g., in the form of auditing) and getting feedback are essential activities in keeping patients safe and sparing clinicians the trauma of being involved in serious adverse events.

Evaluating quality in the perioperative period for the orthopedic patient therefore also considers the extent to which care is also effective, delivered timely, and individualized for each patient's unique risks (patient centered). Clinicians and organizations need to consider the menu of measures for each of these domains and should consult the literature to develop population-specific measures of care. The adequacy of risk adjusting for patient and procedural complexity in orthopedics and the dearth of orthopedic benchmarks must be recognized as a continuing challenge in evaluating performance. The future of quality is linked to developing meaningful measures of quality, to the practice of EBM and physician leadership of quality initiatives, to furtherance of an information technology infrastructure, and to supporting national data registries for longer term comparative effectiveness research.

**Summary Bullet Points**

- The surgeon and surgical team must adopt the few critical safety practices involved in anesthetic, implant, and surgical verification. These very brief time-outs must be an inviolable space where all other actions halt to bring full attention to the verification.
- The organization must improve systems of care in the processes leading up to surgery and support a safety culture through actions such as team training and human error education. Giving and getting feedback must be consistently reinforced.
- Professionals and the public need to understand the potential uses and limitations of current nationally endorsed quality data.
- The future of quality depends on investment in a technology infrastructure including establishment of national data registries for use in comparative effectiveness research.
- Quality is the responsibility of the entire institution, but inculcating it throughout the entire institution is the responsibility of leadership, which begins in the executive suite. Physician expertise in quality should serve as the basis for academic achievement and promotion.

## Appendix 1: Quality Organizations

| Organization/URL | Pertinent information |
|---|---|
| TJC http://www.jointcommission.org/ | Current core measure sets and annual reports of compliance rates; opportunities to field test new quality standards; *Targeted Solutions Tool*™ Web-based tools for organizational improvement projects (e.g., WSS, hand hygiene, and hand-off communications); library of *sentinel event alerts* with prevention recommendations; sentinel event statistics |
| The CMS http://www.cms.gov/ | Regulations for quality including links to proposed and final rule which anticipate measures to be included in mandated quality programs 3 years in advance of inclusion and measures to be added to VBP |
| NQF http://www.qualityforum.org/Home.aspx | Complete lists of endorsed standards and quality measures; opportunity to track specific consensus development projects currently under way and to receive notice of voting, information on the standard development process; *The ABCs of Measurement* basic educational resource |
| The Leapfrog Group http://www.leapfroggroup.org/home | Information for consumers and participating payers (members); comprehensive hospital self-survey tool measuring applicable structure (e.g., CPOE, policies, and ICU staffing), processes, and outcomes for voluntarily participating hospitals; hospital comparison results for select clinical areas (e.g., high-risk deliveries, bariatric surgery, and aortic valve repair) and patient safety areas (e.g., reduction of ICU infection rates, medication errors, and managing sentinel events) |
| HQA http://www.hospitalqualityalliance.org/ | Its mission completed with sustained improvement on the initial ten quality measures and collaboration with CMS to bring the Hospital Compare website to fruition; the website will close in December 2012 |
| Hospital Compare http://hospitalcompare.hhs.gov/ | Hospital-specific Medicare data on certain conditions (e.g., surgical care, heart failure, children's asthma), outcomes (e.g., disease-specific mortality and readmission rates), complications and patient safety outcomes (e.g., URFOs), appropriate use of imaging and Medicare spending per beneficiary—facilitating comparison across hospitals and to state and national averages |
| Association for Healthcare Research and Quality (AHRQ) http://www.qualitymeasures.ahrq.gov/index.aspx | Formerly the Agency for Health Care Policy and Research; one of a dozen agencies within the Department of Health and Human Services and funds quality and safety research; develops measures and maintains a searchable database of measures (*National Quality Measures Clearinghouse*) across a wide setting of care environments and includes evidence for measure adoption and related sources and elaborated measure specifications such as numerator, denominator, computation, measure developer, development, and revision dates. Includes current measure status |

## Appendix 2: Select Perioperative Orthopedic Quality Measures

| | Structure | Process | Outcome |
|---|---|---|---|
| Safe | | | |
| Mortality: Hip replacement, hip fracture, death in low-mortality DRGs | | | x |
| Foreign body left in during procedure | | | x |
| Iatrogenic pneumothorax | | | x |
| Postoperative hemorrhage or hematoma | | | x |
| Postoperative physiologic or metabolic derangements | | | x |
| Postoperative respiratory failure | | | x |
| Postoperative PE or DVT | | | x |
| Postoperative sepsis | | | x |
| Postoperative myocardial infarction within 48 h of surgery | | | x |

| | Structure | Process | Outcome |
|---|---|---|---|
| Accidental puncture or laceration | | | x |
| Teamwork training and skill building | x | | |
| Medication reconciliation | | x | |
| Procedure-specific SSI rates | | | x |
| Compliance to implant distribution verification process accountabilities | | x | |
| Compliance to anesthesia time-out | | x | |
| Compliance to surgical safety checklist-specific accountabilities | | x | |
| Physician procedural volume | x | | |
| Effective: Adherence to evidence-based processes | | | |
| Prophylactic antibiotic selection for surgical patients (SCIP) | | x | |
| Perioperative temperature management (SCIP) | | x | |
| Compliance to bilateral surgery guidelines (clearance, pt. selection) | | x | |
| Prophylactic antibiotics w/in 60 min of incision—discontinued w/in 24 h (SCIP) | | x | |
| Prophylactic anticoagulation ordered, given within 24 h before or after surgery (SCIP) | | x | |
| Beta blockers taken prior to admission received in perioperative period (SCIP) | | x | |
| Urinary catheters removed on post op day 1 or 2 (SCIP) | | x | |
| Timely: Avoid wait times | | | |
| Wait time to surgical evaluation/surgery | | x | |
| Postoperative rehab visit within 7 days | | x | |
| Efficient | | | |
| Cases cancelled in the holding area | x | | |
| On-time starts first case of the day | x | | |
| Surgical case turnover time | x | | |
| Percent of instruments requiring flash sterilization | | x | |
| Percent of ORs closed by (OR day end time) | x | | |
| Fee per Medicare beneficiary | x | | |
| Hospital procedural volume | x | | |
| Patient centered | | | |
| Informed consent (Leapfrog) | x | x | |
| Life-sustaining treatment preferences (Leapfrog) | x | x | |
| Disclosure (Leapfrog) | x | x | |

## References


1. Nightengale F. Notes on hospitals: two papers read before the national association to promote social science at Liverpool. London: John W. Parker and Son, West Strand; 1859.
2. Donabedian A. Evaluating the quality of medical care. Milbank Memorial Fund Quartery. 1966;4:166–203.
3. Committee to Design a Strategy for Quality Review and Assurance in Medicare. Institute of Medicine. Medicare: a strategy for quality assurance, vol. I. Washington, DC: National Academy Press; 1990.
4. Committee on Quality Health Care in America. Institute of Medicine. To Err is human: building a safer health system. Washington, DC: National Academy Press; 2000.
5. Committee on Quality Health Care in America. Institute of Medicine. Crossing the quality chasm: a new health system for the 21st century. Washington, DC: National Academy Press; 2001.
6. National Quality Forum. Consensus development process. http://www.qualityforum.org/Measuring_Performance/Consensus_Development_Process.aspx (2011). Accessed 20 Nov 2011
7. Patient Safety Primers: Never Events. http://psnet.ahrq.gov/primer.aspx?primerID=3 (2011). Accessed 26 Dec 2011
8. The Joint Commission. Summary data of sentinel events reviewed by The Joint Commission. http://www.jointcommission.org/sentinel_event_statistics_quarterly/. Accessed 24 April 2014
9. Gawande AA, Studdert DM, Orav EJ, Brennan TA, Zinner MJ. Risk factors for retained foreign bodies after surgery. N Engl J Med. 2003;348(3):229–35.
10. Cima RR, Kollengode A, Garnatz J, Storsveen A, Weisbrod C, Deschamps C. Incidence and characteristics of potential and actual retained foreign object events in surgical patients. J Am Coll Surg. 2008;207(1):80–7.
11. Egorova NN, Moskowitz A, Gelijns A, Weinberg A, Curty J, Rabin-Fastman B, Kaplan H, Cooper M, Fowler D, Emond JC, Greco G. Managing the prevention of retained surgical instruments. What is the value of counting? Ann Surg. 2008;247(1):13–8.
12. Stawicki SP, Evans DC, Cipolla EJ, Seamon MJ, Lukaszczyk JJ, Prosciak MP, Torigian DA, Doraiswamy VA, Yazzie NP, Gunter OL, Steinberg SM. Retained surgical foreign bodies: a comprehensive review of risks and preventive strategies. Scand J Surg. 2009;98:8–17.
13. Greenberg CC, Diaz-Flores R, Lipsitz SR, Regenbogen SE, Mulholland L, Mearne F, Rao S, Toidz T, Gawande AA. Barcoding surgical sponges to improve safety: a randomized controlled trial. Ann Surg. 2008;247(4):612–6.
14. Regenbogen SE, Geenberg CC, Resch SC, Kollengode A, Cima RR, Zinner MJ, Gawande AA. Prevention of retained surgical sponges: a decision-analytic model of predicting relative cost-effectiveness. Surgery. 2009;145(5):527–35.
15. Neily J, Mills PD, Eldridge N, Carney B, Pfeffer D, Turner JR, et al. Incorrect surgical procedures within and outside of the operating room. Arch Surg. 2011; E1-E4. www.archsurg.com at Roger Williams Hospital. Accessed August 19, 2011.
16. Joint Commission on Accreditation of Healthcare Organizations. Sentinel Event Alert. Issue 24: A follow-up review of wrong site surgery. 2001. http://www.jointcommission.org/daily_update/joint_commission_daily_update.aspx?k=721&b=&t=4. Accessed 27 Dec 27 2011
17. Devine J, Chutkan N, Norvell D, Dettori J. Avoiding Wrong Site Surgery. Spine. 2010;35(95):S28–36.
18. Kwann MR, Suddert DM, Zinner MJ, Gawande AA. Incidence, patterns, and prevention of wrong-site surgery. Arch Surg. 2006;141:353–8.
19. Robinson PM, Muir LT. Wrong-site surgery in orthopedics. J Bone Joint Surg (Br). 2009;91(10):1274–80.
20. Cowell HR. Wrong-site surgery. J Bone Joint Surg Am. 1998;80-A(4):463.
21. Mody MG, Nourbakhsh A, Stahl DL, Gibbs M, Alfawareh M, Garges KJ. The prevalence of wrong level spine surgery among spine surgeons. Spine. 2008;13(2):194–8.
22. Meinberg EG, Stern PJ. Incidence of wrong-site surgery among hand surgeons. J Bone Joint Surg Am. 2003;85-A(2):193–7.
23. Ring DC, Herndon JH, Meyer GS. Case 34-2010: a 65-year-old woman with an incorrect operation on the left hand. N Engl J Med. 2010;363:150–7.
24. Seiden S, Barach P. Wrong-side, wrong-site, wrong-procedure and wrong-patient adverse events: are they preventable? Arch Surg. 2006;141:931–9.
25. Hsiang J. Wrong-level surgery: a unique problem in spine surgery. Surg Neurol Int. 2011;2:47.
26. Hsu W, Kretzer RM, Dorsi MJ, Gokaslan ZL. Strategies to avoid wrong-site surgery during spinal procedures. Neurosurg Focus. 2011;31(4):E5.
27. Cohen SP, Hayek SM, Datta S, Bajwa ZH, Larkin TM, Griffith S, Hobelmann G, Christo PJ, White R. Incidence and root cause analysis of wrong-site pain management procedures. Anesthesiology. 2010;112(3):711–8.
28. Lowry KJ, McGrath MS, Mihalko WM. The impact of standardized implant labels. American Academy of Orthopedic Surgeons (AAOS Now). 2009. http://www.aaos.org/news/aaosnow/mar09/clinical12.asp. Accessed 15 Oct 2011
29. Fakler JK, Robinson Y, Heyde CE, John T. Errors in handling and manufacturing of orthopedic implants: the tip of the iceberg of an unrecognized system problem? Patient Saf Surg. 2007;1:5. http://www.pssjournal.com. Accessed 15 Nov 2011.
30. Ast MP, Mayman DJ, Su EP, Gonzales Della Valle AM, Parks ML, Haas SB. The reduction of implant-related errors and waste in total knee arthroplasty using a novel, computer-based, e.Label and compatibility system. J Arthroplasty. 2014;29(1):132–6.
31. Agency for Healthcare Research and Quality. Patient Safety Network/Cognitive Errors. The case for medical team training. http://psnet.ahrq.gov/search.aspx?searchStr=cognitive%20errors. Accessed 3 March 2012
32. The Invisible Gorilla Awareness test. http://video.search.yahoo.com/search/video?p=the+invisible+gorilla+awareness+test. Accessed 28 Dec 2011
33. The Joint Commission. Topic Library. Sentinel event data- root causes by event type 2004-second quarter 2011. http://www.jointcommission.org/. Accessed 13 Oct 2011
34. QI Patient Safety-Quality Improvement: Anatomy of an Error. http://patientsafetyed.duhs.duke.edu/module_e/swiss_cheese.html. Accessed 28 Dec 2011
35. Cima RR, Hale C, Kollengode A, Rogers JC, Cassivi SD, Deschamps C. Surgical case listing accuracy. Arch Surg. 2010;145(7):641–6.
36. Wachter RM, Pronovost PJ. Balancing "No Blame" with accountability in patient safety. N Engl J Med. 2009;361(14):1401–6.
37. Helmreich RL, Merritt AC, Wilhelm JA. The evolution of crew resource management training in commercial aviation. Int J Aviation Psychol. 1999;9(1):19–32. http://homepage.psy.utexas.edu/homepage/group/HelmreichLAB/Publications/pubfiles/Pub235.pdf. Accessed 28 Oct 2011.
38. Agency for Healthcare Research and Quality. Medical teamwork and Patient Safety. The case for medical team training. http://www.ahrq.gov/qual/medteam/medteam4.htm. Accessed 3 Mar 2012
39. Agency for Healthcare Research and Quality. Medical teamwork and patient safety. Chapter 2. training teams. http://www.ahrq.gov/qual/medteam/medteam2.htm Accessed 3 Mar 2012
40. Joint Commission on Accreditation of Healthcare Organizations. Sentinel Event Alert. Issue 48: Health care worker fatigue and

patient safety. December 14, 2011. http://www.jointcommission.org/sentinel_event.aspx. Accessed 29 Feb 2011
41. World Health Organization. WHO surgical safety checklist and implementation manual. http://www.who.int/patientsafety/safesurgery/ss_checklist/en/index.html. Accessed 28 Feb 2012
42. Haynes AB, Weiser TG, Berry WR, Lipsitz SR, Breizat AS, Dellinger EP. A surgical safety checklist to reduce morbidity and mortality in a global population. N Engl J Med. 2009;360(5):491–9.
43. Devries EN, Prins HA, Crolla R, den Outer AJ, van Adel G, van Helden SH, Schlack WS, van Putten MA, Gouma DJ, Dijkgraaf MG, Smorenburg SM, Boermeester MA. Effect of a comprehensive surgical safety system on patient outcomes. N Engl J Med. 2010;363(20):1928–37.
44. Panesar SS, Noble DJ, Mirza SB, Patel B, Mann B, Emerton M, Cleary K, Sheikh A, Bhandari M. Can the surgical checklist reduce the risk of wrong site surgery in orthopaedics?-can the checklist help? Supporting evidence from analysis of a national patient incident reporting system. J Orthop Surg Res. 2011;6:18.
45. The Joint Commission. Universal Protocol (Poster). http://www.jointcommission.org/standards_information/up.aspx. Accessed 10 Feb 2012
46. Knight N, Aucar J. Use of an anatomic marking form as an alternative to the universal procol for preventing wrong site, wrong procedure and wrong person surgery. Am J Surg. 2010;200(6):803–9.
47. Agency for Heathcare Research and Quality. Surveys on patient safety culture. http://www.ahrq.gov/qual/patientsafetyculture/. Accessed 28 Feb 2012
48. Centers for Medicare & Medicaid Services. National healthcare projections 2010–2020, forecast summary and selected tables. https://www.cms.gov/. Accessed 15 Jan 2012
49. Fisher E, Goodman D, Skinner J, Bronner K. Healthcare spending, quality and outcomes: more isn't always better. The Dartmouth institute for health policy & clinical practice. February 27, 2009. http://www.dartmouthatlas.org/downloads/reports/Spending_Brief_022709.pdf. Accessed 23 Jan 2012
50. Willis CD, Evans SM, Stoelwinder JU, Cameron PA. Measuring quality. Aust Health Rev 2007; 31(2): 276–81. http://www.publish.csiro.au/?act=view_file&file_id=AH070276.pdf. Accessed 28 Dec 2011
51. Haller G, Stoelwinder J, Myles PS, McNeil J. Quality and safety indicators in anesthesia: a systematic review. Anesthesiology. 2009;110(5):1158–75.
52. FY 2012 IPPS hospital final rule published August 18, 2011. http://www.gpo.gov/fdsys/pkg/FR-2011-08-18/pdf/2011-19719.pdf. Accessed 1 Jan 2012
53. Wood-Buhlman N, Matthes N. The time to prepare for value-based purchasing is now. 2011. http://www.pressganey.com/researchResources/hospitals/whitePapers.aspx. Accessed 1 Mar 2012
54. Improving America's Hospitals. The joint commission's annual report on quality and safety. 2011. http://www.jointcommission.org/annualreport.aspx. Accessed 1 Feb 2012
55. Bhattacharyya T, Freiberg AA, Mehta P, Katz JN, Ferris T. Measuring The report card: the validity of pay-for-performance metrics in orthopedic surgery. Health Aff. 2009:28(2): 526–532.
56. Hawn MT, Vick CC, Richman J, Holman W, Deierhoi RJ, Graham LA, Henderson WG, Itani KMF. Surgical site infection prevention: time to move beyond the surgical care improvement program. Ann Surg. 2011;254(3):494–501.
57. Anthony T, Murray BW, Sum-Ping JT, Lenkovsky F, Vornik VD, Parker BJ, Mcfalin JE, Hartless K, Huerta S. Evaluating an evidence based bundle for preventing surgical site infection. Arch Surg. 2011;146(3):263–9.
58. Pierce RG, Bozic KJ, Bradford DS. Pay for performance in orthopedic surgery. Clin Orthop Relat Res. 2007;45:87–95.
59. Nuckols TK, Gibbons MM, Harness NG, Chang WT, Chung KC, Asch SM, et al. Clinical quality measures for intraoperative and preoperative management in carpal tunnel surgery. HAND 2011:6:119–131. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3041902/. Accessed 1/1/12.
60. Ramanujam CL, Zgonis T. Perioperative care for rheumatoid foot and ankle surgery patients. Perioper Nurs Clin. 2011;6:9–16.
61. Gillaspie M. Better pain management after total joint replacement surgery. Orthopedic Nurs. 2010;29(1):20–4.
62. Soohoo NF, Lieberman JR, Farng EF, Jain S, Ko CY. Development of quality indicators for patients undergoing total hip or knee replacement. BMJ Qual Saf. 2011;20:153–7.
63. Technical Panel Overview. https://www.cms.gov/MMS/Downloads/MMSHipArthroplastyTotalKneeArthroplastyTEP.pdf. Accessed 3 Feb 2012
64. Auerbach A. Healthcare quality measurement in orthopedic surgery. Clin Orthop Relat Res. 2009;467:2542–7.
65. Joint Commission Top Hospitals List Shuns Academic Medical Centers. Health Leaders Media. http://www.healthleadersmedia.com/content/QUA-270925/Joint-Commission-Top-Hospitals-List-Shuns-Academic-Medical-Centers.html. Accessed January 13, 2012.
66. The High Cost of Weak Compliance with the New York State Hospital Adverse Event Reporting and Tracking System. Office of the New York Comptroller Policy Report. March 2009.
67. Utter GH, Zrelak PA, Baron R, Tancredi DJ, Sadeghi B, Geppert JD, Romano PS. Positive predictive value of the AHRQ accidental puncture or laceration patient safety indicator. Ann Surg. 2009;250(6):10411046.
68. Benneyan JC. Number-between g-type statistical quality control charts for monitoring adverse events. Health Care Manage Sci. 2001;4:305–18.
69. Institute For Healthcare Improvement. Knowledge Center Presentations. Measuring rare events and time between measures. http://www.ihi.org/knowledge/Pages/Presentations/default.aspx. Accessed 20 Aug 2011
70. Clement ND, Muzammil A, MacDonald D, Howie CR, Biant LC. Socioeconomic status affects the early outcome of total hip replacement. J Bone Joint Surg (Br). 2011;93(4):464–9.
71. Judge A, Welton NJ, Sandhu J, Ben-Shlomo Y. Equity in access to total joint replacement of the hip and knee in England: cross sectional study. BMJ. 2010;341:c4092.
72. Speech Recognition. Medical knowledge and speech recognition. http://speechrecognition.wordpress.com/2007/11/26/clinical-knowledge-doubles-every-18-months/. Accessed 2 Mar 2012
73. Little Things Matter. You Can't Improve What You Don't Measure. http://www.littlethingsmatter.com/blog/2010/08/23/You-Cant-Improve-What-you-Dont-Measure/. Accessed 26 Feb 2012
74. Wahl MM, Parks DV, Skeate RC, Goldin SB. Reducing errors from the electronic transcription of data collected on paper forms: a research data case study. J Am Med Inform Assoc. 2008;15(3):386–9.
75. Khoury M, Burnett L, Mackay MA. Error rates in Australian chemical pathology laboratories. Med J Aust. 1966;165:128–30.
76. Jha AK, DesRoches CM, Kralovec PD, Joshi MS. A progress report on electronic health records in U.S. Hospitals. Health Aff. 2010;29(10):1951–7.
77. Health IT and Patient Safety. Institute of Medicine. http://hcrenewal.blogspot.com/2011/11/iom-report-on-health-it-safety-nix-fda.html. Accessed 2 Mar 2012
78. Lansky D, Milstein A. Quality measurement in orthopaedics: the Purchasers' view. Clin Orthop Relat Res. 2009;467(10):2548–55.
79. HHS.gov/Recovery. Federal Coordinating Council for Comparative Effectiveness Research Membership. http://www.hhs.gov/recovery/programs/os/cerbios.html. Accessed 15 Oct 2011

80. Quimbee. Darling v. Charleston Community Memorial Hosp. http://quimbee.com/cases/707242. Accessed 3 Mar 2012
81. Jiang J, Lockee C, Fraser I. Board engagement in quality: findings of a survey of hospital and system leaders. 2008. http://www.thefreelibrary.com/Board+engagement+in+quality%3a+findings+of+a+survey+of+hospital+and. . .-a0177719968. Accessed 12 May 2011
82. Ranawat AS, Nunley R, Bozic K. Executive summary: value-based purchasing and technology assessment in orthopedics. Clin Orthop Relat Res. 2009;467(10):2556–60.
83. Shojania KG, Levinson W. Clinicians in quality improvement: a new career pathway in academic medicine. JAMA. 2009;301(7):766–8.

# Introduction of Clinical Pathways in Orthopedic Surgical Care: The Experience of the Hospital for Special Surgery

31

Shivi Duggal, Susan Flics, and Charles N. Cornell

**Objectives**

- To document the foundation for and the success of the adoption of clinical pathways for the care of patients undergoing routine orthopedic procedures
- To describe the HSS experience which illustrates the benefit given to patients and hospitals through the adoption of clinical pathways for the care of total joint replacement patients
- To discuss the potential value of the adoption of clinical pathways for complex surgery of the spine and to address their increasingly important role in the challenging economic environment associated with healthcare reform

**Key Points**

- Clinical pathways are structured multidisciplinary care plans which address specific clinical scenarios which help to standardize and coordinate care.
- Clinical pathways are evidence based incorporating proven best practice but ideally can be adopted to any given hospital environment and culture.
- Clinical pathways aim to optimize the quality and efficiency of care. These care plans must address pre-hospital preparation, the in-hospital care, and the post-hospital discharge.
- The patient experience can be optimized leading to improved overall patient satisfaction. The care plan must be focused on the patient experience primarily. Managing patient expectations through pre-hospitalization education and counseling is a key element of success.
- Adoption of clinical pathways demands physician championship which is best achieved by recording and providing feedback on outcomes following adoption of the new care plans.
- In high-volume clinical settings adoption of standardized care plans known as clinical pathways can improve patient outcomes and safety and provide for more efficient and satisfying care.
- The creation of clinical pathways should be based multidisciplinary involving all members of the healthcare team. Each hospital should design clinical pathways based on their unique environment and should be specific to patients undergoing particular medical procedures.
- Through rigorous planning and following of procedures in clinical pathways, hospitals are able to decrease the incidence of complications and length of stay, improve budget planning, and much more.
- Following implementation all clinical pathways must be routinely monitored for success and for modification to ensure that best clinical practices are represented and that continuous process improvement is assured.

S. Duggal (✉)
Department of Orthopaedic Surgery, Hospital for Special Surgery, New York, NY, USA
e-mail: duggals@hss.edu

S. Flics
Hospital for Special Surgery, New York, NY, USA
e-mail: flicss@hss.edu

C.N. Cornell
Department of Orthopedic Surgery, Hospital for Special Surgery, Weill Cornell College of Medicine, New York, NY, USA
e-mail: cornellc@hss.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_31, 

## Introduction

The adoption of clinical pathways in patient care has grown from the necessity of providing consistently high quality of care for an increasing demand for clinical services. Clinical pathways are structured multidisciplinary care plans that detail the essential steps in the care of patients with specific clinical problems. Clinical pathways provide hospitals with a consistent template for patient care by creating a predetermined standardized approach to care that should be adhered to by each member of the healthcare team. Clinical pathways are especially suited to the high volume and elective nature of much of orthopedic surgery. In our specialty quality and efficiency must be optimized. To help achieve this clinical pathways are used as standard protocols [1]. Each process, in a clinical pathway, is followed in order to ensure that the desired end results are achieved. The pathway also ensures that each patient is receiving optimum levels of care pre, intra-, and postoperatively. Clinical pathways are evidence based using the common international experience but must be adapted to the culture of any given hospital. Clinical pathways are effective because they standardize care, help develop measures for prevention of patient discomfort and harm, and provide ongoing performance measures that promote effective and useful change in practice.

In the United States, the demand for joint arthroplasty has steadily been increasing, which in turn has been placing pressure on hospitals to provide efficient care delivery models for joint arthroplasty. The demand for total knee replacements is predicted to increase by 673 % in 2030 [2, 3]. In order to provide this high volume, service hospitals have to adjust and develop new strategies which focus on quality, safety, and efficiency or they risk exhausting financial resources that are not incorporated into their budget plans. For instance, hospitals create a budget that provides for a fixed bed capacity and overhead cost, but reimbursement for the surgical procedures performed may have a small profit margin per case. To remain profitable hospital processes must insure a minimum of complications, an efficient length of stay, and high patient satisfaction. Clinical pathways introduce a process, which standardizes care among all caregivers. Individual practitioner practice is standardized into a team approach that allows for better coordination of care, communication, and process improvement based on the post-implementation experience. Clinical pathways are excellent tools, which help hospitals become safer, more efficient, and profitable [3–10].

Since the 1990s Hospital for Special Surgery has adopted the use of clinical pathways for patients undergoing total hip and knee replacement surgery [11]. These pathways include standardized patient orders that ensure that the most important elements of care are routinely addressed. Over the years, modifications to the Hospital for Special Surgery's clinical pathways have been initiated in response to clinical advances, hospital processes, and third-party payer demands. For example, the original clinical pathways were designed to improve the patient experience focusing primarily on improvements in pain management and postoperative physical rehabilitation [11, 12]. In spite of early success in achieving these goals it became clear by 2007 that the pathways needed modification to help reduce the length of stay to accommodate a large increase in the volume of these procedures in the setting of a fixed bed capacity. One of the advantages of standardized pathways is that they lend themselves to evaluation and provide simple ground work for modification based on their own results. Evaluation of our initial clinical pathway results directed the changes needed to address the length of stay and provided the elements of the updated pathway adopted in 2007 (Table 31.1) [3].

## The Key Elements of Clinical Pathways Addressing Total Joint Arthroplasty

The success of total joint replacement is ultimately judged by the patient experience. Total joint arthroplasty intends to provide improved quality of life. With that specific goal, the surgical care plan must be safe, predictable, and efficient. The experience can be compared to air travel. A passenger books a flight expecting a predictable outcome with little to no expectation for failure. Air travel is obviously complex requiring a detailed approach to the delivery of a safe and efficient service. The happy passenger is usually unaware of the planning and complex processes involved. The processes used by the airline industry provide a model for us in arthroplasty. Each surgical procedure should be planned with optimal preparation of the patient in the pre-hospital phase, executed with best practice during the hospital stay and a detailed plan for the postoperative recovery ensuring the desired restoration of pain-free mobility and quality of life expected. As such, clinical pathways must address preoperative preparation, in-hospital care, and post-hospital rehabilitation period.

## Elements of Pre-hospital Preparation for Total Joint Replacement

Preoperative preparation of patients for total joint surgery is perhaps the most critical element of a successful outcome. It was our experience prior to adoption of our current clinical pathway that many phases of the preoperative process failed to address the complex issues that arose during the hospital stay. In particular we noted that inadequate preparation of

**Table 31.1** Comparison of the elements of the old TKR clinical pathway and the new pathway. Comparison of the elements of the old TKR clinical pathway and the new pathway

| Features of TKR pathway | Old pathway (1996–August 2007) | New pathway (initiated in August 2007) Changes |
|---|---|---|
| Patient education | Patient instructed in TKR Care Plan, use of PCEA, PT protocol, and use of CPM | All elements of old pathway |
| | | Discharge planning addressed |
| | Class Q and A | Discharge planner attends class |
| | | Individual patient D/C plan formulated |
| Pain management | Femoral nerve block with epidural monitored daily by acute pain service | Meloxicam 7.5 mg or 15 mg Decadron |
| | | 6 mg 1 h prior to surgery |
| | Discontinued by 48 h based on patient VAS | Ondansetron during surgery |
| | Nausea management PRN by nursing staff | PCEA demand only: D/C by 36 h |
| Physical therapy | BID sessions beginning on POD #1 | Mobilized to upright position and ambulation attempted on POD 0 |
| | | BID sessions on POD #1 |
| Discharge planning education | Begun in post-op period | Plan initiated during pre-op education |
| | | Plan reinforced by pre-hospitalization |
| | | Phone call by discharge planner |

Used with permission from Ayalon O, Liu S, Flics S, Cahill J, Juliano K, and Cornell CN. A Multimodal Clinical Pathway Can Reduce Length of Stay After Total Knee Arthroplasty. HSS Journal: The Musculoskeletal Journal of Hospital for Special Surgery. HSS J. 2011 February; 7(1): 9–15

the patients with medical comorbidities led to postoperative complications. We are now convinced that meticulous preparation of patients, especially those with complex medical histories, is required before surgery can proceed. We have developed guidelines for patients with cardiovascular disease and diabetes mellitus which are detailed in the prior chapters of this text. We also established a complex case panel to which our surgeons can refer their complex cases to help develop plans for preparation and execution of surgery in especially high-risk scenarios. We have established a perioperative medical service that provides for preoperative evaluation and preparation of all scheduled arthroplasty patients with the goal that each is medically optimized before the day of surgery. We attribute our recent improvements in the incidence of infection and perioperative cardiovascular and thromboembolic complications, in part, to this process.

Additionally, addressing each patient's psychosocial readiness for surgery has been extremely helpful in improving the quality and efficiency of care. Preoperative education of arthroplasty patients has become an accepted standard practice [11, 13–15]. A preoperative education program can effectively address what information patients need prior to surgery and helps to manage and organize the postoperative care. Patients should be encouraged to attend interdisciplinary preoperative total knee/hip arthroplasty educational classes prior to the surgery. The patient educational class describes in detail the expectations and outcomes that any patient should expect from a total knee/hip arthroplasty. The plan of care should be presented so that patients understand what is expected of them and the hospital staff during their perioperative period. In particular, information regarding all aspects of the process should be clearly explained and the daily in-hospital routine should be emphasized. In particular the approach to pain management and physical therapy should be clear, and the details for items such as DVT prophylaxis, hip precautions, pain management, and physical therapy should be covered. Of particular importance is to address patient expectations for their level of pain and physical mobility and dependence by the time of discharge. It was our experience that most patients have little understanding of the nature of recovery following arthroplasty and often anticipate extreme dependency and prolonged disability. By incorporating our experience into the educational curriculum [12] we have allayed patient and family fears regarding a prolonged post-op disability or dependency. This has allowed for acceptance of earlier discharge to home plans. In addition to the class, the hospital's Department of Case Management and the patients' surgeons develop a combined preliminary discharge plan for each patient which is discussed with the patients via phone during the week prior to the surgical admission date. In this way, the discharge plan is firmly established before the admission making the post-admission case management process more automatic and efficient.

## Perioperative Pain Management

It is now clearly established that optimal pain management is a critical element in the quality and efficiency of care of orthopedic patients. Poorly controlled postoperative pain delays postoperative mobility, contributes to adverse outcomes, and results in poor patient satisfaction with their

experience [16]. On the other hand, overmedication is also associated with side effects and morbidities that also negatively influence patient outcome [17, 18]. To address this new multimodal, preemptive pain management strategies have been developed which can be easily incorporated into total joint replacement clinical pathways. Multimodal and preemptive strategies to prevent postoperative pain have benefitted from recent advances in the understanding of neuronal plasticity and how undertreated acute pain can lead to chronic pain. Also, clarifying the role that local inflammation plays in injured tissue increasing the sensitization of nociceptors has led to drug therapies incorporating nonsteroidal anti-inflammatory drugs (NSAIDs) and COX-2 agents in preemptively controlling post-op pain. Blocking the pain signal by a variety of methods including narcotics, anti-inflammatories, and peripheral nerve blockade (multimodal) has improved postoperative pain management and the overall quality and efficiency of care [19].

The preemptive pain management procedure involves preoperative administration of medications, which blunt or even prevent post-op pain and other side effects such as nausea. Preemptive pain management strategies usually call for administration of a COX-2 NSAID to reduce the development of post-op pain along with steroid medications which are extremely effective and safe in preventing post-op nausea [3, 16, 18]. Embedded in the latest HSS THR and TKR clinical pathways are a preoperative order set that calls for the administration of a COX-2 agent and oral steroid (dexamethasone 6 mg) to each patient 1 h prior to surgery. In addition, the pathway established the anesthesia practice of administration of ondansetron (Zofran) intravenously to each patient during surgery to reduce the occurrence of postoperative nausea.

New strategies for pain management are rapidly emerging which are designed to rely less on the epidural or the intravenous route focusing on locally applied pain management techniques. It is hoped that these will decrease the side effects and morbidity associated with neuraxial analgesia while permitting more aggressive mobilization. These include local injections of long-acting anesthetics and intraarticular infusion of pain medication [18, 20].

## Post-mobilization and Physical Therapy: Fast-Track Rehabilitation

The traditional approach to rehabilitation following joint replacement has in most cases relied on transfer of patients from the acute hospital setting to in-patient rehabilitation facilities where intensive physical therapy is applied to ready patients for the home setting. This approach reduced the expectations for an early in-hospital recovery and thereby directly increased the length of stay and the cost of care per beneficiary. It is not surprising that most health insurance programs currently seek to limit access to post-discharge rehab facilities. Since the coordination of transfer is also time consuming lengthening the acute hospital length of stay, it is also not surprising that hospitals delivering these procedures have sought means for early home discharge as well. Traditional approaches to physical therapy and mobilization have had to be modified to achieve more efficient hospital stays and earlier recovery. Although immobilization and bed rest have been known to contribute to postoperative complications, it has not been until recently that efforts to rapidly mobilize following total joint replacement have been implemented. Postoperative orthostasis, syncope, and falls have been relatively common in our own experience, and we believe that 24–48 h of bed confinement as a result of epidural analgesia contributes to this. New "fast-track" approaches to mobility and physical therapy have been implemented with great success [4, 9, 21–23]. Combined with our new multimodal management strategies early and rapid mobilization has become the norm. Patients are encouraged to stand and ambulate on the day of surgery, and our fast-track protocols include three visits per day from the physical therapists and mobility technicians. With the understanding that recovery of range of motion following total knee replacement is a gradual process, the emphasis of the post-op in-hospital program is on gait training and mobility rather than a range of motion prior to discharge. We have partnered with our local visiting nurse service to provide an accelerated in-home early PT program which front loads a patient's therapy from a 4-week to a 2-week program to continue the pace of early recovery avoiding the need for a rehab hospitalization. We now aim for a 2-day length of stay for THR and 3 days for TKR with an emphasis on home discharge (Fig. 31.1).

## Successful Implementation of Clinical Pathways

Adoption of clinical pathways requires a multidisciplinary team approach. All disciplines involved in the care of the patient must be involved. In general we have worked to establish the principles of care for each of the disciplines involved and then implemented these through the creation of standardized order sets which are now a part of our electronic medical record and computerized order entry. Physician and surgeon buy-in is critical to the success of this process, and every effort has been made to involve them in the process. The most effective tool in physician recruitment is the generation of evidence that the pathways work leading to better quality of care, fewer complications, shorter length of stay, and improved patient satisfaction. At HSS we now have achieved an overall length of stay below 4 days with

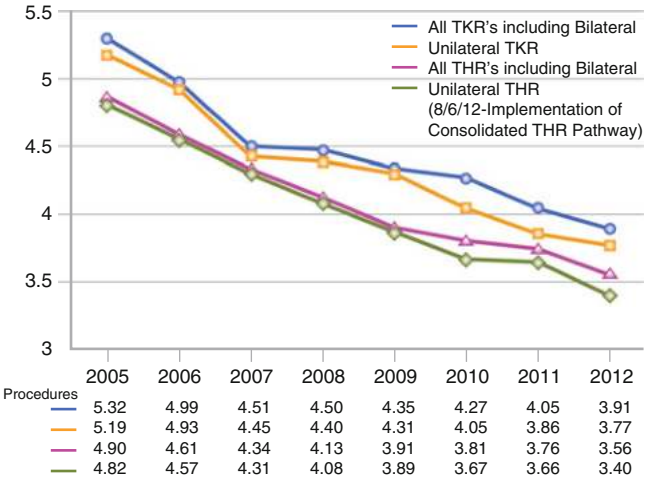


**Fig. 31.1** Average length of stay trends from 2005 to 2012 at HSS for TKR/THR patients. The first clinical pathway was enacted in 2005. Updates with new protocols were introduced in 2007 and 2011. Continual reductions in length of stay have been achieved in spite a large increase in surgical volume. Readmission rates have remained stable throughout this period

the highest patient satisfaction ratings as recorded by Press Ganey in our history. We continually review the established pathways searching for improvements as our post-implementation experience develops. Our success is mirrored by the success in many other hospital settings [24]. Based on the success we have achieved with total hip and knee arthroplasty we have developed and adopted clinical pathways for both simple and increasingly complex spinal surgery.

One concern often voiced regarding efforts to shorten length of stay reflects a common belief that decreasing the hospital length of stay would increase the incidence of complications in patients with a need for readmission. This belief has been proven to be inaccurate. Studies have shown that decreasing the length of stay to less than 5 days does not have any correlation with increased risks of complications or hip dislocation [6, 7]. Contrary to the dogma, decreasing the length of stay also benefits patients by allowing them to return to their natural environment, which is generally the patient's home. A patient's natural environment is usually safer and more comfortable for them, as patients have created this environment to reside in, as a niche. Patient in-home care, which provides physical therapy and visiting nurse services, allows the patient to recover at a pace comfortable to them and still be satisfied with the environment in which he or she is recovering. Many studies have also demonstrated that an increase in the length of hospital stay after total joint arthroplasty does not improve patient outcome. Instead it simply decreases patient satisfaction [6, 8].

Patient satisfaction is a vital component to patient care. Satisfaction is a state of mind that allows patients, or individuals, to be pleased with the work they or others have performed. Patients that are satisfied with the surgical or the medical procedures performed on them have a higher recovery rate with less probability of complications. Satisfied patients generally believe that their surgeons/physicians have provided the best possible care in an environment that values their safety and comfort. Studies have indicated that hospitals that create clinical pathways that decrease the patient's length of stay in hospitals have a higher number of satisfied patients [6]. Patients who are satisfied have a higher rate of compliance with prescribed medications as well as other instructions given to them. This is particularly important in total joint arthroplasty to avoid complications such as falls and dislocation of the prosthetic joint and to ensure that the proper approach to physical therapy and rehabilitation is followed.

Adoption of clinical pathways can be met with skepticism and resistance from any member of the multidisciplinary team involved in patient care. Because clinical pathways standardize care they reduce reliance on individual decision making or traditional approaches to care. Every effort must be made in adopting new clinical pathways to educate and inform the multidisciplinary team of the evidentiary basis on which the principles of the new pathway are based. Physician, nursing, and administrative champions must work together to develop and institute new pathways. The process should be communicated in a completely transparent manner. The thought processes involved should be clearly documented, and every member of the patient care team must be trained and oriented to the new process. Following implementation documentation of important clinical indicators should be monitored and regular reports of outcome must be communicated back to the hospital staff. The pace of implementation must be geared to the tolerance of the staff at each individual hospital. Often implementation should be conservative with realistic expectations. As success is garnered more progressive modifications to the pathway based on real outcomes can be pursued. It is critical that the clinician champions involved in this process be sensitive and realistic as well as willing to devote their time and energy to the process.

## Summary

Hospital for Special Surgery has benefitted from the fact that it is a hospital dedicated solely to the care of musculoskeletal disease. This focus has allowed the hospital to develop specialized care plans and a patient-centered approach to care that would be a greater challenge in other more general hospital settings. However, this specialization has led to the development of approaches to care that can benefit patients in any hospital setting. The adoption of clinical pathways has

led to safer and more efficient care that has reduced perioperative complication and hospital length of stay and significantly improved patient satisfaction as well as the hospital's reputation as a center of excellence. This experience has also been achieved in many hospital settings throughout the world. It is now clear that hospitals, as well as patients, benefit from the creation and implementation of clinical pathways.

The procedures adopted in clinical pathways must be created through the cooperation of all members of the healthcare team. Physician champions are especially important to help educate and train their colleagues and to provide the convincing evidence that the pathways are successful in improving overall care. Each hospital must customize the clinical pathways to their own environment and subspecialty focus. Following implementation, the success of the pathway must be routinely monitored to encourage continued participation of the healthcare team as well as to allow modification of the pathways based on evidence and experience. Surgical procedures such as total joint arthroplasty and spinal reconstruction are extremely amenable to adoption of standardized approaches to care, and the implementation of clinical pathways in these subspecialties has been met with success throughout the world.

**Summary Bullet Points**

- In high-volume clinical settings adoption of standardized care plans known as clinical pathways can improve patient outcomes and safety and provide for more efficient care. Clinical pathways have been shown to improve the patient experience.
- The creation of clinical pathways should be multidisciplinary involving all members of the healthcare team. Each hospital should design clinical pathways based on their unique environment and should be specific to patients undergoing particular medical procedures.
- Clinical pathways aim to optimize the quality and efficiency of care. The patient experience can be optimized leading to improved overall patient satisfaction. These care plans must address prehospital preparation, the in-hospital care, and the post-hospital discharge. The care plan must be focused on the patient experience primarily. Managing patient expectations through prehospitalization education and counseling is a key element of success.

## References


1. Pennington JM, Jones DP, McIntyre S. Clinical pathways in total knee arthroplasty: a New Zealand experience. J Orthop Surg (Hong Kong). 2003;11(2):166–73.
2. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am. 2007;89:780–5.
3. Ayalon O, Liu S, Flics S, Cahill J, Juliano K, Cornell CN. A multimodal clinical pathway can reduce length of stay after total knee arthroplasty. HSS J. 2011;7(1):9–15.
4. Walter FL, Bass N, Bock G, Markel D. Success of clinical pathways for total joint arthroplasty in a community hospital. Clin Orthop Relat Res. 2007;457:133–7.
5. Husted H, Holm G. Fast track in total hip and knee arthroplasty—experiences from Hvidovre University Hospital, Denmark. Injury. 2006;37S:S31–5.
6. Healy WL, Iorio R, Ko J, et al. Impact of cost reduction programs on short-term patient outcome and hospital cost of total knee arthroplasty. J Bone Joint Surg. 2002;84:348–53.
7. Pilot P, Bogie R, Draijer WF, Verburg AD, van Os JJ, Kuipers H. Experience in the first four years of rapid recovery; is it safe? Injury. 2006;37S:S37–40.
8. Pinzur MS, Gurza E, Kristopaitis T, Monson R, Wall MJ, Porter A, Davidson-Bell V, Rapp T. Hospitalist-orthopedic co-management of high-risk patients undergoing lower extremity reconstruction surgery. Orthopedics. 2009;32(7):495.
9. Larsen K, Hvass KE, Hansen TB, Thomsen PB, Soballe K. Effectiveness of accelerated perioperative care and rehabilitation intervention compared to current intervention after hip and knee arthroplasty. A Before-After Trial of 247 patients with a 3-month Follow-up. BMC Musculoskeletal Disord. 2008;9:59.
10. Teeny SM, York SC, Benson C, Perdue ST. Does shortened length of hospital stay affect total knee arthroplasty rehabilitation outcomes? J Arthroplast. 2005;20:7.
11. Peterson MGE, Ciopa-Mosca J, Finerty E, Graziano S, King S, Sculco TP. Effectiveness of best practice implementation in reducing hip arthroplasty length of stay. J Arthroplast. 2008;23:1.
12. Ganz SB, Wilson Jr PD, Cioppa-Mosca J, Peterson MGE. The day of discharge after total hip arthroplasty and the achievement of rehabilitation functional milestones. J Arthroplasty. 2003;18:4.
13. Husted H, Holm G. Jacobsen s, predictors of length of stay and patient satisfaction after hip and knee replacement surgery. Acta Orthop. 2008;79:168–73.
14. McDonald S, Hetrick S, Green S. Pre-operative education for hip or knee replacement. Cochrane Database Syst Rev. 2004;1, CD003526.
15. Yoon RS, Nellans KW, Geller JA, Kim AD, Jacobs MR, Macaulay W. Patient education before hip or knee arthroplasty lowers length of stay. J Arthroplasty. 2010;25:547–51.
16. Hebl JR, Dilger JA, Byer DE, Kopp SL, Stevens SR, Pagnano MW, Hanssen AD, Horlocker TT. A pre-emptive multimodal pathway featuring peripheral nerve block improves perioperative outcomes after major orthopedic surgery. Reg Anesth Pain Med. 2008;33:510–7.
17. Choi PT, Bhandari M, Scott J, Doukitis J. Epidural analgesia for pain relief following hip or knee replacement. Cochrane Database Sys Rev. 2003;3, CD003071.
18. Andersen KV, Pfeiffer-Jensen M, Haraldsted V, Soballe K. Reduced hospital stay and narcotic consumption and improved

mobilization with local and intraarticular infiltration after Hip arthroplasty. Acta Orthop. 2007;78(2):180–6.
19. Ekman EF, Koman LA. Acute pain following musculoskeletal injuries and orthopedic surgery: mechanisms and management. Instr Course Lect. 2005;54:21–33.
20. Gómez-Cardero P, Rodríguez-Merchán EC. Postoperative analgesia in TKA: ropivacaine continuous intraarticular infusion. Clin Orthop Relat Res. 2010;468:1242–7.
21. Larsen K, Hansen TB, Thomsen PB, Christiansen T, Soballe K. Cost-effectiveness of accelerated perioperative care and rehabilitation after total hip and knee arthroplasty. J Bone Joint Surg Am. 2009;91(4):761–72.
22. denHertog A, Gliesche K, Timm J, Muhlbauer B, Zebrowski S. Pathway controlled fast track rehabilitation after total knee arthroplasty: a randomized prospective clinical study evaluating recovery, drug consumption and length of stay. Arch Orthop Trauma Surg. 2012 Aug;132(8):1153-63.
23. Rapheal M, Jaeger M, van Vlymen J. Easily adoptable total joint arthroplasty program allows discharge home in two days. Can J Anesth. 2011;58:902–10.
24. Rotter T, Kinsman L, James E, Machotta A, Goethe H, Willis J, Snow P, Kugler J. Clinical pathways: effects on professional practice, patient outcomes, length of stay and hospital costs. Cochrane Database Syst Rev. 2010;17(3), CD006632.

# Ethical Considerations in Perioperative Orthopedic Medicine

32

M. Michael Khair, Douglas S.T. Green, and C. Ronald MacKenzie

**Objectives**

- To impart concepts concerning how ethical questions that arise in the practice of medicine can be evaluated
- To examine ethical problems arising in the perioperative setting
- To review selected concepts in medical ethics including informed consent, competency, and decision making

**Key Points**

- How we interact with patients during this particularly vulnerable time should reflect an appreciation and understanding of the importance of the perioperative period.
- Discussions that take place with the patient should be detail oriented and seek to address each patient individually.
- The absence of a single unifying theory of morality should not dissuade us from attempting to achieve ideals of morality in our interactions with patients.
- As the surgeon is the one performing the intervention, the ultimate responsibility for ensuring that the patient has a full understanding must lie with him or her. Anyone who is involved with the patient's preparation and recovery from the procedure must ask himself or herself whether the patient is a willing autonomous participant, actively involved in decisions that have a direct impact on his or her health and well-being. If this is not the case, it is their responsibility to help amend the situation.
- The perioperative decision makers need to be aware of what it means to be deemed competent and to have capacity. They need to have an understanding of who makes that determination and also what process is employed to identify a decision maker if an advance directive or another similar legally binding directive is not in place.

## Introduction

Ethics is the study and application of moral reasoning in human endeavor. Etymologically rooted in the word *customary*, the term morality references a set of behaviors that govern how one should act, implying expectations concerning how one's character should be expressed in given circumstances [1]. Comprising good and bad character as well as behaviors right and wrong, ethics asks "What ought to be done?" in specific situations [2]. Medical ethics, as a subdiscipline, focuses on such reasoning in health care. Arising over the last half century as a consequence of advances in medical knowledge and technology, medical ethics has become a distinct specialty spawning its own textbooks, journals, conferences, and, at the local level, ethics committees established to help institutions and their practitioners confront the formidable array of ethically charged dilemmas arising in everyday medical practice.

M.M. Khair (✉)
Department of Orthopedics, Hospital for Special Surgery, New York, NY, USA
e-mail: khairm@hss.edu

D.S.T. Green
Department of Anesthesiology, Hospital for Special Surgery, New York, NY, USA
e-mail: greendo@hss.edu

C.R. MacKenzie
Department of Medicine, Hospital for Special Surgery, Weill Cornell Medical College, New York, NY, USA
e-mail: mackenzier@hss.edu

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1_32, 

A consideration of the ethics of the perioperative period brings together many of the essential issues of medical ethics. This chapter reviews the important ethical challenges arising in this clinical setting. Before doing so a summary of the fundamental concepts that guide all analyses and discussions in medical ethics is presented.

## The Fundamentals of Moral Reasoning

What makes something good or bad? How can we discuss and debate the qualities of good actions and bad ones? What defines the moral and the immoral? These core philosophical questions have challenged sentient man throughout recorded history. As such, ways of thinking about morality and methods for ordering approaches to the moral questions of medicine have been developed to guide medical ethicists (Table 32.1). Many schools of thought have contributed, though two theoretical approaches have dominated: consequentialism and deontology [3]. Consequentialists judge the rightness or the wrongness of an action by its consequences. Thus an action should be done if it results in the best outcome to the most people. For example, using the logic of a consequentialist, breaching patient confidentiality would be justified, if overall the benefits outweighed the harms. In contrast, deontology holds that regardless of the outcome, certain actions are inherently right (or wrong) and that the "right" action should be chosen. Thus, according to this point of view, the breaching of patient confidentiality is simply wrong and is never the appropriate choice, regardless of the circumstances. Clinicians, when faced with a difficult decision, may employ a hybrid approach utilizing both to the degree they help resolve the problems at hand.

Due to the inherent difficulties in the resolution of many ethical dilemmas of modern medicine, ethicists have developed a third, *principle*-based approach to moral reasoning. The core elements (principles) that comprise this approach are shown in Table 32.2 [3]. The four principles—autonomy, beneficence, nonmaleficence, and justice—have become enormously influential in the discourse pertaining to medical ethics, despite some detractors [4, 5].

The absence of a single unifying theory of morality should not dissuade us from attempting to achieve ideals of morality in our interactions with patients. Ideals of ethics in the perioperative period can be extraordinarily demanding. In the following section of this chapter we introduce several of the salient considerations in the form of a case study. While not illustrative of the entire range of potential challenges in the perioperative period, this analysis represents our views concerning some of the important ethical challenges arising in this clinical context.

**Table 32.1** Framework for moral reasoning

| Consequentialism | Deontology | Principlism |
|---|---|---|
| Outcome based | Rule based | Principle based |

Data from Beauchamp TL and Childress JF: Principles of Biomedical Ethics. New York: Oxford University Press; 1994

**Table 32.2** Basic principles of medical ethics

| | |
|---|---|
| Autonomy | Respect for autonomous decision making |
| Nonmaleficence | Avoidance of harm |
| Beneficence | Relief, lessening, or prevention of harm |
| Justice | Fair distribution of benefits, risk, and costs |

Data from Beauchamp TL and Childress JF: Principles of Biomedical Ethics. New York: Oxford University Press; 1994

**Case Study**

An orthopedic surgeon specializing in total joint replacement sees Mrs. S., a 75-year-old woman, in his private office for a chief complaint of chronic left knee pain. Mrs. S is accompanied by her 40-year-old daughter. Mrs. S is Spanish speaking, a widower who lives alone. She has a high school-level education. Her daughter speaks both Spanish and English fluently. She has an associates degree and works as a teller in a local bank. After examining the patient, and looking at her radiographs, the surgeon determines that the patient has advanced osteoarthritis in her left knee and recommends that she consider a total knee replacement. The total time spent with the patient is 10 min. There is a brief discussion in Spanish, followed by the daughter saying that they have some questions but would like to proceed. The surgeon, well aware that he has 15 patients in the waiting room, smiles, says it is great that they want to go forward, and has his surgical scheduler, a man with no formal medical training, come in to answer the patient's questions and schedule her for surgery. At the same time, the scheduler coordinates all of the patient's preoperative assessment including lab work and a consultation with an internist who will provide medical "clearance" for the procedure.

Three weeks later, the surgeon, having just finished his first two joint replacements that day, sees the patient in the holding area. He looks at the faxed medical note in the chart stating that the patient is "cleared" for surgery. He then signs the standard hospital consent form that the physician assistant has already "gone over" with the patient, proceeds to go in the room, reassuringly smiles at the patient, asks her if she has any final questions, and signs her

left knee. This entire interaction lasts for 2 min. The patient is then taken to the operating room where she undergoes a total knee replacement.

Mrs. S. wakes up in the postoperative care unit late in the evening. The surgeon has left the hospital, so the patient is dependent on her daughter to tell her how the operation went. She is in tremendous pain and has difficulty explaining this to the residents and physician assistants who care for the admitted patients overnight. Finally, after several calls from the floor nurses, the resident increases her pain medication, and as a result, Mrs. S becomes confused and agitated, a problem that persists through the next day; as a result she misses several therapy sessions. Finally, the on-call hospitalist determines that her pain medication should be reduced. With this dosing adjustment her confusion slowly improves. On her sixth postoperative day, her surgical wound is dry and she is deemed fit for discharge. She is sent home on Coumadin, and the nurse quickly provides instructions on how to take the medication and the need for monitoring; the patient nods understanding. Her follow-up is scheduled, paperwork is completed, and Mrs. S is discharged home where her daughter will help care for her.

## Case Discussion

This case study is informative not in that it describes a serious complication of the procedure, nor it is illustrative of a unique situation. In fact, it is informative because it is so commonplace, as identical scenarios occur every day in clinics and hospitals across the country. Yet, there is much to learn about the ethics of perioperative medicine from such a common narrative.

## Informed Consent

One important theme arising from this narrative is the question of informed consent. At several points over the course of her care the patient was "informed" about her surgery. Yet to what extent was she truly "informed"? Further is "informing" someone the same as the recipient understanding the information? Was the language barrier adequately addressed? Was the discussion held at a level she could understand? Was the patient "informed" simply so that the surgeon and institution could check a box, or was she informed so that she would have a full understanding of the nature of the procedure that was performed on her?

Informed consent is crucial to perioperative ethics because it is vital to the beginning of a surgeon's clinical relationship with a patient and persists throughout the entire episode of care. In essence, it is the surgeon describing to the patient exactly what he or she plans to do and what the potential outcome(s) of that action (or the lack of performing that action) will have on the patient. Perhaps the most important concept derived from the principle of respect for patient autonomy, this ethical tenant is now fully entrenched in modern medical practice.

To the moral philosopher, the concept of autonomy is a reference to personal self-governance. To respect someone as an autonomous agent, one must recognize the person's capacities and perspective, including a person's right to hold certain views and make choices and take actions based on those personal views and beliefs. It is important to recognize this and not conflate autonomy with voluntariness, privacy, freedom to choose, or other ideas that are sometimes associated with informed consent in the literature. It is the medical professional's responsibility to have an understanding of autonomy and informed consent and be able to engage with patients in a way that displays that understanding.

The surgeon, in obtaining "informed consent," is responsible for explaining in the language that the patient can understand, the nature of the patient's condition, its natural history if left untreated, recommendations for treatment, and delineation of risks and benefits of that treatment. Further, the surgeon is responsible for describing the anticipated outcomes and the alternative treatments that are available. As one can imagine, this can be a daunting task, especially when confronted with the varying language barriers and educational backgrounds of a busy surgical practice [6].

In the medical ethics literature, informed consent is carefully defined and has essential elements. Not simply a matter of "shared decision making" between a physician and a patient, it should be understood in at least two ways. The first sees informed consent as an "autonomous authorization" [3]. In this sense, informed consent is more than just an individual agreeing to comply with a medical intervention or procedure. It implies that in agreeing to move forward, the patients have a substantial *understanding* of what they are agreeing to have done to them and that in making a decision they are acting without the undue influence by others. It is a deeper sense of informed consent that states that the patients understand what exactly they are consenting to have performed on them. Alternatively, informed consent refers to a legally effective authorization as determined by the rules of that institution. This *institutional* sense of informed consent is met when a patient signs the standard informed consent form in the hospital chart before proceeding to surgery.

One can clearly see that these notions of informed consent are not bound together. For example, it would be

possible for an exceptionally mature minor to have a full understanding of a procedure that is to be performed and be able to autonomously authorize that procedure. In such circumstances the first sense of informed consent is met; yet, as a minor under the law such an individual would not meet the requirement of the second, institutional sense of informed consent. Similarly, using the example of Mrs. S, one can imagine a person unable to grasp the full extent of the procedure he or she is consenting to (for reasons of language, education, or insufficient explanation on the part of the physician) and hence unable to satisfy the criteria of a truly autonomous decision. Nonetheless, as in the case of Mrs. S, such a patient could sign the presented consent forms and thereby meet the conditions for the second sense. In an ideal world, every patient would both make an autonomous decision and meet institutional requirements.

As the perioperative period, by definition, revolves around a specific procedure, indicating that procedure, preparing the patient for that procedure, performing the procedure, and seeing the patient through the recovery period, it is the duty of everyone involved to insure that the patient meets the requirements of informed consent. As the surgeon is the one performing the intervention, the ultimate responsibility for ensuring that the patient has a full understanding must lie with him or her. Still, the medical consultant, nurses, physician assistants, and resident—that is anyone who is involved with the patient's preparation and recovery from the procedure—must ask themselves whether the patient is a willing autonomous participant, actively involved in decisions that have a direct impact on his or her health and well-being. If this is not the case, it is their responsibility to help amend the situation.

## Competency and Decision Making

In the case of Mrs. S, the patient who initially was a competent adult with the capacity to make decisions for herself later loses that capacity as a result of medication side effects. This is a common occurrence, especially in the elderly. Who then becomes the primary decision maker for the patient when she is unable to make a decision for herself? How do health care providers proceed when a once competent patient with capacity suddenly loses that capacity?

Any discussion regarding capacity, competence, and surrogate decision making must first start with definitions of those terms. This is not, however, a simple task as the perspectives of those involved in medicine, law, philosophy, and psychiatry may differ with respect to the abilities a person must have in order to be deemed competent. When thinking about the patients in the perioperative setting, we are concerned about their ability to make informed decisions about their care. Beauchamp and Childress state that a patient is competent to make a decision: "... if he or she has the capacity, to understand the material information, to make a judgment about the information in light of his or her values, to intend a certain outcome, and to freely communicate his or her wish to caregivers ..." [3]. Dan Brock defines the competent patient as needing: "... adequate capacity to understand relevant information about alternatives and their consequences, together with the ability to apply one's own values to those alternatives and to select on as best" [7].

The definition of capacity can be similarly difficult, but most would agree that there are at least four important aspects to capacity: understanding of the facts involved in making a decision, an appreciation of the nature and potential consequences of the decision they have to make, an ability to rationally reason through the different aspects of the decision, and, perhaps most importantly, the ability to make a choice and communicate that decision. In everyday medical practice, it is often the role of the psychiatrist to determine whether or not a patient has capacity to make decisions.

If a patient is deemed unfit to make medical decisions, a surrogate decision maker becomes important. One way for patients concerned about losing their competence to control their own care is to use an advance directive. The two principle forms of advance directives are instructional directives and proxy directives. Instructional directives state the patient's wishes about treatment. Living wills are perhaps the best known example of instructional directives. Proxy directives name a surrogate to decide for the patient. Of course, advance directives can only be used if they are completed prior to a patient losing competence. Often, health care providers have to deal with incompetent patients who do not have an advance directive in place.

In Mrs. S's case, it appears obvious that the daughter, who accompanied her mother to her medical appointment, would be the person charged with medical decision making if the patient were deemed unfit to make decisions for herself. This, however, would be too narrow a focus as there are qualifications that a surrogate decision maker should possess that include the ability to make reasoned and rational judgments; adequate knowledge and information regarding the patient and the patient's condition; emotional stability; and a commitment to the patient's interests that is both free of conflicts of interest and free of controlling influence by those persons who might not act in the incompetent person's best interests. This is where the notion of *substituted judgment* comes into play. This principle maintains that the surrogate decision maker should attempt to decide as the patient would have decided under similar circumstances if he or she were competent. Family members are generally considered the most fit to fill the position of surrogate decision maker for three reasons. First, it is assumed that in most situations, it is the family member who the patient would have wanted to make critical decisions. Second, in most cases, it is a family member who knows the patient the best and cares most about the patient; hence, it is a family member who would best be able to articulate what the

patient would have wanted. Finally, in our society, family is commonly given a significant amount of authority to care for its direct members.

In the perioperative setting, patients will have often completed advance directives stipulating whom, during times of incompetence, they deem a surrogate to make decisions on their behalf. Owing to the dynamic and potential volatile nature of the postoperative setting, those involved in perioperative medicine should be familiar with advance directives and be able to engage in conversations with patients about the possibility of an advance directive in the preoperative time period. In situations where the patient has not completed an advance directive, it is the responsibility of those caring for the incompetent patient to determine who the best surrogate decision maker is for the patient. This may sometimes be a family member, a health care provider, or in more extreme circumstances a hospital-appointed ethics committee or a court of law. Regardless, the perioperative decision makers need to be aware of what it means to be deemed competent and to have capacity. They need to have an understanding of who makes that determination and also what process is employed to identify a decision maker if an advance directive or another similar legally binding directive is not in place.

## Other Ethical Issues in the Perioperative Period

Certainly, informed consent, capacity, competence, and surrogate decision making are not the only ethical issues that arise in the perioperative period. End-of-life decisions, discussions of futility of care, and even topics like conflict of interest and health care inequality arise frequently. Additionally, research and medical education can often become issues in this setting. Such issues add new levels to informed consent and also can alter the care of the patient in the pre- and postoperative period. Research ethics, primarily the domain of the Institutional Review Board (IRB) within the hospital, add further strain as study protocols can have a significant impact on the kind of care that is provided by the perioperative team. Lastly, the effect of different cultural beliefs and norms on the care provided should not be minimized. Busy hospitals and clinics in areas with highly diverse populations need to have a systematic way of dealing with the needs and beliefs of the population they serve.

## Summary

Ultimately, the perioperative period is a subset of the larger medical system and thus is challenged by the same ethical issues stressing the organization in which it resides. From the perspective of the healthcare provider, the entire perioperative process is designed to efficiently and safely shepherd patients through a surgical procedure. This is different from other aspects of medicine in that surgery, perhaps more so than any other aspect of health care, asks the patient to completely give over control of their physical bodies with confidence that a team of individuals will help them overcome a specific disease process. It is an immense investment of trust by the patient and an equally significant offer and acceptance of responsibility by the perioperative team. Unfortunately, while the patient's best interest should be at the core of every health care decision, this is not always the case as the perioperative period is also designed to be efficient from a health system point of view. Patients are seen by the surgeon, decisions regarding surgery are made, patients are deemed suitable for procedures, and then they enter a system that seeks to get them in and out of hospital as efficiently as possible. This can lead to segmented care, where each individual on the perioperative team simply does what he or she deems to be his or her role. Patients, rather than being seen as individuals, can be viewed as procedures or a series of checkboxes: "Are the labs done? Has the surgical site been signed? Is the consent in the chart?"

Rather, one would hope that the discussion that takes place is more detail oriented and seeks to address each patient individually: "Does this patient really understand what is going to happen to them? Has he or she identified someone who will make decisions for him or her if he or she becomes unable?" Such a balance is difficult to strike as, on the one hand, there is a need for systems that promote efficiency (and safety); on the other hand, we must never lose sight that health care decisions, especially those regarding surgery, are amongst the most important in one's life. That being the case, how we interact with patients during this particularly vulnerable time should reflect an appreciation and understanding of the importance of the perioperative period.

**Summary Bullet Points**

- Methods have been developed to guide ethical analysis in the clinical setting.
- Ethical problems arising in the clinical setting can be framed according to specific principles: autonomy, beneficence, nonmaleficence, and justice.
- Informed consent, competency, and decision making are common and often challenging issues arising in the perioperative setting.

## References

1. Jones JW, McCullough LB, Richman BW. The ethics of surgical practice: cases, dilemmas, and resolutions. New York: Oxford University Press; 2008.
2. McCullough LB, Jones JW, Brody BA. Surgical ethics. New York: Oxford University Press; 1998.

3. Beauchamp TL, Childress JF. Principles of biomedical ethics. New York: Oxford University Press; 1994.
4. Toulmin S. The tyranny of principles. Hastings Cent Rep. 1991;11 (6):31–9.
5. Jonsen AR. Of balloons and bicycles-or-the relationship between ethical theory and practical judgment. Hastings Cent Rep. 1991;21(5):14–6.
6. Pearson SD, Sabin J, Emanuel EJ. No margin, no mission: health care organizations and the quest for ethical excellence. New York: Oxford University Press; 2003.
7. Buchanan AE, Brock AW. Deciding for others: the ethics of surrogate decision making. Cambridge: Cambridge University Press; 1989.

# Appendix: Case Studies

# Appendix A: Case Study for Chapter 4 on the Pathophysiologic Events of Total Joint Replacement Surgery

Stavros G. Memtsoudis

## Case Study

A 58-year-old male with a history of obstructive sleep apnea, hypertension, and obesity presented for right total knee arthroplasty. His preoperative evaluation was unremarkable, except a right bundle branch block on the electrocardiogram. A recent nuclear stress test was negative for inducible ischemia.

After admission to the hospital, he proceeded to the operating room where a combined spinal and epidural was placed to provide surgical anesthesia. A femoral nerve block was added for postoperative pain control and a radial arterial line was inserted for close hemodynamic monitoring. Intravenous sedation was provided with midazolam 5 mg while supplemental oxygen at 3 L/minute was delivered via nasal cannula. Because of the tendency for airway obstruction with deeper levels of sedation, the patient was kept mostly awake during the procedure. The total knee arthroplasty procedure was conducted uneventfully under tourniquet inflation. Hemodynamics, respiration, and oxygenation remained normal throughout surgery. After implantation of the hardware, the tourniquet was released and closure of the wound commenced. Shortly after, the patient's blood pressure dropped from previously 112/65 to 76/43 mmHg, and his heart rate increased from 65 to 101 beats per minute. A concomitant drop in the pulse oximetry reading to 82 % was noted. Ephedrine 10 mg was given intravenously, and a mask was placed over the patient's nose and mouth in order to deliver 100 % oxygen. The patient's blood pressure improved to 94/52 and his oxygenation to 92 %. After conclusion of surgery the patient was brought to the recovery room where his $O_2$ saturation was noted to be 90 % on a non-rebreather mask. On exam, diffuse rales were noted on chest auscultation, and a chest radiograph revealed bilateral, diffuse edema. Diuresis with intravenous furosemide was initiated. The patient became agitated and confused, and given his persistent hypoxia the decision was made to intubate his trachea.

Laboratory tests revealed a hematocrit of 29 %, a white cell count of 18,000 and a platelet count of 76,000/dL. A cardiac echo revealed a normal left ventricular function, moderate pulmonary hypertension, and right heart dilatation. A pulmonary embolism was ruled out by computed tomography with contrast. Based on these clinical findings, the diagnosis of fat embolism syndrome was made. Imaging of the brain was negative for an intracranial process. The patient remained intubated utilizing a lung protective ventilation approach with low tidal volumes, and he was successfully extubated on postoperative day 2. Supportive care consisted of diuresis and empiric use of bronchodilators. His central nervous system symptoms subsided. He was transferred to the ward and discharged from the hospital on postoperative day 7.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, 

# Appendix B: Case Study for Chapter 5 on Anesthesiology in the Orthopedic Patient

Shawna Dorman and Richard L. Kahn

## Case Study

A 75-year-old female with a history of rheumatoid arthritis and hypertension presents for a left total hip replacement. The rheumatoid arthritis was diagnosed 15 years ago and was managed with multiple disease-modifying agents. Her other medications include Metoprolol and Aspirin. The patient's vital signs, EKG, and chest X-ray are normal. She has full range of motion of her neck, thus extension–flexion X-rays were not obtained preoperatively. The patient's exercise tolerance is limited by her hip pain; however, no further cardiac workup was obtained.

After transporting the patient to the operating room, standard monitors are applied and a right radial arterial line is placed for close hemodynamic monitoring. Oxygen is applied via nasal cannula with end tidal carbon dioxide monitoring. The patient is positioned in the right lateral position and a combined spinal and epidural is placed to provide surgical anesthesia. Ten milligrams of isobaric bupivacaine 0.5 % is given as the spinal injectate. While positioning the patient, special care is taken to ensure that the head and neck remain neutral and an axillary roll is placed under the upper chest in order to prevent any pressure on the down shoulder or brachial plexus. Intravenous sedation is obtained with a propofol infusion and midazolam. The epidural is dosed with lidocaine 2 % in order to obtain a T4 level. An epinephrine infusion is started and titrated to maintain the MAP between 50 and 60 mmHg. The heart rate remains stable at 50–60 beats per minute. The surgery proceeds uneventfully, lasting for 70 min. Estimated blood loss is 150 mL. 1,500 mL of lactated Ringer's is given intraoperatively. The intravenous sedation is stopped and the patient wakes up neurologically intact. The patient is taken to the recovery room where an epidural PCA consisting of bupivacaine 0.06 % and hydromorphone 10 mcg/mL is initiated. The epidural is programmed to have a basal rate of 2 mL per hour, a patient bolus of 4 mL with a lockout of 10 min. Other analgesics include intravenous ketorolac and hydrocodone/acetaminophen by mouth as needed every 4 h. Deep venous thrombosis prophylaxis consists of aspirin and a lower extremity intermittent compression device. Postoperative laboratory results are unremarkable and no transfusion is required. The epidural basal rate is changed to zero in the morning of the first postoperative day. The patient is transitioned to oral pain medication, and the epidural is removed at noon that day. She is able to complete physical therapy and remains comfortable with a VAS pain score of 2–3/10. The patient reaches discharge criteria on postoperative day two and is discharged without issue to a rehabilitation facility.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, 

# Appendix C: Case Study for Chapter 6 on Pediatric Anesthesia for Orthopedic Surgery

Kathryn R. DelPizzo, Naomi Dong, and Carrie R. Guheen

## Case Study

An 11-year-old female presents for a left pelvic osteotomy, left hip varus derotational osteotomy, and left hamstring and iliopsoas tendon releases. She suffers from spastic cerebral palsy and was born prematurely at 27 weeks post-conception. After birth she remained intubated and mechanically ventilated in the NICU for 2 weeks. She is developmentally at the kindergarten level. She ambulates, but walking has become difficult in the last few weeks due to increasing weakness. She has a seizure disorder that is well controlled with medication. She uses bronchodilators for asthmatic events that occur with upper respiratory infections. Her last use was 1 month ago, and the patient has no history of pneumonia or obstructive sleep apnea. She weighs 30 kg and her height is 128 cm. She routinely takes oxcarbazepine, and she took albuterol and budesonide for 3 days before surgery prophylactically. Her only past surgical history is for strabismus. An allergy to penicillin was reported, but her mother reports that she has taken cephalosporins and amoxicillin without problems.

In preparation for surgery, the patient received 2 mg of intravenous midazolam in the holding area. In the operating room she was induced with propofol without muscle relaxant and the trachea was intubated. The epidural space was easily accessed via the loss-of-resistance technique and 25 mg of bupivacaine was given through the epidural needle. An epidural catheter was threaded smoothly. A 22-gauge radial arterial line and an additional peripheral venous catheter, 18 g, were easily placed. Cefazolin was given for antibiotic prophylaxis. Surgical incision was made, and the patient showed no hemodynamic response. She was maintained on oxygen and nitrous in a 50 % mixture, with isoflurane 0.3 % end-tidal. Glycopyrrolate was given to reduce secretions and diazepam for the treatment of postoperative spasms. Forty-five minutes after the start of surgery, the patient became hypotensive with an increase in peak airway pressures. One hundred percent oxygen was administered and isoflurane was discontinued. There was no wheezing, but hand-ventilation was difficult. A latex reaction was suspected and surgery was halted. The wound was flushed with saline, and all surgeons changed their gloves. Epinephrine was administered in small doses (0.5 mcg/kg) with a slight increase in the blood pressure. When larger doses were given (1–2 mcg/kg), the patient's blood pressure stabilized and her airway pressures decreased. An infusion of epinephrine and intravenous fluids was maintained, serum tryptase levels were checked, and other routine blood laboratory tests were performed. The patient was taken to the pediatric intensive care unit and remained on the epinephrine infusion for 24 h. Her serum tryptase and IgE levels were elevated. She was extubated on postoperative day two and went home on postoperative day five. Six weeks later she underwent allergy testing which revealed a level 5 reaction to latex. She was not allergic to neuromuscular blockers or any antibiotics.

Five months later she returned for surgery in a latex-free environment with the same anesthetic technique without sequelae.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, 

# Appendix D: Case Study for Chapter 7 on Anesthetic Techniques and Their Clinical Application for Specific Orthopedic Procedures

Cephas P. Swamidoss and Ottokar Stundner

## Case Study

A 27-year-old woman (68 kg, 165 cm) with a history of shoulder pain over several months presented for ambulatory diagnostic shoulder arthroscopy. Her preoperative vital signs, clinical examination, and routine laboratory workup were unremarkable.

The patient was monitored as per routine and a 20 Gauge intravenous cannula was placed. The injection site for an interscalene block was determined using a 30 mm insulated needle attached to a nerve stimulator. After biceps response was evoked at 1.8 mA and intravascular needle position was ruled out by negative aspiration, 30 mL of 0.375 % bupivacaine was injected, with aspiration occurring at 5 mL intervals.

The patient immediately began to complain about acoustic sensations as well as feelings of dry and itchy mouth and eyes. The injection was interrupted and the needle withdrawn; within 20 s, generalized convulsions resembling a grand mal seizure developed, and the patient was found to be apneic. Mask ventilation with 100 % oxygen was initiated, midazolam 5 mg was administered, and the anesthesia technician was instructed to get a lipid rescue kit from the cardiac arrest cart located outside the room. The convulsions stopped and the anesthesiologist noticed broad complex tachycardia with a heart rate of 140 bpm on the ECG; a pulse was difficult to palpate at the carotid artery. Intralipid® 20 % 500 mL intravenously was started. Attempts to place a radial arterial catheter failed at that point. An attempt of cardioversion was unsuccessful. After 50 mL of Intralipid® was infused, a brief period of ventricular fibrillation was immediately followed by asystole. After commencement of cardiac compressions, administration of epinephrine 1 mg, and successful tracheal intubation, another 150 mL of Intralipid® was infused rapidly. Return of spontaneous circulation occurred approximately 45 s after initial appearance of ventricular fibrillation. A narrow complex tachycardia was present on the ECG; a radial arterial catheter was successfully placed. The initial blood pressure obtained was 140/90 mmHg, but rapidly declined to 80/40 mmHg. Circulation was supported with repetitive boluses of phenylephrine and epinephrine, until a central line and continuous epinephrine infusion was established. Analysis of arterial blood samples revealed the following values: pH 6.8, $PaCO_2$ 116 mmHg, $PaO_2$ 144 mmHg, lactate exceeding 15 mmol/L. Intermittent positive pressure ventilation was maintained to counteract hypercapnia and acidosis; To facilitate ventilation and prevent reoccurrence of convulsions, another 7.5 mg bolus of midazolam was administered. The remaining 300 mL of Intralipid was infused over 20 min (0.22 mL/kg/min). The patient was transferred to the intensive care unit. A repeated arterial blood sample after 2 h revealed a pH of 7.33, $PaCO_2$ of 48 mmHg, $PaO_2$ of 222 mmHg, lactate of 9.2 mmol/L, potassium of 2.7 mmol/L, and glucose of 90 mg/dL. The ECG showed a sinus tachycardia at a rate of 110 bpm with occasional ventricular ectopy. An amiodarone loading dose (300 mg) and potassium were subsequently administered, and the patient was maintained on continuous inotropic support (epinephrine 0.02 mcg/kg/min) and sedation (propofol 50 mcg/kg/min). Epinephrine and propofol were gradually decreased and eventually discontinued 4 h after admission to the intensive care unit. The patient was extubated shortly thereafter. The patient was transferred to a cardiac ward on day three and discharged 7 days after the initial event. The surgical procedure was carried out 4 weeks later using general anesthesia without any incident.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, 

# Appendix E: Case Study for Chapter 8 on the Role of the Post-anesthesia Care Unit in the Perioperative Care of the Orthopedic Patient

Michael K. Urban

## Case Study

An 80-year-old female with a past medical history significant for hypertension, coronary artery disease, depression, and elevated cholesterol was scheduled for right total knee arthroplasty. The surgical course was uneventful, and the anesthesia was performed using a combined spinal epidural technique with 12 mg of bupivacaine and a femoral nerve block with 30 mL of 0.25 % bupivacaine. The patient's surgery ended at 10:30 am, and she was admitted to the PACU for an overnight stay for a rule-out myocardial infarction protocol and observation.

At 10 pm on the night of surgery, the patient was complaining of extensive pain despite an epidural infusion of 0.06 % bupivacaine and 10 μg/mL of hydromorphone. The PACU team decided that the epidural was not adequately functioning and she was switched to an intravenous patient-controlled pump containing hydromorphone.

By 1 am the PACU team was called to the patient's bedside for assessment of aggressive and combative behavior. Her vital signs included a blood pressure of 190/100 mmHg, a heart rate 100 bpm, a temperature of 37.8 °C, and oxygen saturation of 90 %. The patient complained that she was being held captive in a hotel in Chicago and demanded to have the police called so that she could be released immediately. An arterial blood gas was obtained and revealed a pH of 7.36, a $CO_2$ of 44 mmHg, and an $O_2$ of 66 mmHg. A chest radiograph demonstrated bilateral lower lobe atelectasis.

The differential diagnosis included pulmonary embolism, a cerebrovascular event, fat embolism syndrome, and postoperative delirium. Since the patient had been ambulatory prior to surgery and when taking the timing of events into account, a thromboembolic event was considered to be unlikely. The symptoms of hypertension and confusion could be the result of cerebrovascular occlusion and/or cerebral hemorrhage; however, the patient's neurological exam was non-focal. In addition, the elevated blood pressure was more likely the result of her pain. With regard to infection, her chest radiograph was clear except for atelectasis, the knee incision was clean and the wound was not hot or tense. Fat embolism syndrome was also considered, but as other signs like alveolar infiltrates on chest radiograph and hematologic signs such as thrombocytopenia were missing, this was also considered less likely.

The team decided that her primary problem was postoperative delirium secondary the stress of surgery, inconsistent and inadequate analgesia, and sleep deprivation in the PACU. The patient was given intravenous enalapril and metoprolol for her elevated blood pressure and heart rate. An infusion of dexmedetomidine at 0.5 μg/kg/h was initiated, and once the patient was sedated, she was placed on noninvasive positive pressure ventilation. At 7 am the following morning, the infusion was stopped and by 8 am the patient was awake, oriented, and alert. Her pain was well controlled with intravenous hydromorphone. Her vital signs had normalized and she was discharged to the ward.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, 

# Appendix F: Case Study for Chapter 9 on Postoperative Pain Management in the Orthopedic Setting

Cassie Kuo and Spencer S. Liu

## Case Study

A 67-year-old gentleman with a history of hypertension, non-insulin-dependent diabetes mellitus, and obstructive sleep apnea was scheduled for total knee arthroplasty under a spinal anesthetic with 12.5 mg of bupivacaine and intrathecal morphine 0.2 mg for postoperative analgesia. An epidural was contraindicated as enoxaparin was to be used for postoperative thromboprophylaxis. After resolution of the spinal anesthetic in the post-anesthesia recovery unit, he complained of severe anterior knee pain. While in the PACU for the past 3 h, he has taken 2 tablets of oxycodone/acetaminophen 5 mg/325 mg with minimal pain relief. Unfortunately, he developed nausea shortly after taking the oral analgesics. His vital signs included a heart rate of 88, a blood pressure of 175/86, and an $SpO_2$ 98 % on 4 L/min $O_2$ nasal cannula. The acute pain service was consulted.

Multiple pain management options were deliberated and limitations considered. Additional analgesia could be provided with systemic opioids either in the form of an IV PCA or as additional oral medications. However, the patient's complaint of nausea indicated substantial side effects from the spinal morphine and the oral analgesics already taken. Also, additional concern arose given his history of obstructive sleep apnea, and the potential effects that additional opioids could have on his respiratory status. Therefore, systemic non-opioid analgesics such as nonsteroidal anti-inflammatory drugs including meloxicam, ketorolac, and/or acetaminophen as adjunctive agents with virtually no respiratory depression or potential for nausea were considered to be good alternatives. Given the concern that these alternative medications are likely insufficient as a primary analgesic technique, a regional analgesic approach resulting in analgesia without the need to administer large doses of systemic opioids was deemed appropriate. Common choices for regional analgesia after total knee arthroplasty include a femoral nerve block. Given the patient's uncontrolled pain and nausea with opioids, the decision was made to offer him a continuous femoral nerve block as a primary analgesic in order to prolong analgesia beyond the potential of a single injection approach. The femoral nerve block and catheter placement were performed in the post-anesthesia recovery room, utilizing an ultrasound guided approach in order to avoid vascular trauma in the setting of planned anticoagulation. This approach was able to provide significant analgesia for 3 days and facilitated postoperative physical rehabilitation. The local anesthetic infusion for the continuous femoral nerve block was combined with a patient controlled function with the goal to tailor dosing to the patient's needs and minimize excessive motor block. The patient required minimal systemic opioids and did not develop any adverse respiratory depression.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, 

# Appendix G: Case Study for Chapter 10 on Perioperative Care of the Orthopedic Patient with Connective Tissue Disease

Susan M. Goodman and Stephen Paget

## Case Study

A 49-year-old man with a 25-year history of seronegative systemic onset juvenile rheumatoid arthritis (JRA), treated with anakinra and methotrexate, was referred for therapy of a left prosthetic hip infection. His original surgery was performed in 1990. The patient also had a right hip arthroplasty in 1988, which was revised in 2007 for aseptic loosening of the prosthesis. He developed groin pain and fevers and was admitted to an outside hospital with. Methicillin-sensitive staphylococcus (MSSA) was identified from blood cultures and a hip aspirate, and the hip was explanted after stabilization with placement of an antibiotic spacer. He received 8 weeks of cefazolin 2 g three times a day, and he normalized his C-reactive protein and white blood cell count. He subsequently underwent an uncomplicated reimplantation of the left hip. No source for the infection could be identified.

One month later he developed pain in the left hip and underwent a debridement procedure; MSSA was cultured, and he was again treated with cefazolin resulting in improvement of symptoms. However, he developed recurrent pain with a draining sinus and was referred to HSS for further therapy.

At the time of his presentation, he was afebrile. His exam was remarkable for a draining sinus track at the left hip incision. The right hip incision was well healed, and the hip motion was pain free. There was no evidence of active synovitis, but bilateral wrist and elbow motion were restricted.

Aspiration of the right hip revealed $125 \times 10^3/\mu L$ white blood cells, and a culture that was obtained at that time was negative for bacterial growth. His erythrocyte sedimentation rate was 110 mm/h and a C-reactive protein was 12.5 mg/L. He underwent explantation and debridement of the left hip prosthesis. MSSA was grown from all operative cultures, and he completed 6 weeks of cefazolin. Bactericidal titers were obtained. Lovenox was used for thromboprophylaxis. His anakinra was discontinued, and he was treated with methotrexate 12.5 mg BID once weekly, and remained without flare. He was readmitted 3 months later for reimplantation, which was successful.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, 

# Appendix H: Case Study for Chapter 11 on Perioperative Care of the Orthopedic Patient with Cardiac Disease

Lawrence F. Levin

## Case Study

A 73-year-old man was seen for cardiac evaluation prior to total knee replacement. He had a history of hypertension, hyperlipidemia, and a 60 pack year tobacco exposure though he quit smoking 1 year previously after being told that he had severe emphysema. He was able to walk up to a mile in 30 min without exertional cardiac symptoms. His knee pain was minimal, but he was concerned that it would progress and eventually limit his quality of life. An echocardiogram performed 4 months earlier confirmed normal left ventricular function without significant structural heart disease. An adenosine technetium perfusion study was mild-to-moderately abnormal revealing a moderate intensity partially reversible distal anterior and apical defect. The patient was referred for cardiac catheterization that revealed a completely occluded mid left anterior descending artery collateralized via a right coronary artery with high grade proximal stenosis; the circumflex system had multiple partial stenoses approximating 50 % with normal flow. The patient was referred to a cardiothoracic surgeon who deemed him to be at high risk for complications from cardiac bypass grafting surgery based on his significant pulmonary disease. Two interventional cardiologists also independently concluded that revascularizing a chronic total occlusion in the LAD was associated with high risk and, given the retained normal RCA blood flow, that he would not benefit from its revascularization.

According to the Revised Cardiac Risk Index (RCRI), the patient had a single risk factor (ischemic heart disease) in the setting of a favorable exertional tolerance (at least 7 METS). As such he was considered intermediate risk for orthopedic surgery; indeed, his risk of major adverse cardiac events from such surgery was approximately 1 %. The risks and benefits of surgery were discussed with the patient. The discussion included the elective nature of the surgery, his current absence of symptoms, the complex nature of his coronary anatomy, and finally how the long-term outcome of the surgery would not be decreased by postponing the procedure. Upon further deliberation, the patient decided to cancel the surgery.

He returned for cardiac reassessment 3 years later, now able to walk only 1 block on flat surfaces and unable to climb more than a single flight of stairs due to severe knee pain. He reported no cardiac symptoms at this exertional tolerance. While he had not undergone additional stress testing or angiography since his previous visit, an echocardiogram confirmed normal left ventricular size and function. As judged by the Revised Cardiac Risk Index, the patient still had only one postoperative risk factor though now experienced poor exertional tolerance (<4 METS).

Despite his limited functional capacity, he was deemed still as low risk for cardiac events. Further, given the development of symptoms and the potential for improvement in his quality of life, the benefits of knee arthroplasty now appeared to justify the risks. Already optimally medicated with a statin, aspirin, and B-blockade (pulse rate 60, BP 110/70), he went to the operating room on these medicines, was observed in a monitored setting overnight and had an uneventful postoperative course.

This case demonstrates the primacy of the clinical evaluation over cardiac testing. Even in the setting of his significant multivessel coronary disease, the patient remained low risk for cardiac complications. Yet it was not until he would derive significant benefit from the surgery that it was deemed worth his assuming any risk. Arguably, a stress test could have been performed just before the knee surgery; however, as it was unlikely to influence his treatment or influence his long-term cardiac prognosis, it was decided not to repeat the study.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, 

# Appendix I: Case Studies for Chapter 13 on Perioperative Care of the Orthopedic Patient with Renal Disease

James M. Chevalier

## Case Studies

### Case 1

A 47-year-old woman, with a history of systemic lupus erythematosus since age 17 required a total hip replacement because of avascular necrosis and had scheduled the surgery for 2 months from the time of her office visit. She had stable chronic kidney disease secondary to diffuse proliferative lupus nephritis that had previously been treated with cyclophosphamide and prednisone.

Her medications included enalapril, sodium bicarbonate, twice monthly darbepoietin, and weekly vitamin D. Remarkably, she required almost no pain medications, using acetaminophen sparingly.

On exam, her blood pressure was 104/68, her heart rate 64, and her weight was stable at 117 pounds. Her lungs were clear, heart sounds regular, and no lower extremity edema were present. The rest of her physical exam was also unremarkable.

Previous creatinine values had been in the 2.7–2.9 mg/dL range with an eGFR in the 20s. Laboratory results obtained at the most recent visit revealed the following values: HCT = 27 %, Cr = 2.9 mg/dL (eGFR = 23), K = 4.7 mEq/L, $HCO_3$ = 21 mEq/L, Ca = 9 mg/dL, $PO_4$ = 4.6 mg/dL, Alb = 3.8 g/dL, unremarkable liver function tests, PTH = 26 pg/mL, vitamin D 25 = 34 ng/mL.

The nephrologist was asked to counsel the patient on her renal risk from the surgery and to make recommendations for the surgery.

The patient was counseled that she was at risk for acute kidney injury (AKI) after the surgery, given her kidney disease, but that measures would be taken to decrease her risk of AKI, including the adjustment of her medications and use of other medications and intravenous (IV) fluids. Further, she was informed that there were no tests available that could determine if she, or any given patient, would develop AKI. In favor of a good outcome, did not have risk factors commonly associated with an increased risk of AKI, including advanced age, diabetes mellitus, hypertension, congestive heart failure, peripheral vascular disease, liver disease, or chronic obstructive pulmonary disease.

The following preoperative recommendations were made:

- Renal dosing of medications, including antibiotics, for an estimated creatinine clearance of 20–29.
- Avoidance of dehydration/hypotension and use of isotonic fluids such as Normal Saline during the procedure.
- Avoidance of potassium containing IV fluids, i.e., lactated Ringer's, in order to decrease the risk of hyperkalemia.
- Continuation of sodium bicarbonate perioperatively.
- Stopping of enalapril 24 h prior to surgery
- Avoidance of other nephrotoxins perioperatively, such as aminoglycosides, NSAID's, ACE/ARB, IV contrast, etc.
- Treatment of iron deficiency and administration of darbepoietin continued to achieve a HCT > 30 % prior to surgery.

The patient received a course of IV iron in the kidney center and continued her darbepoietin with an improvement in her hematocrit to 34 % prior to surgery. The use of desmopressin was not recommended; the patient did well without bleeding complications. She had an uneventful hip replacement and continued to remain dialysis independent 1 year later.

### Case 2

An 82-year-old man was seen by nephrology in the hospital on postoperative day (POD) #2 for asymptomatic hyponatremia and acute kidney injury (AKI) which developed on the night of POD #1. The patient was status post a total knee replacement, secondary to osteoarthritis. He had a history of hypertension, chronic obstructive pulmonary disease (COPD), and gout. The patient had nothing by mouth the morning of surgery and had a late afternoon case. He reported not eating or drinking much on POD #1 but had been eating and drinking more on POD#2. He was receiving Normal Saline at a rate of 50 mL/h at the time of the renal consultation.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, © Springer New York 2014

His medications included inhaled fluticasone/salmeterol, allopurinol, and ketorolac every 6 h for seven doses.

On exam, his blood pressure was 108/62 mmHg. His heart rate was 88 supine but increased to 112 beats per minute while sitting. The lungs were clear on auscultation, and his heart beat was regular. No lower extremity edema was noticed. The rest of the physical exam was unremarkable.

On POD #1 the serum Na was 132 mEq/L in the morning and 126 mEq/L in the evening. POD #2, the serum Na was 122 mEq/L. The serum osmolarity was 252 mOsm/kg, urine osmolarity was 630 mOsm/kg, and UNa was <10 mmol/L with a urine output of with 480 mL on POD #1. The hourly rate of urine output increased slightly on POD #2. The serum creatinine was 2.4 mg/dL, up from 1.6 mg/dL preoperatively. Other laboratory data of note included a HCT = 33 % (after transfusion), K = 4.3 mEq/L, $HCO_3$ = 24 mEq/L, Ca = 9.4 mg/dL, $PO_4$ = 2.6 mg/dL, Alb = 3.4 g/dL, and unremarkable liver function tests.

The nephrologist was asked to evaluate and make recommendations regarding the hyponatremia and AKI.

The patient was at risk for AKI, given his age, baseline chronic kidney disease, hypertension, COPD, volume depletion, and use of ketorolac. The cause of AKI was deemed to be pre-renal because of the patient's low urine sodium, low fractional excretion of sodium, and physical examination consistent with volume depletion, most notably the low blood pressure for a patient with hypertension and the change in heart rate from the supine to the sitting position. It was concluded that this patient had hypovolemic hyponatremia, for the same reasons that the patient had pre-renal AKI: the urine studies and the physical examination were consistent with volume depletion.

The ketorolac was held. The patient was treated with a slow bolus of Normal Saline: 1 L over 5 h, followed by an increase in the maintenance rate of the Normal Saline to 75 mL/h. The infusion was given slowly, given his age and history of COPD. The patient was also counseled to increase intake of solutes such as protein, salt, and potassium. He was encouraged to take fluids that had osmoles in them such as milk, soup, and oral supplements. He was encouraged to report any respiratory symptoms or lower extremity edema, at which time fluids were to be held.

Because the AKI had a reversible cause and because the hyponatremia had developed quickly, both were amenable to aggressive treatment. By the morning of POD #3, the patient's creatinine decreased to 1.7 mg/dL, and the sodium had increased to 131 mEq/L. The patient was eating and drinking well, and the IV fluids were stopped. On POD #4, the patient's creatinine was 1.5 mg/dL, and the sodium was 134 mEq/L. He was scheduled for discharge to a subacute rehabilitation center.

In this particular patient, a renal ultrasound was not ordered because the cause of both the AKI and the hyponatremia was apparent after physical examination and laboratory testing. A Foley catheter was not placed because the patient refused. It would, however, be reasonable to place a Foley catheter in an oliguric patient with AKI, especially if the urine output did not increase with fluid intake, or if there were to be a suspicion for urethral obstruction.

# Appendix J: Case Studies for Chapter 15 on Perioperative Care of the Orthopedic Patient with Gastrointestinal and Liver Issues

Melissa H. Rosen and Charles Maltz

## Case Studies

### Case 1

A 72-year-old woman scheduled for total knee arthroplasty was seen preoperatively at which time elevated transaminases were noted on routine blood testing. There was no history of excessive alcoholic intake, she was not obese, and hepatitis serologies were negative. Her transaminases were normal in the past with the elevations developing coincident with the institution of diclofenac several months ago. An ultrasound of the liver was normal. A presumptive diagnosis of drug-induced hepatitis was made, diclofenac discontinued, and over the next few months the transaminases returned to normal. Subsequently, she underwent successful surgery.

### Case 2

A 75-year-old woman was admitted for emergent surgery after sustaining a femur fracture from a fall. Preoperative blood work demonstrated transaminases, an INR of 1.3, and an albumin of 2.9 d/dL. She had a history of variable transaminases in the past, was on no potentially hepatotoxic medications and viral serologies were negative. The ANA was positive (3+). A hepatic sonogram demonstrated a cirrhotic liver. Autoimmune induced cirrhosis (Child's Class A) was diagnosed and the surgery was performed without complication. Gastroenterologic follow-up for her liver disease was advised.

### Case 3

A 65-year-old woman with a history of chronic constipation underwent spine surgery. Abdominal distension and no bowel movement was reported 1 week after surgery. On exam she was mildly tender and distended without active bowel sounds. Laboratory testing demonstrated only mild anemia. An abdominal X-ray (Fig. J.1) revealed an intestinal ileus.

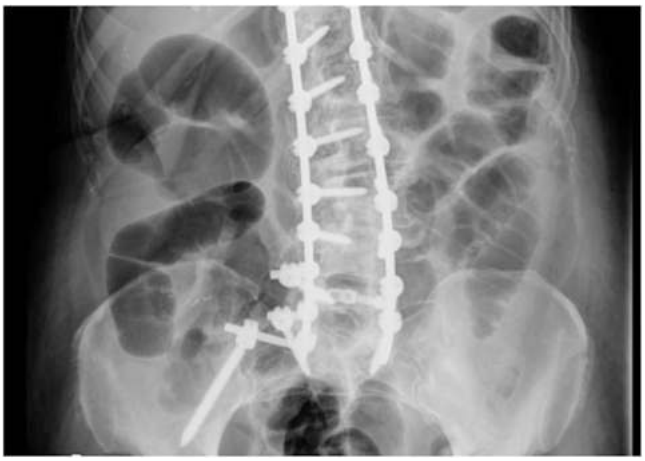

**Fig. J.1** Intestinal Ileus

The discontinuation of narcotics was advised and she was treated with enemas and methylnatrexone. One day after treatment her distention decreased, she developed active bowel sounds and was put on standing dose of polyethylene glycol which resulted in the return of normal bowel function.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, 

# Appendix K: Case Studies for Chapter 17 on Perioperative Care of the Orthopedic Patient with Psychiatric Disease

John W. Barnhill

## Case Studies

### Case 1

An 84-year-old man was brought to the emergency room following a hip fracture. In preparation for surgical repair, the orthopedic team noted that he seemed confused, distracted, and unable to pay attention to the conversation. His wife confirmed that he had been alert and oriented prior to the accident but that he had experienced some mild cognitive decline in recent years.

A psychiatric consultation was called. The patient was diagnosed with mild dementia. The psychiatrist noted that he lacked capacity to provide informed consent and had signs of delirium, so consent for surgery was provided by his wife. In addition, the psychiatrist elicited the fact that the patient had a prolonged period of confusion the prior year when he had a cardiac bypass procedure. After discussion with the surgical team and the patient's wife, the psychiatrist offered the patient a low dose of olanzapine the night before and after surgery. His postoperative course was marked by some nighttime confusion, but he quickly stabilized and was ready for transfer to a subacute rehabilitation center by postoperative day 4.

### Case 2

A 38-year-old former professional athlete suffered a femoral fracture while racing his snowmobile. He was admitted for surgery to a specialty orthopedic hospital after a 4-day hospitalization at a community hospital near the site of the accident. By the time he arrived, the patient was agitated, hostile, and mildly confused. A psychiatric consultation was solicited to help manage the agitated behavior and streamline efforts to repair the fracture.

The patient was able to calm down enough to provide a reasonably coherent history to the psychiatrist, but he did appear agitated, anxious, and tremulous. He was hypertensive and tachycardic. The psychiatrist elicited multiple pertinent historical issues: the patient drank approximately half a liter of vodka per day; he had long-standing pain from his sports injuries; and, while he denied interpersonal issues, his wife insisted that he was an entitled, difficult man who responded to adversity with hostility and rage attacks.

This cluster of symptoms and history suggested that he was at risk for serious alcohol withdrawal. His laboratory data were pertinent for an MCV of 104 and liver function tests with a characteristically elevated AST. A review of his suitcase uncovered a half-full bottle of vodka, and, while he had never been treated for alcohol abuse, his wife indicated that he had twice been arrested for driving under the influence. The patient was more focused on his pain, which he believed was being vastly undertreated, and he was threatening to leave against medical advice.

The psychiatric intervention was multifold. First, a long-acting benzodiazepine was prescribed with the goal to reduce his somatic complaints of shakes and anxiety and to reduce his heart rate and blood pressure. Secondly, the psychiatrist worked with the pain service to increase his pain medications with the recognition that his tolerance to opiates was greatly increased. By adding methadone to a standing pain regimen, he was able to tolerate his pain before and after surgery.

In regard to therapy, it became clear that the patient's esteem had been badly injured since the end of his athletic career. The psychiatrist intervened by diagnosing depression with prominent anxiety which the patient had been partly self-medicating with pain medications. The psychiatrist prescribed an antidepressant medication. In addition, he began to work with the patient by allying with the aspects of the patient that were still intact: his competitive spirit, his discipline, and his need to be seen as in charge. By dealing with the medication issues and focusing on the patient's strengths, the psychiatrist was able to smooth the perioperative period and increase the likelihood of a successful postoperative course. He also laid the groundwork for later interventions that would involve treatment for his alcohol and opiate abuse, therapy for his interpersonal conflicts, and a neuropsychiatric evaluation for possible sports-related traumatic brain injury.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, 

# Appendix L: Case Study for Chapter 22 on Infection and Perioperative Orthopedic Care

Andy O. Miller and Barry D. Brause

## Case Study

A 54-year-old woman with a history of asthma, diabetes mellitus on oral agents, obesity, eczema, and active tobacco use, is scheduled for elective revision instrumented thoracolumbar spine surgery. The surgery is expected to last 7 h. She is not on immunosuppressive medications. She has no known drug allergies. Physical examination reveals a healthy-appearing woman, weighing 100 kg which relates to a BMI of 34. Eczematous skin is noted on her hands, legs, and near the proposed surgical incision. Preoperative laboratory tests reveals no evidence of active infection.

The patient has risk factors of surgical site infection. Obesity and smoking are modifiable risk factors, but frequently cannot (or will not) be modified in the perioperative setting. Nonetheless, patients should understand that these are established risk factors for infection, that infection can be a devastating complication, and that through a modification in the patient's behavior the risk can be decreased. Tobacco cessation and dietary counseling should be offered routinely.

The patient's eczema is another an important modifiable risk factor. Nearly 90 % of patients with eczema harbor *Staphylococcus aureus* on their skin and therefore may be at increased risk of surgical site infection. Therefore, this patient should have her dermatitis evaluated and treated prior to surgery. In addition, strong consideration should be given to screening the nares, eczematous skin, and perhaps other sites as well to detect the presence of *S. aureus*, or to empiric *S. aureus* decolonization with topical mupirocin/bactroban. MRSA carrier status may alter the choice of perioperative antibiotics and infection control practices in the inpatient setting.

The patient's history of a prior, same-site surgery (microdiscectomy) is a non-modifiable risk factor.

In the hour prior to incision, the patient should receive 2 g of intravenous cefazolin (or, in case MRSA colonization is detected, 1 g of vancomycin. In the absence of compelling data in either direction, some suggest giving both vancomycin *and* cefazolin prior to incision given cefazolin's antimicrobial spectrum and its added potency against beta-lactam sensitive organisms). The expected surgical time for this complex spine case exceeds 4 h, and therefore, a second dose of cefazolin 2 g should be provided intraoperatively.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, 

# Appendix M: Case Study for Chapter 23 on Risk and Benefits of Bilateral Total Knee Replacement Surgery

Ettore Vulcano, Alejandro González Della Valle, and Stavros G. Memtsoudis

## Case Study

A 56-year-old male, motivated, physically active, chemical engineer presented at our outpatient clinic complaining of a 5-year history of bilateral knee pain with severe varus deformity and osteoarthritis. With a body mass index of 28, his medical history was unremarkable except for hypertension treated with an ACE-inhibitor. He had no medical history of pulmonary, renal, liver, vascular, hematologic, or thromboembolic disease. The patient had been trying to manage the symptoms of osteoarthritis conservatively using anti-inflammatory medication and doing physical therapy. He received a cortisone injection in each knee which provided him with relief for only 3 months. After discussing benefits and drawbacks of staged and single-stage bilateral knee replacement surgery, he elected to proceed with a single-stage procedure. Preoperative medical clearance included a stress test, which was within normal limits. The patient pre-donated 2 units of blood. He was admitted on the same day of surgery. Anesthesia consisted of combined spinal and epidural. Bilateral femoral nerve blocks were placed to supplement postoperative epidural analgesia for the first postoperative day. An arterial line was placed for close blood pressure monitoring and in anticipation of frequent perioperative blood draws. The more painful knee was operated first. During the wound closure, the patient was found to be hemodynamically stable and a decision was made to proceed with TKA in the contralateral knee. Surgeries were performed by the same team, using the same surgical instruments for both procedures. Both surgeries were performed under tourniquet inflation which was released after curing of the cement for meticulous hemostasis. Vacuum drains were used. The total surgical time was 135 min. Upon completion of the second surgery, the patient was transferred to the post-anesthesia care unit for overnight monitoring. One unit of the pre-donated blood was transfused. Multimodal thromboprophylaxis included the use of intermittent pneumatic compression devices, immediate active ankle flexion and extension exercises, and early ambulation beginning on postoperative day 1. Coumadin was started on the same day of surgery with a target INR from 1.8 to 2 for 6 weeks, along with knee-high elastic stockings to be worn during the day following discharge. On postoperative day 3, the patient was transferred to a tertiary acute rehabilitation center. No medical or local complications were observed during the recovery period. At 6-week follow-up, thromboprophylaxis was discontinued, and the patient continued with outpatient physical therapy for an additional 6 weeks. The patient returned to his office work 1 month after surgery and to low-impact sports at 3 months.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, 

# Appendix N: Case Studies for Chapter 24 on Compartment Syndrome and Orthopedic Surgery: Diagnosis and Management

Matthew R. Garner, Samuel A. Taylor, Milton T.M. Little, and John P. Lyden

## Case Studies

### Case 1

A 52-year-old male presented to the emergency department status-post motorcycle accident. On presentation he was alert and oriented, complaining of pain in his left hip and lower extremity. A physical exam revealed a left lower extremity that was shortened and internally rotated and a palpable defect over the distal tibia. Thigh and lower leg compartment were soft and the patient had intact sensation and full motor strength throughout all nerve distributions. Both dorsalis pedis and posterior tibial arteries were palpable. Initial trauma series X-rays showed a left sided posterior/superior native hip dislocation and a distal 1/3 tibia and fibular shaft fracture. The hip was reduced and a well-padded long-leg posterior-U splint was applied. The patient remained neurovascularly intact after reduction and splinting. A subsequent pelvis CT scan showed intraarticular bony fragments within the left hip with a posterior wall acetabulum fracture. A femoral traction pin was then placed to obtain joint distraction.

Throughout the day, the patient's compartment remained soft and his neurovascular status was unchanged. The patient went to the operating room that afternoon and underwent intramedullar nailing of the left tibia followed by an open reduction and internal fixation of the left posterior wall of the acetabulum. Upon completion of the second procedure, compartments were full but compressible and pulses were palpable. A short leg posterior-U splint was applied prior to leaving the operating room. Total operative time was approximately 10 h and the patient remained intubated postoperatively.

Physical examinations overnight were limited by the fact that the patient remained intubated. Compartments were full but compressible, pulses palpable, and toes warm and well perfused with brisk capillary refill. After extubation the patient was again examined. At this time, the anterior and lateral compartments were firm and the patient complained of significant pain with passive flexion of the great toe. The splint was removed; sensation was intact but subjectively diminished in the deep and superficial peroneal distribution. Pulses were palpable with no change from prior exams. At this time, compartment pressures were measured using a manometric gauge. Pressure readings were as follows: Anterior Compartment: 86 mmHg; Lateral compartment: 68 mmHg; Deep Posterior Compartment: 34 mmHg; Superficial Posterior Compartment: 32 mmHg. The patient underwent an emergent four compartment fasciotomy. All muscle tissue appeared viable and wounds were covered with a wound VAC to assist with closure. Three subsequent procedures were required, but both the medial and lateral wounds were closed. At the time of discharge, the patient had regained full motor strength in all distributions but had residual subjective sensory deficits in the superficial and deep peroneal distributions.

This case highlights both the risk of compartment syndrome in the preoperative period after high-risk procedures (i.e., tibial nailing, tibial osteotomy, etc.), as well as the difficulty in assessing for compartment syndrome in an intubated patient. For patients who are unable to respond to stimuli or give a verbal assessment of pain, we recommend a low threshold for use of needle manometry to assess for compartment syndrome.

### Case 2

An 87-year-old female status-post primary left total knee replacement was admitted for a revision surgery due to prosthetic loosening. Preoperatively, the patient had full motor strength and intact sensation in all nerve distributions. A revision left total knee arthroplasty was performed under combined spinal/epidural anesthesia and with use of a tourniquet. The tourniquet time was 1 h and 49 min. Postoperatively the patient had no motor function or sensation below the knee of the left leg despite resolution of the spinal anesthetic and removal of the epidural catheter. Compartments were soft and pulses were palpable.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, 

The neurology service was consulted and recommended a lumbar MRI which was unrevealing and showed no evidence of epidural hematoma. Vascular surgery was also consulted, and an MRI/MRA of the affected leg was performed but showed no obvious abnormalities. The patient's exam remained unchanged with no definitive diagnosis until pulses were noted to be diminished on postoperative day 2. The patient went urgently for angiography with vascular surgery where a popliteal thrombus was found along with poor perfusion. A thrombectomy, four compartment fasciotomy, and deep dorsalis pedis artery bypass were performed at that time, but significant muscle necrosis was present in the anterior and lateral compartments.

The patient underwent multiple incision and debridement procedures to remove necrotic muscle. Despite revascularization, the patient did not regain motor or sensation in the affected leg. Ultimately, plastic surgery concluded that the leg was not suitable for soft tissue coverage due to the amount of tissue loss and an above knee amputation was performed 6 weeks after the initial procedure.

Again, this case highlights the risk of compartment syndrome associated with specific surgical procedures, including those with extended tourniquet times. Further, the use of spinal and/or epidural anesthesia can inhibit a postoperative examination, and there should be a low threshold for removing pain catheters if there is any question of a compartment syndrome. Lastly, this case should highlight the fact that not all compartment syndromes are caused by blunt trauma and that vascular injuries can have equally devastating consequences.

# Appendix O: Case Studies for Chapter 25 on Bone Health and Orthopedic Surgery

Linda A. Russell

## Case Studies

### Case 1

A 65-year-old Caucasian female with lumbar spondylosis and chronic low back pain presented for spine surgery. Treated unsuccessfully with various medications, physical therapy, and several epidural injections, she remained in severe pain and consequently a spinal fusion was advised.

Her past history was notable for menopause at 44 years of age, a wrist fracture at 52 years of age when she slipped shoveling snow, and diabetes mellitus for which she took pioglitazone and metformin. She was a former smoker, but she did not drink alcohol. A bone density test several years ago was said to be "okay." Her mother fractured her hip at the age of 72, when she fell down over the steps in her home. The patient has never been treated for osteoporosis and did not know what her vitamin D level was.

Given her clinical profile, with several important bone related risk factors (early menopause, previous fracture, cigarette exposure, diabetes, and family history), the patient's bone health was addressed. Beginning with a bone density determination, T-scores for lumbar spine and hip (femoral neck) were obtained and reveiled −2.6 and −2.5, respectfully, which was in the osteoporotic range. FRAX analysis in this patient equated these bone densities with a 10-year overall fracture risk of 21 % (5.4 % in the hip), if untreated. Her 25 vitamin D levels were also low (20 ng/mL), and her intact parathyroid hormone (PTH) was mildly elevated at 85 pg/mL (serum $Ca^{++}$9.0 mg/dL).

As a conservative target, the 25-oH vitamin D requires supplementation to maintain a level of 32 ng/mL with some experts recommending levels as high as 50 ng/mL. In addition, the secondary hyperparathyroidism, demonstrated by the elevated PHT level, should be corrected with dietary calcium or calcium supplements and vitamin D.

Further the patient should be started on treatment for osteoporosis. Evidence suggesting that bisphosphonate therapy may slow bone fusion rate makes such therapy unfavorable for patients facing spinal fusion. As teriparatide may hasten spine fusion rates, treatment with PTH is advised.

### Case 2

A 76-year-old Caucasian male was admitted with a hip fracture after having slipped on wet leaves walking to his car. Having enjoyed relatively good health, he was treated only for hypertension and Barrett's esophagitis. He was a 1 pack per day smoker since 18 years of age and admitted to alcohol consumption of 2–3 cocktails nightly. Currently 5′11″ in height, he reported his high school height to have been 6′2″. He weighed 165 lbs. He underwent open reduction and internal fixation and did well postoperatively.

His internist ordered a bone density scan and related laboratory work postoperatively. Bone densitometry revealed T-scores of −2.8 (lumbar spine) and −3.0 in the nonoperative femoral neck. Additional fracture assessment revealed an old L4 fracture. His 25 vitamin D level was 19 ng/mL, serum calcium 8.9 mg/dL, and intact parathyroid hormone level elevated at 92 pg/mL, consistent with secondary hyperparathyroidism.

This patient had several risk factors for osteoporosis including his race (Caucasian), tobacco use including during his peak bone forming years, and regular alcohol use (intake of 3 or more units per day is a risk factor for osteoporosis). He also took a proton pump inhibitor, which may decrease the absorption of calcium carbonate and may contribute to the development of osteoporosis. In addition, a loss of more than two inches in height is considered a predictor of a prior vertebral fracture.

Thus, in order to address this patient's bone health, he should be counseled to discontinue tobacco and limit his alcohol use. Given his history of Barrett's esophagitis, the continued use of a proton pump is warranted, however. Further, he should begin vitamin D3 in conjunction with an

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, 

increase in calcium intake. Lab work should be repeated in 8–12 weeks to ensure improvement in his vitamin D level and correction of the secondary hyperparathyroidism. Bisphosphonate therapy would generally be indicated but their propensity to produce esophagitis precludes such treatment. Zolendronic acid, however, has been shown to reduce fracture risk and decrease mortality after hip fracture. A yearly IV dose (5 mg) is indicated.

# Appendix P: Case Study for Chapter 27 on Management of Blood Products in Orthopedic Surgery

Jad Bou Monsef, Michelle Perna, and Friedrich Boettner

## Case Study

A 56-year-old female was scheduled for bilateral total knee replacement after presenting with progressively worsening pain due to primary osteoarthritis. She reported a medical history of gastroesophageal reflux disease and depression, but no bleeding disorder. In the absence of cardiac disease or peripheral vascular disease, preoperative aspirin was stopped 7 days prior to surgery. After the patient donated 2 units of autologous blood, a preoperative blood count revealed a hemoglobin level of 12.5 g/dL with a hematocrit of 38.3 %. The patient took ferrous fumarate, vitamin B12, and folic acid supplementation 6 weeks prior to surgery. In the operating room, spinal-epidural anesthesia was administered. An intraoperative tourniquet was utilized and released after the hardening of the cement. A perioperative cell saver was used and connected to the deep suction drains. The patient was given Coumadin for DVT prophylaxis, and the drains were discontinued on postoperative day 1. Estimated perioperative blood loss and the drained volume amounted to 1.7 L of which 500 cc of concentrated blood were reinfused. In addition, the patient received 1 unit of autologous blood on the day of the surgery and a second unit on postoperative day 1. The discharge hemoglobin was 9.8 g/dL, and the patient did not receive any allogeneic blood.

C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, 

# Index



C.R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*,
DOI 10.1007/978-1-4614-0100-1, © Springer New York 2014