

# WEM Wilderness & Environmental Medicine

Volume 34 | Number 3 | 2023



Official journal of the  
Wilderness Medical Society  
[wms.org](http://wms.org)





## BRIEF REPORT

# Alaska Backcountry Expeditionary Hunting Promotes Sustained Muscle Protein Synthesis <sup>P</sup>

Robert H. Coker, PhD<sup>1</sup>; Brent C. Ruby, PhD<sup>1</sup>; Melynda S. Coker, PhD<sup>1</sup>; Larry Bartlett, AS<sup>2</sup>; Brandon Kowalski, BS<sup>3</sup>; Anna V. Goropashnaya, PhD<sup>4</sup>; Terry Bateman, MD<sup>3</sup>; Mahalakshmi Shankaran, PhD<sup>5</sup>; Marc Hellerstein, MD, PhD<sup>5</sup>; William J. Evans, PhD<sup>5</sup>

<sup>1</sup>Montana Center for Work Physiology and Exercise Metabolism, University of Montana, Missoula, MT; <sup>2</sup>Pristine Ventures, Inc, Fairbanks, AK; <sup>3</sup>Department of Biology and Wildlife, University of Alaska Fairbanks, Fairbanks, AK; <sup>4</sup>Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, AK; <sup>5</sup>Department of Nutritional Sciences and Toxicology, University of California Berkeley, Berkeley, CA

**Introduction**—We have previously described negative energy balance (ie,  $-9.7 \pm 3.4$  MJ/d) and weight loss ( $\Delta -1.5 \pm 0.7$  kg) influenced by high levels of energy expenditure (ie,  $17.4 \pm 2.6$  MJ/d) during remote expeditionary hunting in Alaska. Despite negative energy balance, participants retained skeletal muscle. The purpose of this pilot study was to measure skeletal muscle protein synthesis and examine molecular markers of skeletal muscle protein metabolism under similar conditions of physical and nutrient stress.

**Methods**—The “virtual biopsy method” was used to evaluate integrated fractional synthetic rates (FSRs) of muscle protein from blood samples in 4 participants. Muscle biopsies were taken to measure molecular markers of muscle protein kinetics (ie, FSTL1, MEF2, MYOD1, B2M, and miR-1-3p, -206, -208b, 23a, and 499a) using real-time polymerase chain reaction.

**Results**—Our findings in 4 participants (2 females [28 and 62 y of age; 66.2 and 71.8 kg body weight; 25.5 and 26.7 kg/m<sup>2</sup> body mass index] and 2 males [47 and 56 y of age; 87.5 and 91.4 kg body weight; 26.1 and 28.3 kg/m<sup>2</sup> body mass index]) describe mean muscle FSRs of serum carbonic anhydrase (2.4%) and creatine kinase M-type (4.0%) and positive increments in molecular regulation.

**Conclusions**—Preservation of skeletal muscle under conditions of physical and nutrient stress seems to be supported by positive inflection of skeletal muscle FSR and molecular activation.

**Keywords:** musculoskeletal, physical activity, caloric balance, energy expenditure

## Introduction

Previous work has confirmed the preservation of skeletal muscle during sustained physical activity under conditions of negative energy balance.<sup>1,2</sup> The levels of energy expenditure and energy deficit during backcountry hunting in Alaska may provide a surrogate model for military training and/or operational scenarios where physiological resilience can be diminished.<sup>3</sup>

Corresponding author: Robert H Coker, PhD, Montana Center for Work Physiology and Exercise Metabolism, University of Montana, Missoula, MT; e-mail: [robert.coker@umontana.edu](mailto:robert.coker@umontana.edu).

Submitted for publication February 2023.

Accepted for publication May 2023.

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<https://doi.org/10.1016/j.wem.2023.05.003>

With respect to mission-centric objectives in a tactical environment, maintenance of skeletal muscle ensures adequate functional performance and reduces the risk of musculoskeletal injury.<sup>3</sup> Without the undue influence of confounding variables, such as extreme heat, sleep deprivation, and/or failure to meet minimal recommendations for protein intake,<sup>4</sup> it seems that muscle remodeling is sufficient even during moderate energy deficit, especially under conditions of movement constancy.

Whereas resistance training and positive caloric balance will likely result in increased muscle mass and/or absolute strength, essential amino acids and/or endurance training positively influence skeletal muscle synthesis.<sup>5</sup> Skeletal muscle microRNAs (myomiRNAs), such as miR-1, 23, 208, and 499, have been implicated in the “fine tuning” of muscle gene expression (ie, *FSTL1*, *MEF2C*, *MYOD1*, and *B2M*).<sup>6</sup> Laboratory-based studies

**Table 1.** Participant information and body composition

	Age (y)	Sex	Height (cm)	Body weight (kg)	Body mass index (kg/m <sup>2</sup> )	$\Delta$ Body weight	$\Delta$ Body mass index (kg/m <sup>2</sup> )
Participant 1	47	M	182.9	87.5	26.1	-0.5	+0.0
Participant 2	28	F	167.6	71.8	25.5	-2.5	-0.8
Participant 3	56	M	180.3	91.4	28.1	-3.1	-1.0
Participant 4	62	F	146.1	66.2	26.7	-2.6	-1.1
Mean $\pm$ SD	48 $\pm$ 15	-	170 $\pm$ 17	79.2 $\pm$ 12.1	26.6 $\pm$ 1.1	-2.1 $\pm$ 1.2	-0.8 $\pm$ 0.5

in this area of investigation have evaluated acute responses to dietary intake, physical activity, or preframe and postframe lifestyle interventions, but these approaches have important drawbacks that include assessments that fail to capture all aspects of the operational scenario. Therefore, the primary purpose of this pilot study was to measure integrated fractional synthetic rates (FSRs) of muscle protein using the virtual biopsy technique during the unscripted, demanding conditions previously described.<sup>7</sup>

## Methods

### STUDY DESIGN AND PARTICIPANTS

Healthy adults were recruited to participate in 2 separate excursions in the Brooks Range of northeastern Alaska (Table 1). All described methods and materials were approved by the Institutional Review Board of the University of Alaska Fairbanks (1102840-12). Each individual had independently secured the consulting services of Pristine Ventures, Inc (Fairbanks, AK). Each participant had backcountry hunting experience and was without any current history of metabolic, pulmonary, or heart diseases; cancer; or other chronic inflammatory condition.

### ALASKA BACKCOUNTRY EXPEDITIONARY HUNTING

Experienced backcountry clients received basic “hunt planner” information on preparation, harvest preservation, and load carriage. These instructions were delivered by Pristine Ventures, Inc (Fairbanks, AK), but the clients were not guided, in accordance with Alaska state law. Clients were then provided with an opportunity to become participants in our research study focused on an evaluation of muscle protein kinetics. Upon obtaining informed consent from these individuals, they were asked to complete a health history questionnaire as research participants. None of the participants were taking medications that would influence metabolism, and all were nonsmokers. None of the participants had been diagnosed

with or exhibited symptoms of neurological, cardiovascular, respiratory, or metabolic disease.

Remote air travel services in 2019 and 2020 were provided by Shadow Aviation (Fairbanks, AK). Participants were already committed to the expeditions, independent of their study participation. No attempts were made to provide shelter, control sleep, or manipulate dietary intake. Our previous work in this cohort described total energy expenditure of ~17 MJ/d, energy intake of ~8 MJ/d, and negative energy balance of ~10 MJ/d. These data indicate a sustained range of mild to intense physical activity.<sup>1,2</sup> Such conditions are consistent with a threshold of negative energy balance that may result in reduced physical performance.<sup>3</sup> The durations of the 2019 (ie, 13 d) and 2020 (ie, 8 d) excursions differed only due to the inextricable connection between bush plane travel and unpredictable weather in the Alaskan wilderness.

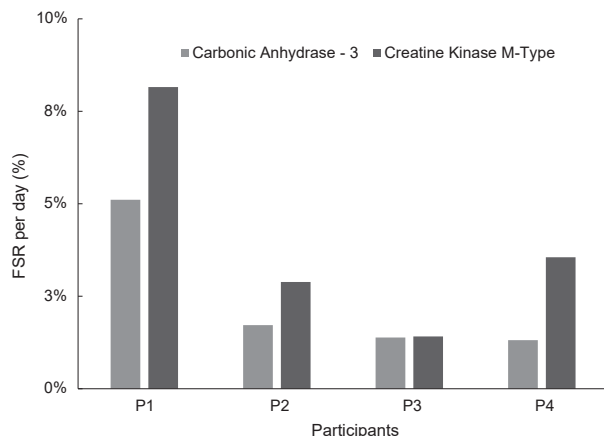
## Procedures

### BODY MASS AND BODY COMPOSITION

A Lunar iDXA scanner (General Electric Healthcare, Chicago, IL) was utilized to measure body composition <24 h before and after expedition. For all measurements taken, participants were provided identical surgical scrubs to wear during both exams.

### VIRTUAL BIOPSY: PROTOCOL AND ANALYSIS

To measure the synthesis of skeletal muscle proteins, we employed isotopic labeling of newly synthesized proteins via oral dosage of deuterated water (<sup>2</sup>H<sub>2</sub>O) (Figure 1). Participants were given 50 mL of 70% enriched <sup>2</sup>H<sub>2</sub>O (Cambridge Isotope Laboratories, Andover, MA) 3 times per day on day 1, 50 mL 2 times per day on days 2 and 3, and 30 mL 2 times per day for the remainder of the expedition. To measure background enrichment levels of total body water, participants were asked to collect saliva samples throughout the expedition. Blood samples were obtained within 72 h of return to determine the FSR of skeletal muscle protein. After collection and



**Figure 1.** Integrated measurement of muscle protein synthesis represented by carbonic anhydrase-3 and creatine kinase M-type FSRs in 4 research participants (ie, P1–P4). Twenty-six carbonic anhydrase-3 peptides and fifty-three creatine kinase M-type peptides were identified by liquid chromatography/tandem mass spectrometry analysis, and kinetic data only include peptides that passed analytic criteria. FSR, fractional synthetic rate.

centrifugation, samples were immediately stored at  $-80^{\circ}\text{C}$  until isotopic analysis.

Creatine kinase M-type (CK-M) and carbonic anhydrase-3 (CA-3) were immunoprecipitated from 1.0 to 1.5 mL of human serum, followed by in-solution digestion with trypsin for liquid chromatography–mass spectrometry analysis, as described previously.<sup>8</sup> Twenty-six CA-3 peptides and fifty-three CK-M peptides were identified by liquid chromatography with tandem mass spectrometry analysis. Kinetic data only include peptides that passed all analytical criteria, and muscle FSR was calculated as described previously.<sup>8</sup>

## MUSCLE BIOPSY AND ANALYSIS

For the purpose of examining molecular regulation, muscle biopsies were obtained from the vastus lateralis using sterile procedures and a local anesthetic (1% lidocaine) <24 h before and after expedition. Muscle tissues were immediately flash-frozen in liquid nitrogen and stored at  $-80^{\circ}\text{C}$  until subsequent analysis.

Total RNA, including small RNA, was isolated from muscle tissue with QIAGEN miRNeasy Tissue/Cells Advanced Mini Kit. Total RNA concentration was measured, and the quality of RNA was evaluated using a Qubit fluorometer, a NanoDrop spectrophotometer, and a Bioanalyzer automated electrophoresis system. Real-time polymerase chain reaction (PCR) was conducted to obtain expression values of *FSTL1*, *MEF2C*, *MYOD1*, and *B2M*. After validation of potential reference genes, *YWHA5* demonstrated stable expression. The reverse transcription was carried out with SuperScript IV VILO (SSIV VILO) Master Mix (ThermoFisher Scientific) in 20  $\mu\text{L}$  following the protocol. Real-time PCR was conducted in triplicates on an ABI-7900 HT using the TaqMan Fast Advanced Master Mix and Applied Biosystems TaqMan Gene Expression assays (ThermoFisher Scientific). Human skeletal muscle RNA was used as a positive control (ThermoFisher Scientific).

For quantification of mature myomiRNAs, copy DNA (cDNA) was generated with a TaqMan Advanced miRNA cDNA Synthesis Kit (ThermoFisher Scientific). Real-time PCR was conducted to obtain expression values of miR-1-3p, miR-206, miR-208b-3p, miR-23a-3p, and miR499a-5p in skeletal muscle using the TaqMan Fast Advanced Master Mix and Applied Biosystems TaqMan Advanced miRNA Assays (ThermoFisher Scientific). We chose miR-16-5p as a reference according to recommendations of ThermoFisher Scientific. Two preparation steps were performed before reverse transcription and the miR-Amp reaction: the poly(A) tailing reaction and the adaptor ligation. Synthesized cDNA from pooled RNA was 10-fold diluted 4 times and used for obtaining standard curves and calculating reaction efficiency. Gene and miRNA expression between before and after expedition was calculated with the Pfaffl method, which considers PCR efficiencies of target and reference genes. A fold change in level of expression of a target gene or miRNA relative to a reference gene or miRNA was calculated for each sample.

## STATISTICS

Data were analyzed using Microsoft Excel and General Electric iDXA and Prism software. Data are reported as mean $\pm$ SD.

**Table 2.** Changes in dual energy x-ray absorptiometry-derived measurements of lean tissue, fat mass, and percentage of fat mass

	Total (kg)	Arms (kg)	Legs (kg)	Trunk (kg)	Android (kg)	Gynoid (kg)
Lean tissue mass						
$\Delta$	+0.3 $\pm$ 1.0	+0.2 $\pm$ 0.1	-0.4 $\pm$ 0.7	1.5 $\pm$ 3.1	0.1 $\pm$ 0.2	0.3 $\pm$ 0.4
Fat mass						
$\Delta$	-1.6 $\pm$ 0.2	-0.1 $\pm$ 0.1	-0.4 $\pm$ 0.3	-1.1 $\pm$ 0.3	-0.2 $\pm$ 0.1	-0.2 $\pm$ 0.1

Data are presented as mean $\pm$ SD.

**Table 3.** Change in Skeletal Muscle MicroRNA

	Fold change
miR-1-3p	8.865
miR-206	4.793
miR-208b-3p	9.867
miR-23a-3p	24.357
miR499a-5p	4.242

**Table 4.** Change in muscle gene expression

	Fold change
<i>FSTL1</i>	3.255
<i>MEF2C</i>	1.014
<i>MYOD1</i>	1.290
<i>B2M</i>	-1.303

## Results

### CLINICAL CHARACTERISTICS AND BODY COMPOSITION

Four adults (2 females, 2 males; age = 48±11 y; body mass index = 25.1±0.69 kg/m<sup>2</sup>) were recruited for this study. Data are reported in Tables 1 and 2. There were absolute reductions in body weight, total fat, trunk fat, and android fat mass (Table 2). There were also absolute reductions in percent total arm, trunk, and android fat masses (Table 2).

### INTEGRATED FSR OF PROTEIN SYNTHESIS

CA-3-derived FSR ranged from 1.3 to 5.1% in participants 4 and 1, respectively (Figure 1). CK-M-derived FSR ranged from 1.4 to 8.2% in participants 3 and 1, respectively (Figure 1). Overall, CA-3-derived FSR and CK-M-derived FSR were 2.4±1.8% per day and 4.0±2.9% per day, respectively.

### MUSCLE GENE EXPRESSION AND MYOMIRNA

We evaluated changes in miR-1-3p, miR-206, miR-208b-3p, miR-23a-3p, and miR-499a-5p in skeletal muscle. Of these, there was a ~5-fold increment in miR-206 (Table 3). Potential alterations in muscle gene expression (ie, *FSTL1*, *MEF2C*, *MYOD1*, and *B2M*) were also examined. There was a ~3-fold increment in *FSTL1* (Table 4).

## Discussion

The primary objective of this pilot study was focused on the measurement of muscle protein FSR in humans using the virtual biopsy method during backcountry hunting in Alaska. The elevations in integrated muscle protein FSR exceed data reported in response to sprint interval training in young athletes.<sup>9</sup> Our data represent the first to employ the “virtual biopsy method” in a remote unsupported field setting, offering insight into the regulation of muscle metabolism under conditions of physical and nutrient stress.

The level of physical activity and negative energy balance previously reported under similar circumstances is similar to those in short-term military operations and/or training scenarios.<sup>1-3</sup> Hunters are focused on operational maneuverability and time constraints for insertion/extraction points that are ~160 km apart and in the context of a remote environment. These factors limit nutritional provisions and demand movement constancy. It is impossible to replicate these unpredictable conditions in a well-controlled laboratory setting. Despite the discrepancy between energy intake and energy expenditure under similar circumstances, lean tissue mass was maintained.<sup>1,2</sup> The unique constructs of this model then provides an opportunity to study alterations in muscle protein synthesis elicited by physical and nutrient stress.

Countless investigations have evaluated exercise-induced and/or dietary-induced alterations in muscle protein synthesis.<sup>4</sup> While informative, stable isotope strategies have primarily focused on acute responses to dietary intake in conjunction with functional overload, usually in the form of resistance exercise.<sup>10</sup> These studies have paralleled intense interest in strategies to promote muscle hypertrophy and/or sports performance. On the other hand, the metabolic intricacies of longer training and/or operational scenarios require a more comprehensive assessment of muscle protein synthesis to advance understanding of protein metabolism in the context of operational conditions. We observed higher integrated muscle protein synthesis in our middle-aged to older research participants than that reported in younger adults following 9 sessions of sprint interval training over a 3-wk period.<sup>9</sup> However, to inform strategies for future countermeasures, we recognize that CK-M FSR and CA-3 FSR primarily represent structural and cytosolic proteins and assert the need for an examination of specific alterations in muscle proteome dynamics.

We also conducted preliminary observations of myomiRs (ie, miR-1-3p, miR-206, miR-208b-3p, miR-23a-3p, and miR499a-5p) and *FSTL1*, *MEF2C*, *MYOD1*, and *B2M* in skeletal muscle, which have been implicated in the regulation of skeletal muscle plasticity.<sup>6</sup> While underpowered to evaluate significance, potential alterations in miR-206 and *FSTL1* inform the need for larger

investigations that connect molecular mechanisms to skeletal muscle resilience under the combined circumstances of chronic physical and nutrient stress.

## LIMITATIONS

We recognize that the small number of participants negatively affects the statistical power of this study and therefore limits the extrapolation of the data presented herein.

## Conclusions

Utilizing the virtual biopsy technique for the first time in a remote field setting, we report levels of skeletal muscle FSR during Alaska backcountry expeditionary hunting that exceeds that reported following sprint interval training during positive energy balance.<sup>9</sup> We also provided myomiRNA and anabolic gene expression data that support our data describing skeletal muscle FSR. Collectively, these data demonstrate the mechanisms that support muscle remodeling despite chronic physical stress and negative caloric balance.

**Acknowledgments:** We would like to express our sincere gratitude to our research participants and Andy Greenblatt of Shadow Aviation.

**Author Contributions:** study concept and design (RHC, BCR, LB, MS, MH, WJE); data acquisition (RHC, MSC, BK, AVG, TB, MS); data analysis (RHC, MSC, BK, AVG, TB, MS); drafting and critical revision of manuscript (RHC, BCR, MSC, AVG, MS, MH, WJE); all authors approved the final manuscript.

**Financial/Material Support:** This research was primarily supported by Pristine Ventures, Inc (Fairbanks, AK). This research was also supported in part by the National Institute of General Medical Sciences

of the National Institutes of Health under awards P20GM130443 (Center for Transformative Research in Metabolism) and P20GM103395 (Alaska IDeA Network of Biomedical Research Excellence).

Disclosures: None.

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## ORIGINAL RESEARCH

# Arterial Occlusion Effectiveness of Space Blanket–Improvised Tourniquets for the Remote Setting

Hannah Salchner, MD<sup>1,2</sup>; Markus Isser, SRN<sup>2</sup>; Lukas Banyai, MD<sup>1</sup>; Thomas Schachner, MD, MS<sup>3</sup>; Franz J. Wiedermann, MD<sup>1</sup>; Wolfgang Lederer, MD, MS<sup>1</sup>

<sup>1</sup>Department of Anesthesiology and Critical Care Medicine, Medical University of Innsbruck, Innsbruck, Austria; <sup>2</sup>Medical Division, Austrian Mountain Rescue Service–Tyrol, Telfs, Austria; <sup>3</sup>Department of Cardiac Surgery, Medical University of Innsbruck, Innsbruck, Austria

**Introduction**—Control of severe extremity hemorrhage by tourniquet can save lives. In remote areas or in mass casualty incidents with multiple severely bleeding victims, lack of conventional tourniquets may make it necessary to improvise tourniquets.

**Methods**—Occlusion of the radial artery and delayed onset of capillary refill time resulting from windlass-type tourniquets were experimentally investigated by comparing a commercial tourniquet and a space blanket–improvised tourniquet with a carabiner as a rod. This observational study was conducted on healthy volunteers in optimal application circumstances.

**Results**—Operator-applied Combat Application Tourniquets were deployed more swiftly (27 s, 95% CI: 25.7–30.2 vs 94 s, 95% CI: 81.7–114.4) and achieved 100% complete radial occlusion compared with improvised tourniquets, as assessed by Doppler sonography ( $P<0.001$ ). When space blanket–improvised tourniquets were used, traces of radial perfusion persisted in 48% of the applications. In Combat Application Tourniquets, capillary refill times were significantly delayed (7 s, 95% CI: 6.0–8.2 vs 5 s, 95% CI: 3.9–6.3) compared with those when using improvised tourniquets ( $P=0.013$ ).

**Conclusions**—Improvised tourniquets should be considered only in dire circumstances with uncontrolled extremity hemorrhage and when no commercial tourniquets are available. Complete arterial occlusion was achieved in only half of the applications using a space blanket–improvised tourniquet when a carabiner was used as a windlass rod. The speed of application was inferior to that for Combat Application Tourniquets. Similar to Combat Action Tourniquets, the correct assembly and application of space blanket–improvised tourniquets on upper and lower extremities have to be trained.

**Trial registration:** [ClinicalTrials.gov](https://clinicaltrials.gov) identifier: BASG No.: 13370800/15451670

**Keywords:** emergency medical services, hemorrhage control, rescue work, test, Stop the Bleed, tourniquet pain, wilderness medicine

## Introduction

Control of severe extremity hemorrhage by tourniquets (TQs) in patients with peripheral vascular injuries can prevent trauma deaths.<sup>1,2</sup> Commercial TQs have been found to effectively control extremity hemorrhage.<sup>3–5</sup>

Corresponding author: Wolfgang Lederer, MD, MS, Department of Anesthesiology and Critical Care Medicine, Medical University of Innsbruck, 6020 Innsbruck, Austria; e-mail: [wolfgang.lederer@i-med.ac.at](mailto:wolfgang.lederer@i-med.ac.at).

Submitted for publication September 2022.

Accepted for publication February 2023.

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<https://doi.org/10.1016/j.wem.2023.02.007>

Application of a TQ demands adequate tightness, proper placement technique, and correct positioning in order to exert sufficient vascular compression to control bleeding by completely stopping the blood flow in an extremity.<sup>3,5,6</sup> An improperly tightened TQ that occludes only the venous return can even increase blood loss.<sup>7</sup> Obstruction of only venous outflow increases the likelihood of developing compartment syndrome. Pain from both compression and ischemia is common with TQs, but the rate of lasting complications has been reported to be low.<sup>8</sup> Potential complications include nerve palsy, compartment syndrome, venous thromboembolic events, and posts ischemic reperfusion damage.<sup>5</sup> There are multiple commercially available TQs designed for bleeding control, such as windlass-type,

elastic-type, ratchet-type, and pneumatic-type TQs.<sup>2,4</sup> Originally adopted by the military, the windlass-type Combat Application Tourniquet (CAT) is now frequently used by first responders and emergency medical services.<sup>2,4,7,8</sup>

In an emergency setting where commercial devices are not available and prolonged direct pressure is not practicable, an improvised TQ (I-TQ) may be an effective bridge to definitive care.<sup>7,8</sup> Early hemorrhage control is crucial.<sup>9</sup> This particularly applies to severe hemorrhage in the wilderness setting under extreme environmental conditions when mountaineers have to rigorously stop bleeding until professional rescuers arrive on the scene.<sup>3</sup> For mass casualty incidents with multiple severely bleeding victims, even rescue personnel can quickly run out of commercial TQs.<sup>10,11</sup> When applied properly, I-TQs were reported to reliably stop severe extremity hemorrhage in prehospital emergency care.<sup>7,10</sup> Although the cloth and wooden dowel design achieved 42 to 100% success, an effective and safe I-TQ design has not yet been found.<sup>10</sup> To lay rescuers keeping an eye out for materials suitable for building an I-TQ, a space blanket (SB) may appear adequate at first glance. SBs are generally available as common components of the first aid equipment used in Europe in prehospital emergency medicine and outdoor sports as part of hypothermia prevention.<sup>12</sup>

In this experimental study, we aimed to investigate whether rescuers can apply an SB as an I-TQ to provide adequate vascular occlusion of the upper extremity. We compared the quality of radial occlusion achieved with an SB to that of a conventional CAT in a controlled environment.

## Methods

An experimental trial concerning rescuer application of an I-TQ compared with a commercial TQ was conducted with uninjured test subjects in the training rooms of Innsbruck Medical University Hospital. The target group of this study focused on mountaineers performing bystander hemorrhage control in the wilderness setting. All voluntary participants were recruited from Mountain Rescue Tyrol (MRT) Group Innsbruck. After announcing the study on social media, 25 eligible volunteers responded, 23 (17 male, 6 female) of whom participated (inclusion rate: 92%). Written informed consent was obtained from all subjects prior to the study investigation. Inclusion criteria were volunteers >18 and <80 y of age, in good general health. Exclusion criteria were missing informed consent, vascular comorbidities, pregnancy, and untimely dropout. Investigations were performed on

both upper arms consecutively with the sequence of TQs applied in random order (Figure 1). The study was approved by the institutional ethics committee (EK No.: 1039/2020) and registered (BASG No.: 13370800/15451670) with the Austrian Federal Office for Safety in Public Health Services (<https://www.basg.gv.at>). After approval and registration, the measurements were made under stationary conditions on a single day in October 2020. Data were collected on a work chart and transferred to electronic files for data processing. Reporting followed the CONSORT 2010 checklist of what information to include when reporting a randomized trial and the extension to randomized pilot and feasibility trials.<sup>13,14</sup>

Subjects were distributed randomly in a crossover trial to 2 study arms and allocated CAT and SB applications. All participants received the same 2 treatments in alternate order. Random assignment of upper limbs was achieved by rolling 2 dice (simple randomization) and predetermining even numbers for the right and uneven numbers for the left upper limb.<sup>15</sup> Sequence of participation depended on the sequence of arrival of participants.

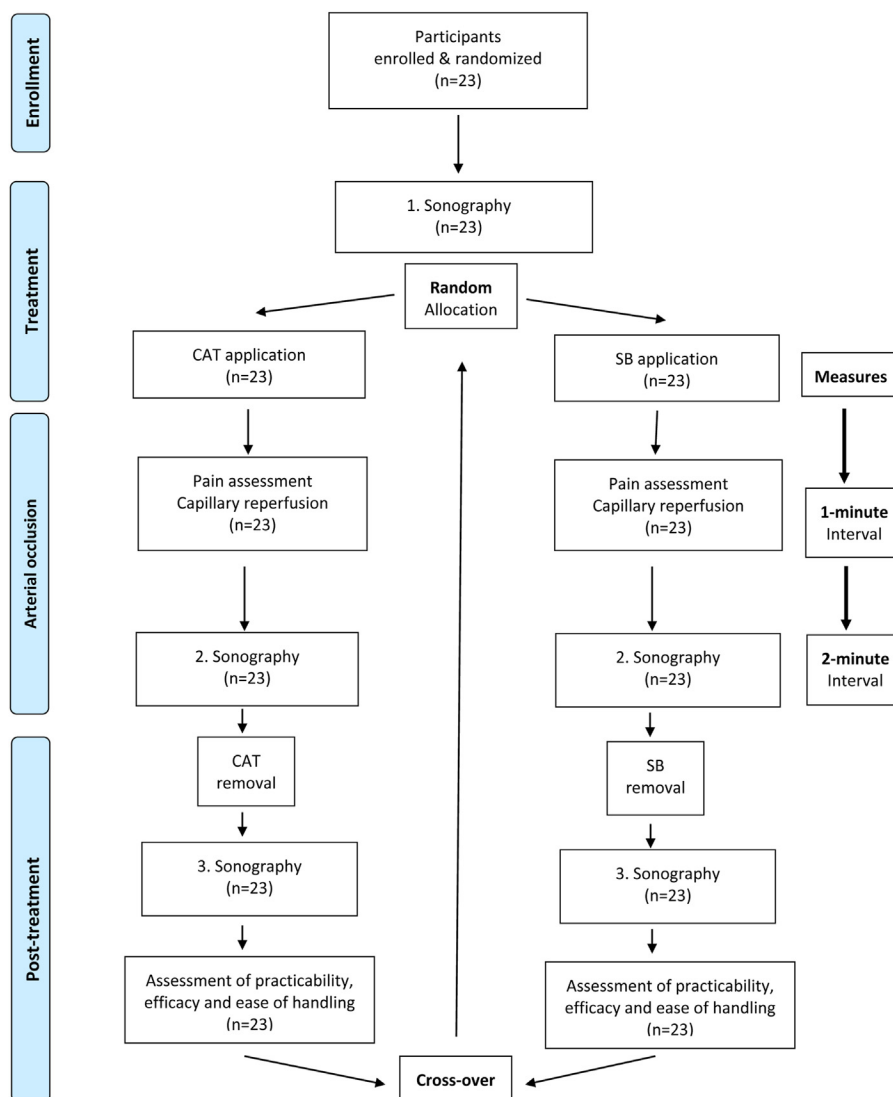
Focusing on bystander first aid in the out-of-hospital setting, the primary endpoint was assessment of the efficacy of bleeding control by the investigators using 2 assessment devices. The secondary endpoint was the operator's assessment of practicability, and the tertiary endpoint was his ease of handling. Outcomes were recorded immediately after each application. Data were previously evaluated as part of an academic thesis.<sup>16</sup>

## APPLICATION OF TEST DEVICES

This study was conducted by a single operator (M.I.; mountain rescuer) to avoid interoperator bias. The operator was experienced in applying commercial TQs during first aid training but was not familiar with I-TQs. All TQs and I-TQs were applied 2-handed by the operator to the upper extremity of a supine participant on the investigation table. The proximal edge of each device was located within 5 cm of the armpit, a distance that was measured and marked on the skin prior to investigation.

The CAT (Gen 7, Rock Hill, SC) was selected as a commercial TQ as used by MRT and Helicopter Emergency Medical Services (HEMS) in Austria. CAT-7 was one of the nonpneumatic TQs recommended in 2019 for tactical combat casualty care when evaluating the following criteria: arterial occlusion, TQ pressure, simplicity of application, TQ specifications, retention mechanism, complications, safety, usage reports, user preferences, and logistics.<sup>17</sup> The device was applied by inserting the patient's arm into the pre-arranged loop and pulling the end of the self-adhering





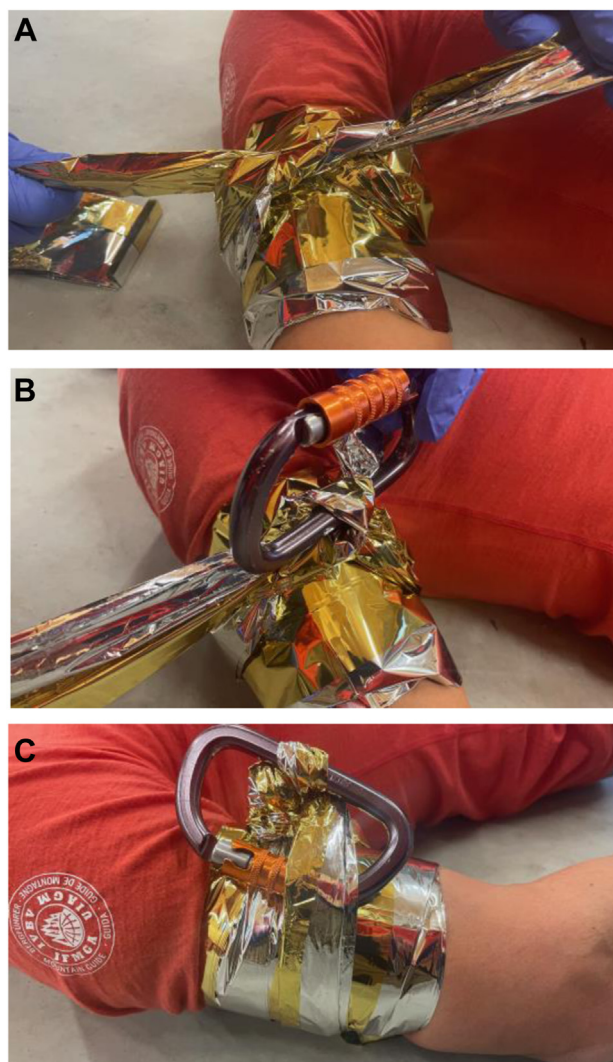
**Figure 1.** Trial design of the arterial occlusion effectiveness of a space blanket (SB)–improvised tourniquet compared with the Combat Application Tourniquet (CAT).

band tight and securing it back on itself. Then, the operator turned the windlass rod until loss of distal radial pulse was achieved. Finally, the twisted rod was locked in place with the clip and secured with the windlass strap.

One brand of SB (Rescue Blanket; Leina-Werke GmbH, Windeck, Germany)—used by MRT and HEMS in Austria—served as I-TQs. Blankets were selected for their general disposability and their confirmed high tear resistance.<sup>18</sup> The blankets, composed of a polyethylene terephthalate sheet coated with a thin aluminum layer, were 160 × 210 cm in size. In the original packaging, the blankets were laid in 23 layers (22 foldings) of 6.9 cm

width; in an unpacked and vertically aligned position, the segment fanned out to 7.8 cm in width.

The SB was routed twice around the upper arm using the single segment longitudinally unfolded. Then, the 2 ends of the SB were joined using a half-square knot (Figure 2a). Another half-square knot was made on top, and a carabiner (passO-SC, Skylotec GmbH, Neuwied, Germany) was inserted between the 2 knots (Figure 2b). This helped protect the skin from direct constriction and doubled the width on the opposite side of the torque. Torque was applied by twisting the carabiner until the radial pulse was eliminated. Then, the twisted carabiner was locked into position with one end of the SB and



**Figure 2.** Application of a space blanket-improvised tourniquet to the left upper arm with the participant supine using a carabiner as a provisional windlass rod. a, A blanket was routed around the upper arm twice, then the 2 ends were joined with a half-square knot. b, A second half-square knot was tied above the first; then, a carabiner was inserted between the knots and turned to apply torque until radial pulse elimination. c. Finally, the twisted carabiner was locked into position with one end of the SB and secured to the other end on the opposite side with another 2 to 3 knots.

secured to the other end on the opposite side with another 2 to 3 knots (Figure 2c).

## INVESTIGATIONS AND MEASUREMENTS

To diminish interobserver bias, measurements were made by Investigator 1 (T.S., cardiac surgeon), assigned to objective assessment using Doppler sonography, and by Investigator 2 (H.S., anesthetist) for assessment of capillary refill times and for recording subjective

assessments made by the operator and participants using a questionnaire.

Vascular compression was verified using a portable Doppler sonography device (Huntleigh Dopplex D900, Huntleigh Healthcare Ltd, Diagnostic Products Division, Cardiff, Wales, UK) using a 10-MHz probe. In addition, pressure under the TQs was measured using a slightly inflated neonate blood pressure cuff connected via a rubber tube to a manometer (roid I, bosco, CE 0124, Bosch + Sohn GmbH u. Co KG, Jungingen, Germany) for blood pressure measurement. Participants underwent 3 sonographic examinations (the first examination immediately before applying the TQ, the second examination 2 min after obstructing circulation, and the third examination after removing the TQ).

Objective assessment of efficacy was based on results obtained from radial blood flow with Doppler sonography by Investigator 1, 2 min after vascular compression (no flow: missing signal; low flow: trace signal; regular flow: full signal). Capillary refill time was assessed 1 min after vascular compression by Investigator 2. Maintenance of TQ pressure and associated ischemia was restricted to 2 min.

Subjective assessment of efficacy by Investigator 2 was based on results of a capillary refill under the nail of the index finger. Refill time was defined as the time taken for the capillary bed to regain its color after short pressure has been applied to cause blanching.<sup>19</sup> The operator's subjective assessment of practicability and efficacy and ease of handling were categorized by Investigator 2 on a 5-item Likert-type scale using scores between 0 and 10 (1–2=very good, 3–4=good, 5–6=satisfactory, 7–8=moderate, 9–10=inadequate) and a hardcopy questionnaire. At 1 min after application of either the SB or the CAT, participants were asked to define the maximum intensity of pain using numerical rating scores between 0 and 10 (0=none, 5=medium, 10=most severe). In addition, Investigator 2 recorded participant feedback regarding paresthesia and quality and intensity of pain. Application time defined the interval from the beginning of device application until elimination of palpated pulse after having secured either the windlass rod or the carabiner. Sufficient vascular occlusion pressure was assumed when no radial pulse was detected and confirmed by Doppler sonography. Occluding time, the time taken to stop perfusion, was defined as the interval from beginning of twisting the commercial windlass rod or the carabiner until elimination of the pulse.

## STATISTICAL ANALYSIS

In a subjective assessment of efficacy, the estimated sample size was 14 participants to achieve a power of

80% and a level of significance of 5% (2-sided) to detect a true difference in means of 3 points between I-TQ applications and TQ applications. The quotient mean divided by standard deviation equals effect size=1.5. There was no supporting evidence from previous literature for this assumption. Descriptive statistics were applied using the statistical package for the social sciences from International Business Machines Corporation (IBM SPSS Statistics Standard 26, Armonk, NY) to determine measures of central tendency (median) and measures of dispersion (range, SD, variance, minimum and maximum). The null hypothesis to be tested was that there is no difference between SB and TQ regarding the efficacy of bleeding control. The alternative hypotheses were that there are differences between SB and TQ regarding practicability and ease of handling.

A nonparametric test (Wilcoxon Mann-Whitney *U* test) was used for comparison of ordinal data after Kruskal-Wallis analysis of variance. The association between sonographic findings (objective) and radial pulse taken by the operator (subjective) was expected to be statistically significant when using the  $\chi^2$  test of independence.

## Results

The median age of the 23 participants was 40 (range 20–55) y. There were no losses or exclusions after randomization. A total of 46 applications to the right and the left upper arm were performed with 2 randomly assigned devices. Prior to the investigations, median systolic blood pressure was 133 (range 100–150) mm

Hg, median diastolic blood pressure was 72 (range 50–80) mm Hg, and median pulse rate was 68 (range: 50–100) beats·min<sup>-1</sup>. Baseline values and upper arm circumference were comparable between the 2 groups.

Median application time and median choking time were shorter for the CAT (27 s, 95% CI: 25.7–30.2 vs 94 s, 95% CI: 81.7–114.4;  $P<0.001$ ) (Table 1). Most delays in SB application resulted from the time needed to secure the carabiner in position to maintain the constricting force. For the CAT, securing the windlass rod in position took a few seconds. Three windlass rod turns were sufficient in most applications.

Peak pressure under the TQs during adjustment of the SB and the CAT in 8 measurements exceeded 300 mm Hg for both devices. Peak occlusion pressure after 1 min exceeded 300 mm Hg for the CAT and 180 mm Hg for the SB. Complete radial compression 2 min after application of the device was confirmed by the absence of flow in Doppler sonography in 23 (100%) CAT applications and in 12 (52%) SB applications ( $P=0.005$ ). Persistent low flow (traces) was detected in 11 (48%) SB applications. Accordingly, the delay of capillary refill time after 1 min differed between the 2 groups (5 s, 95% CI: 3.9–6.3 vs 7 s, 95% CI: 6.0–8.2;  $P=0.013$ ) (Table 1). When Investigator 1 performed the second sonographic evaluation 2 min after SB application, he observed that as little as an additional quarter to half turn of the carabiner would have been sufficient to achieve arterial occlusion in 4 of the 11 applications with persistent low flow perfusion.

Subjective assessment of practicability, ease of handling, and efficacy scored better marks for the CAT than for the SB (Table 2). Pain intensity 1 min after

**Table 1.** Survey results regarding application time, occlusion time, pain intensity under the device and paresthesia in the upper arm, and efficacy according to sonographic results from radial Doppler (Investigator 1) and capillary refill time 1 min after vascular compression (Investigator 2) with the Combat Application Tourniquet (CAT) and with space blankets (SBs) serving as improvised tourniquets.

<i>Characteristics</i>	<i>CAT</i> ( <i>n</i> =23)	<i>SB</i> ( <i>n</i> =23)	<i>P value</i>
Application time (s)	27	4	<0.001
95% Confidence interval	25.7–30.2	81.7–114.4	
Occlusion time (s)	15	68	<0.001
95% CI	13.5–17.4	59.5–92.4	
Pain intensity (median; range)	4 (2–6)	2 (1–5)	<0.001
Paresthesia (N; %)	13 (57)	19 (83)	<0.001
Radial perfusion sonography (%)			
No flow	100	52	0.005
Low flow	0	48	0.005
Regular flow	0	0	1.000
Capillary refill time (s)	7	5	0.013
95% CI	6.0–8.2	3.9–6.3	

**Table 2.** Survey results regarding ease of handling and practicability (operator) and efficacy (Investigator 2) in 23 measurements when using the Combat Application Tourniquet (CAT) and in 23 measurements when using a space blanket (SB) as an improvised tourniquet

Characteristics	CAT	SB	P value
	(n=23)	(n=23)	
<b>Operator</b>			
Ease of handling (median)	1	3	<0.001
Range (1-10)	1-3	2-7	
Practicability (median)	1	3	<0.001
Range (1-10)	1-2	1-7	
<b>Investigator-2</b>			
Efficacy (median)	1	2	0.014
Range (1-10)	1-2	1-9	

application was significantly lower for the SB and was more frequently observed as pinching, whereas pain intensity from CAT application was higher and more frequently defined as having a cutting quality (Table 1). No severe adverse reactions were observed during the study. Scratches, superficial abrasions, and small skin bruises were observed with both devices. All participants regained normal radial artery perfusion at device removal.

## Discussion

This experimental study compared differences in arterial occlusion between CAT and SB application. The aluminum-coated SB is used for hypothermia prevention in prehospital emergency medicine.<sup>12,20</sup> Although the tool cannot actively rewarm a hypothermia victim, it can at least slow down heat loss from thermoradiation and thermoconvection.<sup>21</sup> In this study, an SB applied as an I-TQ proved to be tear resistant and achieved adequate vascular occlusion pressure for hemorrhage control in half of the cases. However, the difficulty, as presumably for most I-TQs, was the provisional windlass rod and its fixation. Rohrich et al<sup>8</sup> reported that a properly constructed I-TQ can be highly effective when 3 components are provided: a strap, a rod, and a securing mechanism. As our study was tailored to mountain rescue missions, a carabiner was used as a provisional windlass rod. It was secured in position, with the 2 ends of the blanket variously arranged and joined with additional knots. A single half-square knot to join the 2 ends of the SB and insertion of the carabiner underneath would have been adequate. We presume that a small stick or a pair of scissors might have provided more efficient torque and could have been more easily secured in position than a carabiner. Kragh

et al<sup>22</sup> investigated 3 types of provisional windlass rods and found that a pair of chopsticks worked better than pencils or craft sticks. Cremonini et al<sup>7</sup> observed in an experimental study that a standard leather belt was the fastest to place and was able to effectively stop the bleeding when continuous pressure was maintained. An improvised triangle bandage in windlass design was as effective as the commercial devices and was the easiest to apply.

Wood et al<sup>23</sup> observed in volunteers that loss of distal radial pulse does not indicate a lack of arterial flow distal to upper extremity TQ. On average, an additional one-quarter windlass turn was required to eliminate distal flow. In our study, persistent low flow perfusion was detected in 48% of SB applications. As little as an additional one-quarter to one-half rotation would have been sufficient to completely stop circulation in 4 out of 11 applications. It remains a matter of debate whether the decline in blood pressure can increase the success rate in hypovolemic individuals. Then again, pain may have increased the observed failure rate in normovolemic volunteers. However, neither anticipated pain nor skin lesions from TQ application cast doubt on the importance of hemorrhage control by vascular occlusion.

The Hartford consensus proposed hemorrhage control for approaching mass shooting events, which led to implementation of the nationwide hemorrhage control training course "Stop the Bleed" from the American College of Surgeons Committee on Trauma.<sup>9,24</sup> This campaign focuses on laypersons to perform hemorrhage control for extremity injuries. However, the principles for correct TQ application are not fully translatable to different commercial or I-TQ types.<sup>24</sup> Laypersons trained on a specific brand may not be prepared to care for bleeding patients with an unfamiliar type of TQ at hand.<sup>24,25</sup> When an untrained layperson is handed a commonly accepted TQ, failure is unacceptably high.<sup>25,26</sup> A pilot study by Ross et al<sup>26</sup> on the intuitive nature of applying commercially available TQs found unacceptably high rates of failure. Even TQ training may result in poor skill retention and application of various TQs when inefficiencies arise from limited exposure time. Only 6 of 10 trainees succeeded in placing a TQ 30 days after the course.<sup>27</sup> Similar to commercial TQs, the application of I-TQs has to be trained. McCarty et al<sup>24</sup> reported that even laypersons with training in hemorrhage control achieved 92.2% correct application with the CAT but only 32.4% correct application when applying an I-TQ. Ross et al<sup>26</sup> observed CAT application failure in 82.9% of untrained laypersons, with inadequate tightness (74.1%), improper placement technique (44.4%), and incorrect positioning (16.7%) as the most common causes. Effective use of TQs as first aid needs regular training.<sup>6,28</sup>

Regarding application time, application of the conventional CAT was performed very fast.<sup>3,9,24</sup> SB applications required more time than CAT applications but were still within the range of simulation studies using the CAT.<sup>25,29</sup> This is of particular importance as the time required for a single rescuer to build an I-TQ might interrupt the exertion of direct pressure on the patient's bleeding site. Compared with the CAT, application of the SB was associated with less pain because of lower tissue compression. We assume that the broader width of the SB compared with that of the CAT allowed lower vascular occlusion pressures.<sup>7,30</sup> In our study, the peak occlusion pressure after 1 min exceeded 300 mm Hg in the CAT and 180 mm Hg in the SB. This agrees with reported CAT pressures of 250 to 428 mm Hg in normotensive adults.<sup>30</sup> We are aware that with increasing blood pressure, eg, from pain, TQs might become inadequate. However, hypotension from hypovolemia might increase the quality of vascular compression.

## LIMITATIONS

There are several limitations that might have influenced interpretation of the findings. The members of the study population were all members of a mountain rescue unit. Most of the participants were young males. We did not analyze what made contacts choose not to participate in this clinical trial. In this experimental study, we compared 2 devices applied by a single operator in a homogeneous sample of healthy participants with limited representativeness and generalizability.<sup>31</sup> It was not our intention to evaluate interuser variability. The operator and investigators in this study were experienced in medical care, teaching, and research but had only limited experience in out-of-hospital hemorrhage control with TQs. We investigated buddy-aid but did not investigate the TQ self-aid that is part of tactical combat casualty care.<sup>6</sup> We are aware that application of TQs under stress in field conditions may be more frequently unsuccessful.<sup>24,26,28</sup> Furthermore, the results of our experimental investigation in voluntary participants and our conclusions do not permit generalization to all bleeding emergencies in the prehospital setting. At the end of the investigation, there was a training effect of the single operator that was observed in shorter application times for the CAT and a fatigue effect seen in longer application times for the SB. Preinvestigation training of CAT and SB applications might have diminished the learning effect. We are aware that the order of response options in psychometric tests may influence the preference of items. The descending ordered scales, as used in this study, may be associated with more positive responses.<sup>32</sup>

While the sonographic investigation may be regarded as an objective measurement, participants' comments, as well as judgments made by the operator and the investigators, are subjective in nature. This particularly applies to the assessment of practicability and ease of handling. The SB cannot be generalized for all I-TQs, and in this study, the SB was compared with only 1 commercial brand. We cannot tell whether the SB is similarly applicable when used as a lower extremity TQ. Furthermore, the excellent CAT application times in our study are not representative of application times for less experienced rescue personnel working in real emergencies.<sup>15,30</sup>

## Conclusions

I-TQs should be considered only in dire circumstances with uncontrolled extremity hemorrhage and when no commercial TQs are available. Complete arterial occlusion was achieved in only half of the applications using an SB-I-TQ when a carabiner was used as a windlass rod. The speed of application was inferior to that for the CAT. Similar to those required for CATs, the correct assembly and application of SB-I-TQs on upper and lower extremities have to be trained.

**Acknowledgment:** The authors thank Sabine Embacher, M.A., for scientific monitoring and advice.

**Author Contributions:** study concept (MI, WL); study design, protocol and oversight (MI, WL); acquisition of data (HS, MI, TS, WL); analysis of data (LB, FJW); drafting of the manuscript (HS, LB, MI, TS, WL); critical revision of the manuscript (HS, MI, TS, FJW, WL); approval of the final manuscript (HS, MI, TS, LB, FJW, WL).

**Financial/Material Support:** No funding is declared for this manuscript except for the purchase of survival blankets and tourniquets, which was covered by institutional funding.

**Disclosures:** Data were previously evaluated as part of the academic thesis written by Lukas Banyai, published in the German language and kept in 4 copies at the library of the Medical University of Innsbruck.<sup>16</sup> The other authors report no conflicts.

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## ORIGINAL RESEARCH

# Functional and Sport-Specific Outcome Following Traumatic First-Time Shoulder Dislocation and Arthroscopic Surgical Repair in Rock Climbers

Michael Simon, MD<sup>1</sup>; Leonid Geffel, MD<sup>2</sup>; Christoph Lutter, MD, PhD, MSc, MHBA<sup>3</sup>; Volker Schöffl, MD, PhD, MHBA<sup>1,2,4,5</sup>

<sup>1</sup>Department of Trauma and Orthopedic Surgery, Friedrich Alexander University Erlangen-Nuremberg, Erlangen, Germany; <sup>2</sup>Department of Orthopedics and Traumatology, Sozialstiftung Bamberg, Bamberg, Germany; <sup>3</sup>Department of Orthopedics, University Medical Center Rostock, Rostock, Germany; <sup>4</sup>School of Clinical and Applied Sciences, Leeds Beckett University, Leeds, United Kingdom; <sup>5</sup>Section Wilderness Medicine, Department of Emergency Medicine, School of Medicine, University of Colorado, Denver, CO

**Introduction**—Traumatic shoulder dislocations rank among the most common shoulder injuries in climbers, with rising numbers over the last years. The objective of this study was to analyze the outcome following traumatic first-time shoulder dislocation and subsequent surgical treatment in this population.

**Methods**—In a retrospective study, climbers who experienced a traumatic shoulder dislocation were treated with an arthroscopic repair of the labrum-ligament complex (LLC). The functional outcome was assessed with a standardized questionnaire and clinical examination, including the Constant Murley and Single Assessment Numeric Evaluation scores. The sport-specific outcome was analyzed using the Union Internationale des Associations d'Alpinisme (UIAA) scale of difficulty and a sport-specific outcome score.

**Results**—The functional and sport-specific outcome for 27 climbers (20 men; 7 women; 3 with bilateral injuries; age, 34±11 [17–61] y; data presented as mean±SD [range]) was assessed 53±29 (12–103) mo after surgery. The postoperative Constant Murley score was 95±8 (67–100) points. At follow-up, 93% (n=25) of patients had started climbing again. Twenty-one climbers (78%) reached a climbing level within the range of ±0.33 UIAA grades of their initial capability or even exceeded their preinjury grade. Only 7% (n=2) of the patients had a recurrent shoulder dislocation, leading to a secondary surgery, and, therefore, required ongoing postoperative treatment at the time of follow-up.

**Conclusions**—Arthroscopic repair of the LLC following first-time traumatic shoulder dislocation in climbers shows a good outcome and a low recurrence rate. After surgery, most patients are able to regain a high level of rock-climbing ability.

**Keywords:** sports injuries, labrum-ligament complex repair, Bankart lesion, shoulder surgery

## Introduction

Traumatic shoulder dislocations rank among the most common shoulder injuries in climbers, with rising numbers over the last years.<sup>1</sup> A comparison of the incidence of shoulder dislocations in rock climbers in 2 time frames (2009–2012, n=157; and 2017–2018, n=154)

Corresponding author: Michael Simon, MD, Universitätsklinikum Erlangen, Erlangen, Germany; e-mail: [info@michaelsimon.org](mailto:info@michaelsimon.org).

Submitted for publication January 2022.

Accepted for publication May 2023.

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<https://doi.org/10.1016/j.wem.2023.05.001>

revealed an increase from 10% to 18% (percent of total injuries reported), making shoulder dislocations the third most common pathology of the shoulder in climbers after superior labrum anterior posterior (SLAP) lesions (30%) and impingement pathologies (27%).<sup>2</sup> Due to the trauma, the labrum-ligament complex (LLC), rotator cuff, humeral head (eg, Hill-Sachs lesion), and glenoid (Bankart fracture) are especially prone to damage. As insufficient treatment of a first-time traumatic shoulder dislocation often leads to chronic instability with recurrent shoulder dislocations, thus promoting the development of bone loss and osteoarthritis, targeted therapy based on a thorough evaluation of the injury is very important.<sup>3–7</sup>

Athletes—especially contact, collision, and overhead athletes, such as climbers—are an at-risk population for anterior glenohumeral instability, which is most often due to tear and dislocation of the LLC.<sup>8</sup> For this reason, for most first-time labral lesions and/or bony injuries, immediate surgical therapy is considered the therapy of choice, especially for young, active patients and athletes because of their increased risk of redislocation.<sup>4,9-11</sup> In fact, age under 30 y and active lifestyle make shoulder redislocation following conservative therapy far more likely; in contrast, the severity of the injury only seems to have a slight effect on the recurrence rate.<sup>4,8,12</sup>

Depending on the extent of the pathology and associated injuries, various surgical techniques can be used to repair the LLC, such as open or arthroscopic Bankart repair or the Latarjet procedure.

Recent studies that compared the recurrence rate for shoulder dislocation between patients who had been treated conservatively (recurrence rates, 62–70%) and patients who underwent surgical therapy (open or arthroscopic Bankart repair; recurrence rates, 9–14%) following first-time traumatic shoulder dislocation highlighted the role of surgical therapy.<sup>8,12</sup> A study including 65 patients showed a significant long-term benefit in overall shoulder stability and functional outcome for first-time anterior dislocation, comparing patients who had received an arthroscopic washout to those who received an arthroscopic Bankart repair. The rate of recurrent dislocation was significantly higher in the arthroscopic washout group than in the arthroscopic Bankart repair group (47% and 12%, respectively).<sup>9</sup>

For contact and collision athletes, studies highlighted a trend toward decreased recurrence rates using open Bankart repair compared to those using arthroscopic procedures.<sup>13-17</sup> These types of surgeries (open osseous augmentation procedures) are also reliable therapy options and should be used for athletes with glenoid bone loss of >20% to 25%, which can be measured best using computed tomography scans.<sup>8</sup> Recent literature, furthermore, suggests promising results with all-arthroscopic bony procedures such as the Latarjet procedure.<sup>18</sup>

Considering the functional and sport-specific outcome following a traumatic shoulder dislocation, all of the above-mentioned studies have been performed especially for collision and contact sports such as rugby or football, while there is still little knowledge about the outcome for noncontact overhead athletes such as rock climbers.

Rock climbers in particular rely on a stable glenohumeral joint in order to achieve their sport-specific goals. During climbing, complex overhead movements with a wide range of motion are performed while significant forces act on the shoulder. Thus, a high level of

function is mandatory. Still, to the best of our knowledge, there are no data on the postoperative functional (ie, general recovery of the shoulder required for daily activities) and sport-specific (ie, recovery of rock-climbing ability) outcome after surgical treatment of a traumatic first-time shoulder dislocation in rock climbers.

The purpose of this study was to analyze the general and sport-specific outcome following traumatic first-time shoulder dislocation and subsequent arthroscopic refixation of the LLC in rock climbers.

## Methods

The study was approved by the institutional ethics board of the Friedrich Alexander University Erlangen-Nürnberg. All patients gave their informed consent in written form for evaluation and use of anonymized data. Inclusion criteria were active rock climber (climbing at least once a week before the respective trauma), traumatic first-time anterior-inferior dislocation of the shoulder (not necessarily caused by rock climbing), or surgical repair (refixation of the LLC with FASTak suture anchors) performed at our department between 2009 and 2018.

All surgeries were performed by the same experienced shoulder surgeon (VS) in the beach-chair position. The LLC was reconstructed arthroscopically by 1-3 FASTak suture anchors (Arthrex, Naples, FL) depending on the degree of injury. If necessary, associated injuries that were detected in the course of diagnostics (physical examination, magnetic resonance imaging, diagnostic arthroscopy as part of LLC refixation) were simultaneously addressed.

For follow-up, we performed a clinical examination, including inspection and palpation, as well as tests for range of motion, muscle strength, and neurologic outcome. All follow-up examinations were performed by the same physician (LG). For outcome measurement, the Constant Murley score,<sup>19</sup> one of the most commonly used shoulder scores, was used to determine the general function of the shoulder. On a scale of 1 to 100, it combines the results of a questionnaire and physical examination assessing pain, activities of daily living, movement, and strength.

In addition to this examination, all patients completed a standardized questionnaire. The questionnaire included items relating to patient history, injury mechanism, activities of daily life, pain, profession, and expectations with regard to the surgery. We augmented the questionnaire with measurements of subjective postoperative satisfaction and subjective sport-specific outcome. For satisfaction, the Single Assessment Numeric Evaluation (SANE) score was used, wherein patients rated the



**Table 1.** Sport-specific outcome score after climbing injuries<sup>25</sup>

Grade	Outcome	Climbing capacity
V	Excellent	Full load capacity of the former injured joint/limb after 12 mo, no subjective strength deficit, regain of full climbing ability/preinjury climbing level, no pain
IV	Good	Full load capacity of the former injured joint/limb after 12 mo, subjectively minor strength deficit, regain of full climbing ability/preinjury climbing level, minor pain
III	Satisfactory	Minor restricted load capacity of the former injured joint/limb, subjectively major strength deficit of the former injured joint, regain of full climbing ability/preinjury UIAA climbing level minus 1 UIAA grade, minor pain
II	Fair	Major restricted load capacity of the former joint/limb, strength deficit and restricted ability to use the former injured joint while climbing, major decrease in climbing ability and grade, frequent pain
I	Poor	Climbing not possible anymore

UIAA, Union Internationale des Associations d'Alpinisme.

general function of their shoulder between 0% (no function for everyday activities) and 100% (nonimpaired function).<sup>20</sup> For sport-specific outcome, we queried patients' subjective evaluation of their climbing capacity on an ordinal scale from I (poor) to V (excellent) (Table 1).<sup>21</sup>

To objectively analyze the climbing capacity after return to sport, we also calculated the mean climbing level according to the Union Internationale des Associations d'Alpinisme (UIAA) scale of difficulty,<sup>22,23</sup> of the 3 hardest routes climbed in redpoint style within the last year before re-evaluation (ascertained by recall). Redpoint style in this context means to climb a route from the ground to the top in 1 go without falling or even resting on the rope. This level was then compared to the mean level of the 3 hardest redpoint climbs within the last year before the injury. The ability to climb at the same UIAA level<sup>22</sup>  $\pm 0.33$  in redpoint style, in comparison to the hardest preinjury redpoint climbs, was defined as "pre-operative climbing level regained."

Data are presented as mean $\pm$ SD (range) throughout the manuscript.

## Results

We identified 27 climbers (20 men; 7 women; 3 climbers with bilateral injuries; age, 34 $\pm$ 11 [17–61] y) who

**Table 2.** Characteristics of the study collective, N=27 (3 patients with bilateral shoulder dislocation)

Characteristics	n
Sex	
Male	20
Female	7
Side	
Right	18
Left	12
Etiology of anterior-inferior traumatic shoulder dislocation	
Climbing accident	23
Skiing accident	3
Skydiving accident	1
Cycling accident	3
Follow-up time (mo), mean $\pm$ SD (range)	53 $\pm$ 29 (12–103)

experienced a traumatic shoulder dislocation and were treated with arthroscopic repair of the LLC. The overall characteristics of our study collective are summarized in Table 2. In addition to the pathology of the LLC, 63% of our patients (n=17; 2 patients with involvement of both shoulders) presented with associated shoulder pathologies at the time of surgical therapy. If appropriate, these were addressed during surgery. For example, in 11 out of 17 patients with additional SLAP lesions, mini-open biceps tendon tenodesis was performed.<sup>24,25</sup> Furthermore, in 1 patient, a dislocated fracture of the tuberculum majus was addressed with open reduction and internal fixation using a specialized plate and screws (Figure 1).<sup>26</sup> Table 3 depicts all associated shoulder injuries besides the pathologies of the LLC and information on the additional operative treatment.

After surgery, each patient received a personalized follow-up treatment, typically starting with passive mobilization (associated injuries permitting, as early as third postoperative day) and later permitting general sport-related activities (12 wk after surgery), gradual resumption of rock climbing (16 wk after surgery), and, finally, full sport-specific exertion (6 mo after surgery). The detailed rehabilitation protocol following isolated injuries of the LLC that we have used is presented in Table 4. It is based on the recommendations of the current literature<sup>27</sup> and augmented by the authors' experience regarding the specific characteristics of and requirements for rock climbing.

The follow-up examination was then performed at least 12 (53 $\pm$ 29 [12–103]) mo after surgery. In case of revision surgery, follow-up was performed at least 12 mo after the second surgery.

Regarding the general outcome, the mean Constant Murley score was 95 $\pm$ 8 (67–100) points (n=30 shoulders



**Figure 1.** Postoperative x-ray imaging following open reduction and internal fixation of a dislocated tuberculum majus fracture using a specialized “Bamberg” plate and screws.

and  $n=27$  patients). Ninety-two percent ( $n=25$ ) of the patients were satisfied with the postoperative outcome (100% SANE score for everyday activities) and stated that they would choose to undergo the procedure again. Two patients reported persisting complaints in everyday life, stating a SANE score of 80% and 65%, respectively. In all patients with bilateral injuries, we found no difference considering the outcome scores between the 2 shoulders.

Two patients (7%) had a renewed shoulder dislocation. While 1 experienced a new significant trauma, the other patient's shoulder dislocation happened as part of an overhead workout during outpatient rehabilitation 2 months following surgery. These 2 patients had to undergo revision surgery after magnetic resonance re-imaging showed renewed damage to the LLC and, in 1 case, also to the glenoid, with bone loss. The patient who had a bony injury of the glenoid was treated with an arthroscopic assisted mini-open Latarjet procedure,<sup>28</sup> and the other patient was again treated arthroscopically with LLC repair using FASTak suture anchors.

Furthermore, 1 patient developed a secondary adhesive capsulitis, leading to temporarily restricted mobility and pain, which was successfully treated conservatively with physiotherapy.

Regarding the sport-specific outcome, at the time of follow-up, 93% ( $n=25$ ) of our patients had resumed

climbing on a regular basis, at least once a week. The 2 patients with a recurrent dislocation were both already climbing again. Furthermore, 2 patients had not started climbing again. One of those patients stated that family responsibilities were the cause, while he was 100% (SANE score) satisfied with the postoperative outcome and displayed a Constant Murley score of 100. Thus, he was excluded from the following evaluation of the sport-specific outcome. The second patient reported that he was not able to climb because of persistent complaints in his shoulder. While this was reflected in his Constant Murley score of 71, he was still subjectively satisfied with the outcome and reported a SANE score of 95%.

For those patients who had resumed climbing, the mean postsurgery UIAA climbing level had not changed in comparison to the preinjury climbing level ( $9\pm 3$  UIAA grades), while the range had changed from 6.33 to 11 to 4.33 to 11. Specifically, at the time of re-evaluation, 68% ( $n=17$ ) of the patients had regained their initial climbing level, as objectively measured using the UIAA scale, 16% ( $n=4$ ) had not, and 16% ( $n=4$ ) exceeded their initial level (Figure 2).

With regard to the overall sample, 78% (21 of 27 climbers) of patients had returned to the sport at the preinjury level of climbing or even exceeded their preinjury level.

**Table 3.** Associated shoulder injuries besides pathologies of the labrum-ligament complex and their additional treatment

Associated shoulder injuries	n	Additional treatment
Subacromial impingement syndrome <sup>a</sup>	6	Arthroscopic subacromial decompression
Subscapularis muscle tendon rupture	2	Arthroscopic refixation with suture anchors
Supraspinatus muscle tendon rupture	1	Arthroscopic refixation with suture anchors
Hill-Sachs lesion	1	None, due to the small size and depth of the lesion
PASTA lesion	5	Arthroscopic debridement and smoothing, if necessary additional refixation with a suture anchor
Fracture of the tuberculum majus	1	Plate osteosynthesis
SLAP lesion Classification according to Maffet <sup>20</sup>	17	
SLAP I lesion	6	SLAP I: Debridement
SLAP II lesion	3	SLAP II–V: Mini-open long biceps tendon tenodesis using a biocomposite corkscrew
SLAP III lesion	3	
SLAP IV lesion	0	
SLAP V lesion	5	
Osteoarthritis	10	None
Outerbridge classification <sup>28</sup>		
Chondropathy ≥grade II	5	
Chondropathy grade III	2	
Chondropathy grade IV	3	

PASTA, partial articular supraspinatus tendon avulsion; SLAP, superior labrum anterior posterior.

<sup>a</sup>Subacromial impingement syndrome was diagnosed on the basis of a thorough clinical examination and preoperative magnetic resonance imaging.

These results were reflected in our patients' subjective evaluation of their sport-specific outcome (n=26). Here, excellent (V) results were reported in 73% (n=19) of cases, good (IV) results in 12% (n=3), satisfactory (III) results in 4% (n=1), fair (II) results in 8% (n=2), and poor (I) results in 4% (n=1).

**Table 4.** Postoperative rehabilitation protocol.

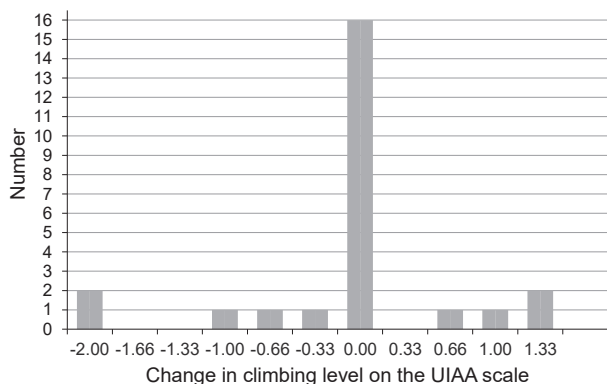
3–21 d	<ul style="list-style-type: none"> <li>Shoulder-arm immobilization bandage (eg, medi Arm fix)</li> <li>Passive/assistive practice up to 60° abduction/elevation</li> <li>No active external rotation; however, passive external rotation from the inner rotation position up to neutral 0 position is possible</li> <li>Careful isometric centering exercises</li> <li>Keep the thoracoscapular sliding plane free, posture training</li> <li>Lymphatic drainage</li> </ul>
4–6 wk	<ul style="list-style-type: none"> <li>Removal of shoulder-arm immobilization bandage</li> <li><b>Passive/assistive practice up to 90° abduction/elevation</b></li> <li><b>No active external rotation</b>; however, passive external rotation from the inner rotation position up to neutral 0 position is possible</li> <li>Submaximal isometric, centering exercises</li> <li>Training of the scapula and thoracic spine musculature in the open system</li> <li>Electrotherapy and lymph drainage (pain therapy, edema reduction)</li> <li>Application of heat</li> <li>Manual therapy of the acromioclavicular joint and sternoclavicular joint</li> </ul>
From 7 wk	<ul style="list-style-type: none"> <li><b>Start of outpatient rehabilitation</b></li> <li><b>Free range of motion</b>, initially active assistive then active</li> <li>Muscular gain training for the shoulder blade muscles and rotation, also in the open system</li> <li>Proprioceptive neuromuscular facilitation</li> <li>Posture training</li> <li>If need be, electrostimulation</li> </ul>
9–16 wk	<ul style="list-style-type: none"> <li>Eccentric and concentric muscle training, increasing up to general muscular full load bearing</li> <li>Training in movement, coordination, reaction, and endurance</li> <li>Training elements specific to a certain sport from the 12th wk</li> </ul>
6 mo	<ul style="list-style-type: none"> <li><b>Full sport-specific exertion</b></li> </ul>

Bolded text indicates the most important steps of the rehabilitation protocol.

## Discussion

The overall outcome following surgical repair of pathologies associated with first-time traumatic shoulder dislocations in climbers shows promising results for activities of daily life and sport.

Our results are consistent with recent literature emphasizing the role of immediate surgical therapy as the treatment of choice for most cases of first-time anterior shoulder dislocations, especially in young patients and athletes.<sup>9,10</sup> While recurrence rates between 62% and 70%



**Figure 2.** The change in climbing level after surgery is depicted for all participating climbers who had returned to sports (n=25) using the Union Internationale des Associations d'Alpinisme scale. UIAA, Union Internationale des Associations d'Alpinisme.

have been described in conservatively treated patients, recent meta studies reported a recurrence rate between 12% and 20% after arthroscopic soft-tissue LLC repair, with recurrence being defined as any report of dislocation or subluxation.<sup>9,29,30</sup> With a recurrence rate of only 7% (n=2), our findings are more favorable than the rates described in the current literature. However, the results are only comparable to a limited extent since many of the athletes included in the studies mentioned above were participating in contact and collision sports, such as rugby or American football, which might present a greater risk for a recurrent dislocation than rock climbing. Compared to collision and contact sports, a direct trauma to the arm and the shoulder girdle occurs much less frequently in rock climbing (specifically, roped climbing, ie, climbing with a rope using fixed bolts for security), thus possibly reducing the risk of repeated shoulder dislocation. However, in the climbing subdiscipline of bouldering (climbing without a rope at relatively short jump-off heights with crash pads for protection), falls onto the shoulder and the arm are

inevitably more frequent than in roped climbing.<sup>31</sup> As the participants in the presented study are mainly sport climbers, further research is necessary to find out if there is an increased risk for recurrent shoulder dislocation in bouldering athletes.

With a return-to-sport rate of 78% at the preinjury level of climbing or above, our results are comparable to those of existing studies including both contact and noncontact athletes, such as volleyball players, water polo, rugby, soccer and tennis players, that found a return-to-sport rate of 81% to 83% at the preinjury level.<sup>17,32</sup> Still, due to the differences between the disciplines, a direct comparison is not feasible.

Our findings are also in line with recent research on the surgical treatment of other climbing injuries, specifically SLAP lesions and rotator cuff tears, which also found favorable functional and sport-specific outcomes following surgery (for a detailed comparison, see Table 5).<sup>24,33</sup>

In total, 4 patients in our study had not returned to their previous climbing level at the time of follow-up, and 1 patient was unable to return to the sport after surgery because of persistent complaints due to secondary adhesive capsulitis in addition to his pre-existing high-grade osteoarthritis. This is a rare but well-known complication after surgical repair following shoulder dislocation.<sup>34</sup> Since the follow-up examination of this patient was performed 15 months after surgery, further improvement in this individual is possible but was not confirmed. It is likely that the presence of associated injuries or pre-existing degenerative pathologies (Table 3) might have led to prolonged or incomplete recovery after traumatic shoulder dislocation.

## LIMITATIONS

Our study might have incorrectly estimated the presurgery climbing level due to recollection bias. Climbers might have misremembered when reporting their

**Table 5.** Comparison of functional and sport-specific outcomes after surgical therapy of shoulder dislocation, superior labrum anterior posterior lesions, and rotator cuff tears in rock climbers

Pathology	Shoulder dislocation (Current study)	SLAP lesion <sup>19</sup>	Rotator cuff tear <sup>34</sup>
Study collective (no. of climbers), N	27	30	12
Age (y), mean±SD (range)	34±11(17–61)	44±9.2 (28–64)	55±9 (28–66)
Sex (male/female)	20/7	23/7	10/2
Follow-up time (mo), mean±SD (range)	53±29 (12–103)	32±19 (12–70)	27±16 (12–72)
Constant Murley Score, mean±SD (range)	95±8 (67–100)	90±8 (75–100)	92±7 (80–98)
Return to sports, percentage of N	93% (n=25)	100% (n=30)	100% (n=12)
Preinjury level of climbing regained or exceeded, percentage of N	78% (n=21)	67% (n=20)	42% (n=5)

maximum climbing level. The postsurgery climbing level might have been influenced by temporary suspension of the patients' training routine, as required by the rehabilitation protocol, wherein full exertion was allowed only 6 mo after surgery. Thus, the climbing level might have been different if we had measured it later than 12 mo after surgery.

We only report descriptive data and did not compare the results following surgery with those of a conservatively treated control group as extant literature highlights the superior efficacy of surgical therapy over conservative treatment.

The generalizability of our findings is limited because of the small sample size. Furthermore, as the performing surgeons' department is a recognized center for the treatment of climbing injuries, a selection bias might have occurred as only active, high-level climbers might have sought out this surgeon's opinion and treatment. Associated with this is the limitation that all operations were performed by only 1 experienced surgeon, which might have further biased our results.

Finally, our sample included not only isolated traumatic pathologies of the LLC of the shoulder, which complicates the assessment of our findings.

## Conclusion

In this study, we presented descriptive data based on a relatively small sample. Our findings are promising and show that a favorable outcome following first-time traumatic shoulder dislocation and arthroscopic repair of the LLC in climbers is likely. This includes both general function and sport-specific performance. Most athletes in our sample were able to return to or near their preinjury level of climbing after surgery, and shoulder dislocation recurrence rates were low.

Our results thus concur with the extant literature centered on other sport disciplines. In summary, we view arthroscopic surgery as an advisable treatment for climbers who wish to return to this sport after a first-time traumatic shoulder dislocation and associated acute traumatic pathologies, specifically of the LLC. Of course, patients still need to be informed about the general risks of the procedure and should be made aware of potential adverse effects on their climbing performance.

Author Contributions: study concept and design (MS, LG, CL, VS); acquisition of data (MS, LG, CL, VS); drafting of the manuscript (MS); critical revision of the manuscript (LG, CL, VS); approval of final manuscript (MS, LG, CL, VS).

Financial/Material Support: None.

Disclosures: None.

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## ORIGINAL RESEARCH

# Illnesses and Injuries at a Remote American Residential Summer Camp Over 3 Seasons

Jeffrey Schlaudecker, MD, MEd; Kevin J. Milligan, MD; Erin Glankler, MD; Angel Pagan, MD; Andrew M. Weller, MD; William Cohn, MS

*Department of Family and Community Medicine, University of Cincinnati, Cincinnati, OH*

**Introduction**—Residential and wilderness excursion summer camps are safe, but outdoor activities can lead to injuries. The frequency of various illnesses and injuries at summer camps has been incompletely described. The treatments provided and the need for escalation to higher levels of care are variable.

**Methods**—A retrospective cohort analysis was conducted for all visits to a camp infirmary over 3 seasons at a residential summer camp in Minnesota. Seventeen descriptive categories of chief complaints and 13 categories of treatment disposition were created for all 695 eligible infirmary visits. The frequency and illness type for which escalation to a higher level of care beyond the camp infirmary was needed were reviewed.

**Results**—Four hundred one campers sought medical care 695 times over 3 seasons. The most common chief complaints were related to skin (35%), musculoskeletal injury (17%), and upper-respiratory symptoms (15%). The most common treatment and dispositions were over-the-counter medications (43%) and simple bandage or dressing (19%). Escalation of care to a clinic or emergency room was uncommon, with 35 (5%) infirmary visits requiring escalation. Musculoskeletal injuries were the most common reason for escalations of care. While overall less common than musculoskeletal injury, dental injury almost always resulted in escalation of care.

**Conclusions**—An analysis of 3 y of visits to a summer camp infirmary was used by camp medical staff to update protocols and obtain new supplies for diagnosis and treatments. A more complete understanding of the prevalence of injuries and illnesses has the potential to allow better preparation for camp medical staff.

**Keywords:** wilderness medicine, dental trauma, camping, childhood accidents, adolescent health

## Introduction

Attending summer camp is a common activity for American children from childhood through adolescence. Before the COVID-19 pandemic in 2018, >14 million children per year attended summer camp in the United States.<sup>1</sup> At residential summer camps, campers stay

overnight. Wilderness excursion summer camps combine residential activities with overnight camping off site. While residential and wilderness excursion summer camps are generally safe and developmentally appropriate activities for children and adolescents, activities in the outdoors can lead to injuries. A 2006 convenience sample of summer camps found that 68% of reported events were illnesses, and of 32% of injury events, cut, scratch, or scrape was the most common.<sup>2</sup> The duration of camps has previously been shown to be associated with an increased risk of injuries; however, residential summer camps have lower rates of injury than most common high school sports.<sup>3</sup> A 2013 review of 5 y of illnesses and injuries at day and overnight or residential summer camps reported that sprains and strains topped the list of injuries, while respiratory and gastrointestinal

Corresponding author: Jeff Schlaudecker, MD, MEd, Department of Family and Community Medicine, University of Cincinnati, Cincinnati, OH; e-mail: [jeffrey.schlaudecker@uc.edu](mailto:jeffrey.schlaudecker@uc.edu).

Submitted for publication September 2022.

Accepted for publication March 2023.

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<https://doi.org/10.1016/j.wem.2023.03.003>

illnesses were the most common communicable illnesses spread at camps.<sup>4</sup>

Camp Kooch-i-Ching opened in 1925 as a residential summer camp for boys and is located in International Falls, Minnesota. The associated girls' camp Ogichi Daa Kwe was founded in 2004 and is located a half mile south of the boys' camp. Campers from both the camps range in age from 8 to 18 y and are divided into 4 groups based on their year in school. Both the camps maintain an in-camp program and a wilderness excursion program. The in-camp program offers >20 land- and water-based activities, while the wilderness excursions involve multiday canoeing or backpacking trips across North America. All campers attend the in-camp program, followed by a wilderness excursion that varies in duration from 2 to 21 d. The camp duration varies from 10 d to 8 wk. The staff-to-camper ratio is 3:1.

Over the 3 y of data collection, the staff members of the camp infirmary included a volunteer family medicine physician (author JS), 2 first-year medical students from the University of Cincinnati College of Medicine (authors KJM and EG), and 2 licensed and practicing emergency medical technicians at the boys' camp. The infirmary staff at the girls' camp included 2 registered nurses. When injuries or illnesses could not be handled by the infirmary staff, transportation was made to urgent care at a nearby community health clinic or to a local emergency department. Both the locations are approximately 16 km (10 mi) from the camp.

## Methods

Our retrospective observational cohort study was designed to illustrate data on the prevalence and frequency of various ailments and treatments for infirmary visits during 3 consecutive years at a residential summer camp. Injuries and illnesses occurring during wilderness excursions were not logged in the electronic health record (EHR) and, thus, not included in this analysis. We also reported the frequency and illness type for which escalation of care to an outside provider was needed.

In 2017, both the infirmaries transitioned to the use of CampMinder (CampMinder LLC; Boulder, CO, 2019), an EHR and data management software, to track the medications, background health needs, and allergies of the campers. This EHR system allowed the infirmary staff to record visits more effectively. The presence of EHR also allowed for retrospective sampling of past visits for illnesses and injuries to the infirmary.<sup>5</sup>

The EHR system was retrospectively queried for all encounters during these 3 seasons. Visits to the infirmary did not include encounters while the camper was on a

wilderness excursion. Demographic information was deidentified. A retrospective cohort analysis was then conducted using EHRs. Visit entries were reviewed, and a database was created using the Excel program (Microsoft, 2017). Upon arrival at the camp and following all overnight wilderness excursions, a screening visit was conducted for all campers, and these visits did not generate an entry into the EHR unless an injury or illness was identified. Additionally, information regarding daily medication administration for chronic conditions was not included in the database. After a review of 695 eligible encounters, authors JS and KJM met and created 17 descriptive categories to describe chief complaints and 13 categories to describe treatment and disposition. The categories were then internally validated by each author based on a consensus. Each of the unique infirmary encounters was coded according to both chief complaints and treatment or disposition by the authors of this study (AP, AMW, and KJM). The University of Cincinnati institutional review board deemed this research study to be not human subject research and, thus, did not require review.

## Results

There were 1259 campers between 2017 and 2019. Four hundred one (32%) campers sought medical care between 1 and 9 times during the summer for a total of 695 unique infirmary visits over 3 seasons from 2017 to 2019. The most common chief complaints were related to skin (35% of all visits), musculoskeletal injury (17%), and upper-respiratory symptoms (15%) (Table 1). Headache and gastrointestinal issues resulted in 60 (9%) and 54 (8%) infirmary visits, respectively. Head injury was an uncommon complaint, contributing only 20 (3%) chief complaints. Only 5 (0.7%) complaints of a burn resulted in an infirmary visit. The most common treatment and dispositions were over-the-counter (OTC) medications (43% of all treatments) and simple bandage or dressing (19%) (Table 2).

Of the 695 total visits over 3 y, 35 (5% of all visits) required escalation of care (Figure 1). Over 3 y, 116 musculoskeletal injuries were logged in the system, representing 17% of the total encounters. Of these 116 musculoskeletal injuries, 12 (10%) musculoskeletal injuries required escalation, most frequently for x-rays. Musculoskeletal injuries were the most common reason for escalation of care, contributing 12 out of the 35 escalations. When their high incidence rate overall (17% of all encounters) was accounted for, musculoskeletal injury was the most frequent chief complaint that required care escalation.



**Table 1.** Frequency of chief complaints presented to the camp infirmary

Chief complaint		2017	2018	2019	Total	
		n (%)	n (%)	n (%)	n (%)	
Total		189 (100)	249 (100)	257 (100)	695 (100)	
Skin	Skin disruption (not requiring repair)	19 (10)	53 (21)	52 (20)	124 (18)	245 (35)
	Rash, insect bites, or stings	19 (10)	20 (8)	21 (8)	60 (9)	
	Cutaneous infection	1 (0.5)	7 (3)	17 (7)	25 (4)	
	Lacerations (requiring repair)	4 (2)	8 (3)	4 (2)	16 (2)	
	Splinter	3 (2)	9 (4)	1 (0.4)	13 (2)	
	Burn	0 (0)	4 (2)	1 (0.4)	5 (1)	
	Animal bite	2 (1)	0 (0.0)	0 (0.0)	2 (0.3)	
MSK injury or pain		19 (10)	62 (25)	35 (14)	116 (17)	
Upper-respiratory infection		50 (26)	21 (8)	33 (13)	104 (15)	
Headache		18 (10)	15 (6)	27 (11)	60 (9)	
Gastrointestinal issue		19 (10)	12 (5)	23 (9)	54 (8)	
Eye issue or injury <sup>a</sup>		13 (7)	5 (2)	6 (2)	24 (4)	
Head injury		4 (2)	14 (6)	2 (0.8)	20 (3)	
Genitourinary issue or injury		9 (5)	0 (0)	7 (3)	16 (2)	
Other		1 (0.5)	2 (0.8)	11 (4)	14 (2)	
Ear infection or injury		1 (0.5)	3 (1)	6 (2)	10 (1)	
Dental issue or injury		3 (2)	4 (2)	1 (0.4)	8 (1)	
Allergic reaction		2 (1)	2 (0.8)	4 (2)	8 (1)	
Tick bites, Lyme disease		1 (0.5)	4 (2)	0 (0)	5 (0.7)	
Epistaxis		0 (0)	1 (0.4)	4 (2)	5 (0.7)	
Home sickness		0 (0)	1 (0.4)	2 (0.8)	3 (0.4)	
Difficulty breathing or asthma		0 (0)	2 (0.8)	0 (0)	2 (0.3)	
Seizure		1 (0.5)	0 (0)	0 (0)	1 (0.1)	

<sup>a</sup>Including sty and conjunctivitis.

While only 8 dental injuries were identified over 3 y, 5 of those 8 injuries (63%) required escalation to a higher level of care. Therefore, while they represented a much

**Table 2.** Rates of treatments and dispositions for all infirmary encounters

Type of treatment		Total	
		n (%)	
Total		695 (100)	
OTC medications		295 (42)	
Simple procedures	Simple dressing	132 (19)	233 (33)
	Splint, wrap, and/or ice	53 (8)	
	Irrigate or compress (eye)	17 (3)	
	Splinter removal	14 (2)	
	Stitches, Steri-Strips, or Dermabond	13 (2)	
	Tick or leech removal	2 (0.3)	
	Skin OTC medications or interventions	55 (8)	
No intervention or reassurance		44 (6)	
Escalation to urgent care		25 (4)	
Bed rest or observation		18 (3)	
Prescription medications		17 (3)	
Escalation to emergency department		10 (1)	

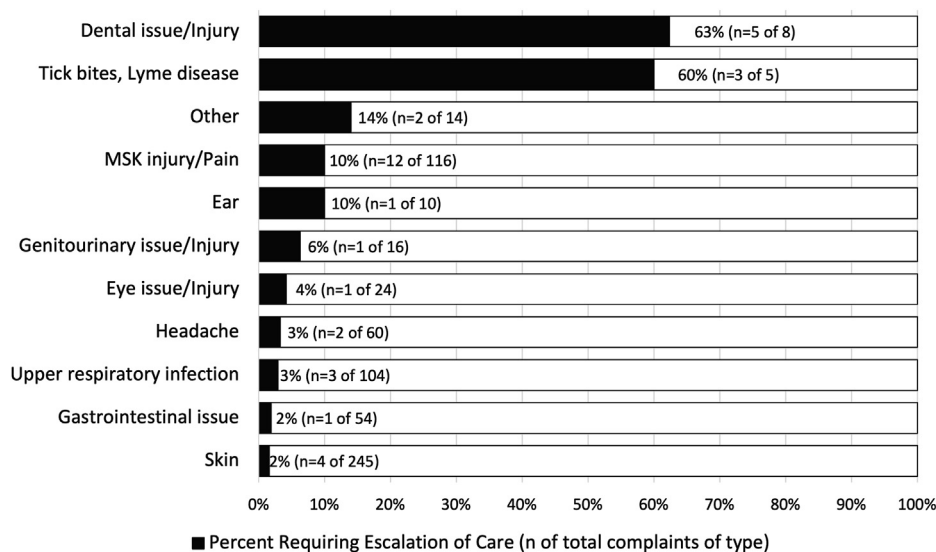
OTC, over-the-counter.

lower absolute number of injuries, dental injuries led to a much higher rate of escalation than musculoskeletal injuries. Five patients presented with tick bites and potential Lyme disease exposure, and 3 instances required escalation to obtain recommended antibiotic treatment.

## Discussion

The most prevalent ailment presenting to the infirmary over 3 seasons was skin disruption. The rate of overall escalation to a higher level of care was 5% of all infirmary visits. This is a rate similar to an escalation rate of 7% at a boy scout camp in Missouri.<sup>6</sup>

While dental injuries were relatively uncommon in all 3 y of visits, 5 of 8 dental injuries required escalation. This high rate of escalation could prompt residential summer camps to have a defined procedure for urgent dental referral. A revised protocol and staff education on dental injury was added to staff training, and the phone number for a local dentist providing urgent referrals was posted in the infirmary. Asthma is a common condition during childhood, but there were only 2 chief complaints of shortness of breath or asthma at the infirmary in 3 y,



**Figure 1.** Relative rate of escalation to a higher level of care based on the chief complaint. MSK, musculoskeletal.

and there were no escalations required for acute asthma exacerbation. The baseline incidence of asthma in the camper population at Camp Kooch-I-Ching and Ogichi Daa Kwe is unknown but potentially low given the selection bias of remote wilderness camps.

Tracking infirmery visits presented several opportunities for process improvement of the summer camp infirmery, including evaluation of tick bites and upper-respiratory infections. Minnesota has the sixth highest prevalence of Lyme disease in the United States, and thus, it must be frequently considered by the infirmery staff. When tick bite was the chief complaint ( $n=5$ ), it resulted in escalations for antibiotics 60% of the time, only slightly trailing dental injuries in escalation rate. In 2019, the infirmery began stocking doxycycline and created a standard algorithm based on Centers for Disease Control guidelines for Lyme disease prophylaxis in the event of tick exposure.<sup>7,8</sup> This allowed for campers with tick exposure to avoid needing to be transported to urgent care for recommended antibiotic prophylaxis.

All 3 escalations for upper-respiratory infections ( $n=3$ ) were because of suspicion of strep throat infection and the need for additional diagnostic testing. In 2019, a rapid strep A antigen throat swab test kit was purchased. This availability decreased the need for escalation of care to obtain diagnostic testing. A greater understanding of any camp’s ailment and treatment records can better improve infirmery efficiency and improve delivery of care to campers; when injury and illness are able to be appropriately handled on site, campers avoid the expense

and time away from the camp for travel to an emergency room. It is possible that a less disrupted camp experience could potentially lead to higher camper retention, decreased parental anxiety, and decreased additional costs through minimization of transportation to emergency departments.

### LIMITATIONS

There are several limitations to our study. Our data are based on 1 organization and 2 summer camps in northern Minnesota, limiting generalizability. The wilderness excursion elements of the camps could likely lead to selection bias of healthier campers, who are less likely to experience exacerbation of a chronic disease such as asthma. The wilderness excursions could also lead to a higher incidence of skin-related and musculoskeletal injuries. A retrospective review could not differentiate a scheduled follow-up visit from a visit to the infirmery for a similar but new condition. With a retrospective analysis of all 695 infirmery visits, it became clear that specific conditions required follow-up more often, leading to potential overrepresentation. For example, wound check of an abrasion and a second abrasion on a different extremity could not be differentiated if they both occurred in the same camper. While we have decided to present data from each year, the variations in the reporting of illnesses and injuries between years are not known. Finally, because some visits for extremely minor complaints might not have warranted creation of a note in the EHR, the true

number of visits to the infirmary and the true number of treatments categorized as “no treatment/reassurance,” are not known. Unknown total visits precluded the ability to know total injury or illness rates.

## Conclusions

Our study described infirmary visits during 3 seasons of a residential summer camp in northern Minnesota. A better understanding of the prevalence of both common and rare injuries and illnesses allowed better preparation for camp medical staff. A review of infirmary visits also presented several opportunities for process improvement of the summer camp infirmary. A review of conditions that were most likely to require escalation of care to a clinic or emergency room enabled better preparation for future illnesses and emergencies at the summer camp. Other camps could improve protocols for common injuries through an understanding of their most common reasons for a visit to the infirmary. While one third of campers visited the infirmary over 3 y, serious injury was uncommon, most illnesses and injuries were treated with OTC treatments, and few campers required escalation to a higher level of care. Our findings support the general safety of residential summer camps for children and adolescents.

Presented by Glankler E, Milligan K, Cohn W, Schlaudecker J as “A Descriptive Evaluation of Two Years of Injury and Illness Patterns at Two Remote Residential American Summer Camps” at the North American Primary Care Research Group (NAPCRG) 47th Annual Meeting, November 19, 2019, Toronto, Ontario.

**Acknowledgment:** The authors wish to thank the dedicated staff of the Camping and Education Foundation for their support of this endeavor.

**Author Contributions:** study concept and design (JS, KM, WC, EG); data acquisition (JS, KM, WC, EG); data analysis (JS, AW, AJ, KM); drafting and critical revision of the manuscript (JS, KM, AW, AJ, WC); approval of final manuscript (all authors approved the final manuscript).

**Financial/Material Support:** None

**Disclosures:** None

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## ORIGINAL RESEARCH

# Self-Reported Injuries in Indoor Gym-Based Rock Climbers: A Retrospective Study of Predictors of Prolonged Injury and Seeking Medical Care

Jonathan Leung, MD<sup>1</sup>; Ziva Petrin, MD<sup>2</sup>; William Southern, MD<sup>1</sup>

<sup>1</sup>Department of Medicine, Albert Einstein College of Medicine, Bronx, NY; <sup>2</sup>Department of Physical Medicine and Rehabilitation, Rutgers New Jersey Medical School, Newark, NJ

**Introduction**—Indoor climbing injuries are often related to overuse, and climbers choose between self-management and seeing a medical practitioner. This study evaluated predictors of prolonged injury and seeking medical care for indoor climbing injuries.

**Methods**—A convenience sample of adult climbers from 5 gyms in New York City was interviewed about injuries over the past 3 y, because of which they stopped climbing for at least a week or saw a medical practitioner.

**Results**—In total, 122 of 284 (43%) participants had at least 1 injury, for a total of 158 injuries. Fifty (32%) were prolonged, lasting at least 12 wk. Predictors of prolonged injury included older age (odds ratio [OR], 2.28, per 10-y increase; 95% CI, 1.31–3.96), hours per week spent climbing (OR, 1.14, per 1-h increase; 95% CI, 1.06–1.24), climbing difficulty (OR, 2.19, per difficulty group increase; 95% CI, 1.31–3.66), and years of climbing experience (OR, 3.99, per 5-y increase; 95% CI, 1.61–9.84). Only 38% of injuries were seen by a medical practitioner. Predictors of seeking care included prolonged injury (OR, 3.04; 95% CI, 1.39–6.64) and rope climbing preference (OR, 1.98; 95% CI, 1.02–3.82). The most common theme for seeking care was serious pain or interference with climbing or daily activities.

**Conclusions**—Despite prolonged injuries being common, especially in older, more experienced, and higher-level climbers, only a third of climbers with injuries seek medical care. Outside of injuries causing minimal pain or limitation, those who self-managed reported receiving advice from other climbers or online research as a prominent reason for that choice.

**Keywords:** athletic injuries, self-managed injuries, surveys and questionnaires, return to sport, prevalence, risk factors

## Introduction

Although rock climbing originated from mountaineering, the number of indoor climbers in the United States now more than doubles those who climb outdoors.<sup>1</sup> Indoor climbing injuries are most often overuse injuries of the upper extremity<sup>2</sup> and less often from acute trauma.<sup>3</sup>

However, many prior studies have used a severity scale that is most suited to the types of injuries that occur when climbing outdoors<sup>4</sup> that classifies most indoor climbing injuries as minor.<sup>3,5,6</sup> As a result, the frequency and duration of injuries that occur indoors are poorly understood as well as the decisions to seek medical care or not.

The purpose of our study was to examine the nature of indoor climbing injuries, focusing on duration of injury and decision to seek medical care. To do this, we conducted an interview study evaluating the frequency, distribution, and duration of injuries in gym-based climbers, the factors associated with prolonged injury, the measured factors associated with seeking medical care, and the subjective reasons for seeking medical care or

Corresponding author: Jonathan Leung, MD, Department of Medicine, Albert Einstein College of Medicine, Bronx, NY; e-mail: [jleung@montefiore.org](mailto:jleung@montefiore.org).

Submitted for publication August 2022.

Accepted for publication May 2023.

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<https://doi.org/10.1016/j.wem.2023.05.002>

self-management. We examined age, sex, experience, climbing difficulty and frequency, style of climbing, and injury location as factors that might be associated with prolonged injury and seeking medical care.

## Methods

The study was approved by the Montefiore Einstein institutional review board.

Indoor climbers were interviewed about their experience with injuries and their decision to seek medical care. A convenience sample of climbers was recruited in person, subject to researcher availability during the pre-determined data collection period, resulting in 19 morning or evening visits to 5 climbing gyms in New York City between October 2020 and July 2021. Climbers were informed about the study and, if interested, were screened to determine eligibility. If eligible, participants were asked for consent and given a choice to be interviewed immediately or contacted at a later date and interviewed over the phone. Verbal responses were written down by the interviewer and then transcribed into the database.

Climbers 18 y or older who climbed  $\geq 4$  times in the past year were eligible to be included in the study. An acute injury was defined as one sustained while climbing within the prior 3 y, a timeframe similar to those used in prior studies,<sup>7</sup> that required the participant to either see a medical practitioner or, after the injury, stop climbing for at least a week. Climbers of <18 y of age and pregnant women were excluded. Chronic injuries, such as those with similar characteristics recurring in the same location, were excluded. Additionally, except as part of the calculation of injury prevalence, injuries for which care was sought from the emergency department were excluded.

For each participant, demographic and climbing characteristics were recorded, including the difficulty grade at which they climbed most often. We used the International Rock Climbing Research Association scale<sup>8</sup> to reconcile the Yosemite Decimal System and the Hueco grades used to measure the difficulty of rope climbing and bouldering, respectively. To account for climbers not reporting on subgrades, for instance 5.10a vs 5.10b, we grouped the grades based on rope climbing difficulty: beginner ( $\leq 5.9$ ), low intermediate (5.10 or V0), high intermediate (5.11 or V1–3), advanced (5.12 or V4–7), and elite (5.13 or  $\geq V8$ ). In addition, whether each participant had medical insurance or a primary care practitioner at the time of at least 1 injury was assessed.

The characteristics of each injury were recorded. To classify the anatomic location of each injury, we used the

Orchard Sports Injury and Illness Classification System,<sup>9</sup> except for identifying finger injuries specifically. Duration of injury was defined as time from injury to return to climbing activities with little or no pain or limitation. An injury of  $\geq 12$ -wk duration was considered prolonged, a definition that has been used previously.<sup>10</sup>

For each injury, participants were asked whether they sought medical care and whether they required surgery. They were asked to report all of the reasons for their decision to self-manage or seek medical care for their injury in an open-ended semistructured interview format (see online [Supplemental Material](#)).

Characteristics of participating climbers and injuries are reported using summary statistics. The primary outcomes were prolonged injury and seeking medical care. The associations between each predictor and outcome were examined using univariable logistic regression models with Wald statistics used to measure significance. *P* values of <0.05 were considered significant. Because the study is considered exploratory, no adjustment for multiple hypothesis testing was done. Stata, version 17.1 (College Station, TX), was used for all statistical analyses.

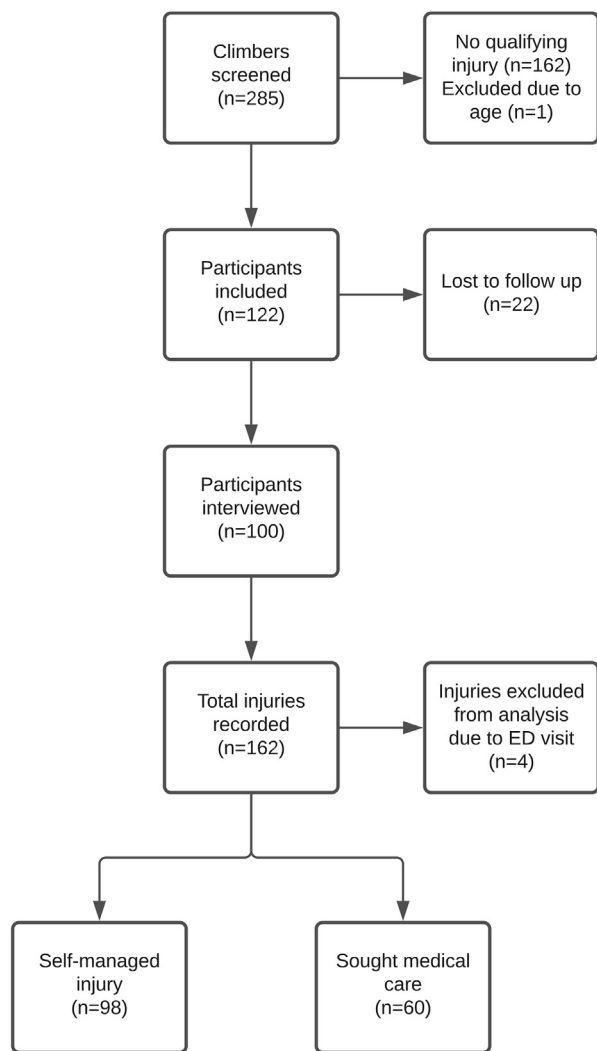
Thematic analysis was performed on the responses to the open-ended question of why each climber sought or did not seek medical care. Reported themes included both those that were anticipated and asked about explicitly and those that were elucidated during follow-up questioning. These themes were then categorized into the final major themes in each of the self-management and seeking care groups.

All recruitment and interview activities were conducted by 1 researcher. Thematic analysis, including categorization and revision of themes, was conducted by the interviewer and a second researcher.

## Results

Of the 284 climbers who met eligibility criteria and agreed to participate, 122 had an acute injury, resulting in a 3-y prevalence of 43%. Of the injured participants, 22 did not complete the interview, leaving a remaining sample of 100 climbers and 158 acute injuries, excluding those who were seen in the emergency department ([Figure 1](#)).

Of the 100 injured participants who were interviewed, the mean age was 31.4 y, and 75 (75%) were men. They reported a mean climbing experience of 5.6 y and a mean climbing frequency of 8.3 h/wk. The most common climbing levels were high intermediate (5.11 or V1–3), 24%, and advanced (5.12 or V4–7), 52%. During the 3-y period, 93% of the participants reported having had



**Figure 1.** Consolidated Standards of Reporting Trials flow diagram. ED, emergency department.

medical insurance but only 58% a primary care practitioner (Table 1).

Of the 158 injuries, 68% were of the upper extremity, 22% were of the lower extremity, and 9% were of non-extremity origin. The 5 most common injury locations were finger (39%), shoulder (14%), ankle (13%), elbow (10%), and knee (6%). Only 6 injuries required surgery, and of those, 3 were for the shoulder (Table 2).

The number of prolonged injuries ( $\geq 12$  wk) was found to be 50 of 158 (32%). Of the 5 most common injury locations, the knee (40%) had the highest proportion of prolonged injuries, followed by shoulder (32%), finger (29%), ankle (25%), and elbow (25%).

Factors significantly associated with prolonged injury included older age (odds ratio [OR], 2.28, per 10-y increase; 95% CI, 1.31–3.96), hours per week dedicated to

**Table 1.** Participant characteristics

	Total (N=100)
Age, y, avg (SD)	31.4 (6.7)
Male, n	75
Female, n	25
Climbing experience, y, avg (SD)	5.6 (5.7)
Climbing frequency, h/wk, avg (SD)	8.3 (4.3)
Preferred climbing style bouldering, n	60
Preferred climbing style rope, n	40
Difficulty grade 1 beginner, n	2
Difficulty grade 2 low intermediate, n	15
Difficulty grade 3 high intermediate, n	24
Difficulty grade 4 advanced, n	52
Difficulty grade 5 expert, n	7
Had medical insurance during at least 1 injury, n	93
Had a primary care practitioner during at least 1 injury, n	58

avg, average.

climbing (OR, 1.14, per 1-h increase; 95% CI, 1.06–1.24), climbing difficulty (OR, 2.19, per difficulty grade group increase; 95% CI, 1.31–3.66), and years of climbing experience (OR, 3.99, per 5-y increase; 95% CI, 1.61–9.84). Sex, climbing style preference, and injury location were not associated with prolonged injury (Table 3).

Of the 158 injuries examined, 98 (62%) were self-managed and 60 (38%) prompted seeking medical care. Factors significantly associated with seeking medical care included prolonged injury (OR, 3.04; 95% CI, 1.39–6.64) and rope climbing preference (OR, 1.98; 95% CI, 1.02–3.82). Age, sex, climbing experience, hours per week, climbing difficulty grade, and having a primary care practitioner or having medical insurance were not significantly associated with seeking medical care (Table 4). Injury location was not significantly associated with seeking medical care, but the knee had the highest proportion of injuries for which medical care was sought (60%), and fingers had the lowest proportion (26%).

Among injuries that were self-managed, reasons for self-management were represented by 5 major themes (Table 5): minimal pain or interference with climbing or daily activities (55%), reassured by another person or self-research (47%), prior experience or knowledge managing the injury (39%), unwillingness to seek medical care (37%), and difficulty accessing medical care (28%) (Table 5).

Among injuries for which the climber sought medical care, reasons for seeking care were represented by 2 major themes: serious pain or interference with climbing or daily activities (87%) and worry about the diagnosis or

**Table 2.** Injury characteristics

	<i>Location, n</i>	<i>Duration, avg (SD)</i>	<i>Required surgery, n</i>
Upper extremity			
Shoulder	22	20.4 (35.9)	3
Upper arm	1	24	1
Elbow	16	9.5 (13.2)	1
Forearm	1	8	0
Wrist	6	26.3 (20.8)	0
Finger	62	10.8 (15.9)	0
Lower extremity			
Thigh	4	6.6 (4.3)	0
Knee	10	16.9 (31)	0
Ankle	20	8.9 (7.4)	1
Foot	1	12	0
Other			
Neck	4	7.3 (11.2)	0
Chest	1	2.5	0
Lumbosacral	8	9.2 (10.4)	0
Unspecified	2	13 (15.6)	0

avg, average.

long-term effects (33%) (Table 5). Less frequent themes included prior positive relationship or experience with a medical practitioner (14%), influenced to see a medical practitioner by another person (14%), and injury recurrence or interest in prevention (12%).

## Discussion

In this retrospective study of self-reported injuries from a convenience sample of climbers at indoor gyms, we found that 32% of injuries studied were prolonged, with symptoms lasting  $\geq 12$  wk. Several factors were associated with prolonged injury, including age, increasing years of climbing, increasing climbing difficulty, and increasing climbing volume. Injured climbers only

sought care for 38% of injuries. Prolonged injury was associated with an increased likelihood of seeking medical care. No association was found between whether the climber had medical insurance or a primary care practitioner and seeking care. The most common theme cited for seeking care was severe pain or limitation to climbing or daily activities.

Two prospective studies evaluating recreational indoor climbers also described elevated injury rates with 1-y incidences of 43% and 44%.<sup>2,5</sup> Our finding of a 3-y prevalence of 43%, although high, may have been an underestimation of true injury burden, as we excluded chronic injuries and those presenting to the emergency department.

We found not only a high frequency of injuries but also a high proportion of prolonged injuries, 32%. Our finding illustrates how duration of acute injury may be important to characterize injury severity in addition to the UIAA (Union Internationale des Associations d'Alpinisme) MedCom Score.<sup>4</sup>

There have been many studies evaluating the risk factors for climbing injury. In the literature review by Woollings et al,<sup>11</sup> some studies found increasing age,<sup>12,13</sup> male sex,<sup>12,14</sup> increasing years of climbing,<sup>14,15</sup> increasing climbing difficulty,<sup>14,15</sup> increasing climbing volume,<sup>15</sup> and bouldering<sup>16</sup> to be associated with increased risk of injury. Other studies did not find such associations.<sup>17-19</sup> In our study, we examined these risk factors, in addition to injury location, not for their association with injury in general but rather for their association with prolonged injury. Despite this difference in study design, we found that the associated factors were similar to many of those described in previous research.<sup>14</sup>

In our study, 38% of climbing injuries were seen by a medical practitioner. This was consistent with other studies showing that a minority of injured climbers (31–40%) seek medical care.<sup>20-22</sup> We found prolonged

**Table 3.** Predictors of prolonged injury

	<i>OR</i>	<i>95% CI</i>	<i>P value</i>
Age (each 10 y)	2.28	1.31–3.96	0.004
Male	1.98	0.70–5.55	0.20
Experience $\geq 5$ y	3.99	1.61–9.84	0.003
Rope climbing preference	0.73	0.33–1.62	0.44
Hours per week (each hour)	1.14	1.06–1.24	0.001
Difficulty grade (each increase in group)	2.19	1.31–3.66	0.003
Injury location (compared to finger)			
Ankle	1.27	0.35–4.62	0.71
Elbow	0.78	0.15–4.03	0.77
Knee	2.19	0.48–9.92	0.31

OR, odds ratio.

**Table 4.** Predictors of seeking medical care for injury

	<i>OR</i>	<i>95% CI</i>	<i>P value</i>
Prolonged injury (>12 wk)	3.04	1.39–6.64	0.005
Age (each 10 y)	0.92	0.58–1.46	0.73
Male	1.39	0.64–3.03	0.40
Experience $\geq$ 5 y	1.22	0.63–2.33	0.56
Rope climbing preference	1.98	1.02–3.82	0.04
Hours per week (each hour)	1.03	0.96–1.11	0.37
Difficulty grade (each increase in group)	0.87	0.62–1.23	0.44
Has primary care practitioner	1.43	0.74–2.76	0.29
Has medical insurance	1.89	0.49–7.27	0.36
Fall	1.50	0.68–3.32	0.32

OR, odds ratio.

injury and preference for rope climbing to be the only 2 factors associated with seeking care. An explanation for the association with rope climbing was not elucidated in our study and could warrant further research. It is notable that we did not find an association between having a primary care practitioner or health insurance with seeking care. Among the climbers who sought care, the predominant reported theme was that of serious pain or limitation. Other themes such as concern about long-term effects or interest in injury prevention were much less common. Accordingly, among those who did not seek care, the absence of such pain or limitation was the most common theme

reported. Taken together with the association between prolonged injury and seeking care, this suggests that climbers may seek care only out of necessity. However, there were additional reported themes that were almost equally as common in injuries that were self-managed, including first, advice or reassurance being obtained from another person or self-research, and second, an unwillingness to seek medical care, such as having a belief that a medical practitioner could not do anything for the injury. Grønhaug et al<sup>23</sup> found similar themes in their study in which 24% of climbers reported a similar doubt about the knowledge of health professionals regarding climbing-related injuries, and 6% reported

**Table 5.** Thematic analysis of the reasoning behind self-management or seeking medical care (major themes)

	<i>Themes</i>	<i>Example statements</i>	<i>n</i>
Self-managed cohort	Minimal pain or interference with climbing or daily activities	The injury did not cause any pain outside of climbing	54
		The injury improved quickly without any intervention	
	Reassured by another person or self-research	The participant engaged in research using online climbing forums and blogs	46
		The participant discussed the injury with another climber at the gym, who provided advice	
	Prior experience or knowledge managing the injury	The participant had the same injury previously from another sport The participant knew how to manage the injury because of undergoing prior physical therapy	38
Unwillingness to seek medical care	The participant did not think that a medical practitioner could do anything for the injury The participant stated that they generally did not see medical practitioners unless absolutely necessary	36	
Sought medical care cohort	Difficulty accessing medical care	The participant was concerned about the financial cost of care, even with medical insurance	27
		The participant did not have time to attend a medical appointment	
	Serious pain or interference with climbing or daily activities	The injury caused severe pain and did not allow the participant to work or function normally	52
		The injury did not allow the participant to climb at their usual grade	
Worry about the diagnosis or long-term effects	The participant was worried about their older age and the long-term consequences of the injury	20	
	The participant was worried about the pop heard when they were injured		



receiving help from a friend. However, our discovery that many climbers prefer self-research, often online, is a new observation.

## LIMITATIONS

The study has several limitations. Retrospective survey data have the risk of recall bias, and participants were asked to recall the details surrounding injuries over the previous 3 y. In-person recruitment and convenience sampling may have increased the risk of sampling bias and led to a low sample size. The participants were recruited from a small number of gyms in New York City, which may limit the generalizability of the results to other geographic areas due to factors such as variability in grading practices. The study was conducted during the early stages of the COVID-19 pandemic, which may have affected injury prevalence and the participants' decision to seek care for some injuries. We did not specifically exclude competitive climbers and those who also climb outdoors. Climbers who engage in these activities may have characteristics or attitudes that may not be found in all gym-based climbers. We excluded injuries for which care was sought in the emergency department. Although we did so to avoid the inclusion of potentially severe injuries in which the climber did not have the choice between self-management and seeking medical care, and there were only 4 such injuries, this may have led to an underestimation of prolonged injury and the neglect of reasons for seeking care unique to those injuries. We excluded chronic injuries, which may have similarly led to an underestimation of injury burden. Furthermore, chronic injuries causing lengthy pain and disability may be common,<sup>24</sup> and we were unable to examine their association with prolonged injury. We did not collect demographic characteristics from the noninjured climbers. Further analysis between noninjured and injured climbers was not possible. The qualitative nature of the semistructured interview process could have led to reasons for self-management or seeking care being incompletely captured.

## Conclusions

In conclusion, in our limited retrospective study of self-reported injuries from a convenience sample of gym-based climbers, we found a 3-y injury prevalence of 43%. Of the injuries analyzed, 32% were prolonged. The results of this study suggest that prolonged injury was common among gym-based climbers, especially those of older age, those who climb at high difficulty levels, those with higher levels of experience, and those who climb frequently, yet only a third of injured climbers sought medical care. Outside of injuries causing minimal pain or

limitation, those who self-managed reported receiving advice from other climbers or online research as a prominent reason for that choice.

**Acknowledgments:** The authors acknowledge the 5 gyms that permitted data collection: The Cliffs at LIC, Brooklyn Boulders Queensbridge, Brooklyn Boulders Gowanus, Vital Brooklyn, and GP81. The authors also thank Amanda Lopez for assistance in data organization.

**Author Contributions:** study concept and design (JL, WS); IRB approval (JL, WS); data acquisition (JL, WS); data analysis (ZP); drafting and critical review of the final manuscript (JL, ZP, WS); approval of the final manuscript (JL, ZP, WS).

**Financial/Material Support:** None.

**Disclosures:** None.

## Supplemental Material(s)

Supplementary material associated with this article can be found in the online version at <https://doi.org/10.1016/j.wem.2023.05.002>.

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