ELSEVIER

PUBLIC HEALTH

www.elsevier.com/locate/puhe

Editorial Board

Editors-in-Chief

Andrew Lee *Sheffield, UK*
Joanne Morling *Nottingham, England, UK*

Senior Associate Editors

Cathy Johnman *Glasgow, UK*
John Ford *Cambridge, UK*
Ryan Swiers *Nottingham, UK*

Associate Editors

Sarah Gentry *Norwich, UK*
Ben Holden *Sheffield, UK*
Perihan Torun *Istanbul, Turkey*

Editorial Office

Melissa Davis
Natalia Camicia
Public Health Editorial Office,
RSPH, John Snow House,
59 Mansell St., London, E1 8AN,
Tel.: +44 (0) 207 265 7331
Fax: +44 (0) 207 265 7301
E-mail: public.health@rsph.org.uk

International Editorial Board

Rifat Atun *Boston, USA*
John Beard *Geneva, Switzerland*
Petri Bockerman *Turku, Finland*
Noriko Cable *London, UK*
Ann DeBaldo *Florida, USA*
Linda Degutis *Atlanta, USA*
Peter Donnelly *St. Andrews, UK*
Mark Eisler *Bristol, UK*
Brian Ferguson *York, UK*
Robert Friis *California, USA*
Sian Griffiths *Hong Kong*
Jay Glasser *Houston, Texas, USA*
John Goddeeris *Michigan, USA*
Lawrence Gostin *Washington, USA*
Michael Kelly *London, UK*
Giuseppe La Torre *Rome, Italy*
Roger Magnusson *Sydney, Australia*
Gerry McCartney *Glasgow, UK*
George Morris *Troon, Ayrshire, UK*
David Pencheon *Cambridge, UK*
Mala Rao *London, UK*
Devi Sridhar *Edinburgh, UK*
Seung Wook Lee *Seoul, Republic of Korea*

RSPH
ROYAL SOCIETY FOR PUBLIC HEALTH
VISION, VOICE AND PRACTICE

PUBLIC HEALTH 179 (2020) 90–99

Available online at www.sciencedirect.com

Public Health

journal homepage: www.elsevier.com/puhe

Original Research

Evaluating health benefits and cost-effectiveness of a mass-media campaign for improving participation in the National Bowel Cancer Screening Program in Australia

J. Worthington [a,*], E. Feletto [a], J.B. Lew [a], K. Broun [b], S. Durkin [b], M. Wakefield [b], P. Grogan [a], T. Harper [b], K. Canfell [a,c]

[a] Cancer Research Division, Cancer Council NSW, New South Wales, Australia
[b] Centre for Behavioural Research in Cancer, Cancer Council Victoria, Melbourne, Victoria, Australia
[c] Sydney School of Public Health, University of Sydney, Sydney, New South Wales, Australia

ARTICLE INFO

Article history:
Received 27 June 2019
Received in revised form
27 September 2019
Accepted 4 October 2019
Available online 22 November 2019

Keywords:
Colorectal cancer
Cancer screening
Cost-effectiveness
Mass media
Health campaigns

ABSTRACT

Objectives: The Australian National Bowel Cancer Screening Program (NBCSP) offers free 2-yearly immunochemical faecal occult blood testing to individuals aged 50–74 years; national participation in 2015–2016 was 41%. In 2017, a 7-week television-led mass-media campaign to increase participation in the Australian state of Victoria was associated with a 1.31-fold increase in participation for 11 weeks. We aimed to evaluate the cost-effectiveness and health benefits of the 2017 campaign and scaled-up equivalent campaigns run over 4 years in Victoria and nationally.

Study design: This study used microsimulation modelling.

Methods: A comprehensive microsimulation model of colorectal cancer (CRC), *Policy1-Bowel*, was used to simulate three scenarios. Scenario 1 simulated the 2017 campaign in Victoria; Scenarios 2 and 3 assumed that campaigns were run three times annually from 2019 to 2022 in Victoria and Australia-wide, respectively. Total campaign costs of AUD$1million, AUD$10million, and AUD$40million were assumed for Scenarios 1, 2, and 3, respectively. The incremental effects and costs of the campaign on the NBCSP were assessed. A governmental perspective was used.

Results: All campaign scenarios were predicted to be highly cost-effective, with cost-effectiveness ratios under AUD$4,800/life-year saved. The actual 2017 campaign in Victoria is estimated to prevent 319 CRC cases and 183 deaths over the following 40 years. A 4-year campaign would prevent 1,750 CRC cases and 987 deaths if conducted in Victoria, and 8,100 cases and 4,330 deaths if conducted Australia-wide.

Conclusion: Mass-media participation campaigns could be highly cost-effective and maximise the potential life-saving impact of bowel screening. These results support ongoing investment in major bowel screening campaigns.

* *Corresponding author*. Cancer Research Division, Cancer Council NSW, 153 Dowling St, Woolloomooloo, NSW, 2011, fax: +61 02 9334 1723.
E-mail address: Joachim.Worthington@nswcc.org.au (J. Worthington).
https://doi.org/10.1016/j.puhe.2019.10.003
0033-3506/© 2019 The Author(s). Published by Elsevier Ltd on behalf of The Royal Society for Public Health. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

© 2019 The Author(s). Published by Elsevier Ltd on behalf of The Royal Society for Public Health. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Introduction

In Australia, more than 5,000 individuals die of colorectal cancer (CRC, also known as bowel cancer) each year.[1] Since 2006, the population-wide government-run National Bowel Cancer Screening Program (NBCSP) has offered free screening by immunochemical faecal occult blood test (iFOBT) to eligible Australians.[2] Screening kits are mailed to eligible individuals which remain useable for approximately a year. As part of the phasing in of the NBCSP, different age groups have been invited to participate each year[2] and communicating eligibility for the NBCSP has required complex messaging. However, from 2019, iFOBT test kits will be mailed to all Australians between the ages of 50 and 74 years every 2 years.[2]

Screening programs are challenging to compare across countries because of variability in their test technology used, delivery method, national coverage, and stage of implementation.[3] Regardless, the aim for any successful program is high participation in the targeted group. In Australia, NBCSP participation in 2015–2016 was 40.9%;[4] globally, participation rates vary widely.[3] Previous evaluations have concluded that biennial iFOBT testing for people aged 50–74 years (i.e. current practice of the NBCSP) is effective and cost-effective. The current approach was found to be optimal for CRC screening in Australia, compared with using other screening technologies, age ranges, and intervals.[5–9] Those studies raised the possibility, but did not formally confirm, that a cost-effective investment to improve NBCSP-related outcomes would involve maximising NBCSP participation in the target age group. Predictions indicate that increasing NBCSP participation from 40% to 60% could save 83,800 lives from 2015 to 2040.[5] The findings of these studies have supported Australian clinical guidelines and future investment into the NBCSP.[8,10]

The challenge is to establish the evidence base to support investment in cost-effective interventions to improve NBCSP participation. As full rollout of the NBCSP has now been achieved, interventions to improve participation will potentially be simpler to implement and have a broader audience, as 2-yearly screening messaging is now applicable to more cohorts. Interventions to improve CRC screening participation internationally have had varying effectiveness[11] with typically modest improvements in participation.[12,13]

In Australia, a mass-media campaign was run in Victoria, a state of Australia, over 7 weeks in July and August 2017, to encourage eligible individuals to participate in the NBCSP.[14] The campaign was run and evaluated by Cancer Council Victoria, a non-government not-for-profit cancer charity, and increased participation 1.31-fold (95% confidence interval [CI]: 1.18–1.45) for 11 weeks. This study aimed to use these data to predict the long-term CRC outcomes and cost-effectiveness of the campaign, using an existing microsimulation platform (*Policy1-Bowel*).[5] We also evaluated hypothetical 4-year campaigns conducted in Victoria and Australia-wide from 2019 to 2022 to determine the effects of a longer increase to participation rates on health and economic outcomes. To date, formal evaluations of the cost-effectiveness and the predicted impact of large-scale real-world cancer screening campaigns on health outcomes have been limited. Only one study of the impact of a mass-media campaign aimed at improving CRC screening participation on long-term health outcomes was identified.[15] That study reported that the campaign would be cost-effective, but did not report long-term health outcomes or downstream costs.

Methods

Cancer Council Victoria mass-media awareness campaign evaluation

An evaluation of the immediate impact of the 2017 television-led mass-media campaign on NBCSP iFOBT kit returns has been described in detail elsewhere.[14] Briefly, a TV advertisement campaign with complementary radio and digital advertisements was run over a 7-week period in July and August 2017 in Victoria. South Australia, a neighbouring Australian region where the campaign was not run, was used as a control. The rate of iFOBT kit returns is here referred to as *NBCSP participation*. Compared with South Australia, a 1.31-fold increase in NBCSP participation was observed in Victoria over an 11-week period that covered both the 7-week on-air campaign and 4 weeks after the campaign finished.

In this study, the *2017 campaign* refers to the 11-week period for which an increase in NBCSP participation was observed.

Policy1-Bowel *model platform description*

The *Policy1-Bowel* microsimulation platform used for this study simulates the development of precancer lesions and CRC via two biological pathways, the conventional adenoma–carcinoma pathway (accounting for ~85% of CRC) and the serrated pathway (accounting for ~15% of CRC), in individuals. *Policy1-Bowel* has been extensively calibrated and validated to the Australian setting; detailed model design, parameter assumptions, model calibration, and validation results have been described previously.[5] A summary of key model parameters and data sources is provided in Appendix A.

For the current evaluation, all individuals were simulated from age 20 years to age 89 years or death (whichever comes first) using an annual time step. The probability of dying from non–CRC-related causes for simulated individuals was derived from the all-cause mortality data (excluding CRC mortality) in the Australian population.[16] The probability of cancer patients dying from CRC over the 5-year period after diagnosis varies by the cancer stage, time since cancer diagnosis, and whether the cancer was diagnosed via screening or was symptomatically detected. Those who survive for 5 years after diagnosis become cancer survivors. Recurrent CRC is not explicitly modelled.

The model simulates the phased implementation of the NBCSP over 2006–2018, and the fully implemented program from 2019.[5] For each year, the model simulates iFOBT kits being sent to all eligible individuals. The modelled proportions of iFOBT kits completed and returned (i.e. NBCSP participation) for each scenario evaluated in this study are described in the following section. *Policy1-Bowel* then calculates the iFOBT result based on the number and characteristics of adenomas and cancers in an individual, which have been calibrated to observed NBCSP positive rates, including false-positive iFOBTs.[5,17] For individuals with a positive iFOBT result, the model conservatively assumed that 67.4% of people in Victoria and 68.1% in Australia completed a follow-up with a diagnostic colonoscopy based on the observed data;[4] these rates are thought to be underestimates because of the non-mandatory reporting of colonoscopy to the NBCSP register.[4] The model assumes that all lesions detected by colonoscopy were successfully removed via a polypectomy. Individuals with lesions detected during a colonoscopy examination are followed up with a surveillance colonoscopy in 1–5 years depending on the colonoscopy outcome, in line with the Australian surveillance guidelines recommendations.[18,19] The compliance rate for surveillance colonoscopies is modelled at 80%, an assumption used by previous studies in the absence of observed data.[5–7,9] A non-fatal adverse event rate of 0.27% for colonoscopies is used, and an additional cost is associated with these cases.[17]

Modelled scenarios

Policy1-Bowel was used to simulate scenarios to estimate the impact of the 2017 campaign and to scale up to 4-year campaigns on NBCSP outcomes in Victoria and Australia-wide. The following scenarios were simulated:

- the **comparators** assumed NBCSP participation continued at rates observed from 2006 to 2015 (with Victorian rates used in the comparator for Scenarios 1 and 2, and Australian rates used in the comparator for Scenario 3);
- **Scenario 1** modelled the short- and long-term outcomes from the actual one-off 2017 mass-media awareness campaign in Victoria;
- **Scenario 2** modelled three (theoretical) scaled-up mass-media campaigns per year from 2019 to 2022 in Victoria; and
- **Scenario 3** modelled the same theoretical campaign duration and effectiveness as Scenario 2, run across all of Australia.

The period 2019–2022 was chosen for Scenarios 2 and 3, as full implementation of biennial screening for all cohorts aged 50–74 years began from 2019. This analysis used a multiple-cohort approach (i.e. simulating events occurring in the lifetime of multiple birth cohorts and providing cross-sectional outcomes over time) and focused on all individuals who were eligible for the NBCSP during the scenario-specific campaign period; this is referred to as the *modelled cohort*. For Scenario 1, this represents those aged 50, 54, 55, 58, 60, 64, 68, 70, 72, and 74 years in 2017. For Scenarios 2 and 3, this represents those born between 1945 and 1972 inclusive.

Policy1-Bowel separates the screening participation rates for individuals who have not previously participated in screening (i.e. screening initiation rates) and for individuals who have participated at least once (i.e. rescreening rates). Individuals who screen for the first time due to a campaign were therefore assumed to screen at the higher participation rate in subsequent NBCSP rounds, as they are assumed to transition to rescreening rates, which have been observed to be higher,[4] rather than screening initiation rates. The comparator NBCSP participation rates, including initiation rates and rescreening rates, were modelled based on the observed NBCSP participation rates in 2006–2016, ranging from 34% to 39% over this period in Victoria (Scenarios 1 and 2) and 36–44% in Australia (Scenario 3).[4] All rates vary by year, age, and sex, with women and older people having higher participation rates. In the absence of detailed data from the NBCSP monitoring reports, the baseline age-specific rates in Victoria were informed by the total participation rates observed in Victoria and the age- and gender-specific rates for Australia overall. For years after 2016, participation rates were estimated from the rates observed in 2014–2016.

Scenario 1 assumed a 1.31-fold increase in overall NBCSP participation rates from previously observed rates during the 11 weeks of the 2017 campaign.[14] Outside of the campaign period, participation rates were assumed to remain the same as the comparator.

Scenarios 2 and 3 assumed that three rounds of mass-media awareness campaigns would be conducted each year between 2019 and 2022 in Victoria and Australia, respectively. To simulate the impact of these campaigns, we assumed that NBCSP participation increased 1.31-fold from the observed rates for 33 weeks each year (accounting for the 11-week impact for each campaign round observed in the 2017 campaign). No increase in NBCSP participation was assumed for the remaining 19 weeks of the year. As *Policy1-Bowel* uses an annual time step, this was converted to an average 1.20-fold increase in NBCSP participation from the observed rates, equivalent to participation rates of approximately 45% in Victoria and 46% in Australia over a full year. For years before 2019 and after 2022, screening initiation and rescreening rates were assumed to be the same as those modelled for the comparator.

Costs

The study used a governmental perspective. The costs considered included those associated with the intervention (campaign), sending the iFOBT kits, laboratory analysis of the completed and returned iFOBT samples, general practitioner visits for follow-up iFOBT results, colonoscopy examination (and polypectomy if required) for follow-up iFOBT results and further surveillance, adverse events resulting from a colonoscopy, and cancer treatment. Overheads related to NBCSP administration (other than the costs of sending the iFOBT kits) and individuals' out-of-pocket costs were not included. For details, see Appendix A.

Based on the Victoria campaign evaluation,[14] campaign costs of AUD$1.06 million were assumed for the 2017 campaign (Scenario 1), and AUD$2.5 million per year was assumed for a 4-year scaled-up campaign (Scenario 2) in Victoria based on advice from campaign administrators regarding repeat versus one-off costs for multiple media campaigns. For Scenario 3, campaign costs of AUD$10 million per year were assumed for a 4-year Australia-wide campaign, to account for the larger target population (approximately four times that of the Victoria population).

Participation ranges

To illustrate the range of plausible outcomes, we also modelled 'high participation increase' and 'low participation increase' alternatives to Scenarios 1–3, based on the 95% CI of the participation increase observed in the 2017 campaign.[14] For high participation, we assumed a 1.45-fold increase in participation rates over 11 weeks, and for low participation, we modelled a 1.18-fold increase in participation rates. Averaged out over the entire year, these correspond to participation rates of 48% and 42%, respectively, in Victoria (Scenario 2), and 49% and 43%, respectively, in Australia (Scenario 3).

Model outcomes

For each scenario, the model was used to estimate the number of iFOBT kits completed and returned, colonoscopy demand (including both diagnostic and surveillance colonoscopies), the number of incident CRC cases and CRC deaths, total costs, and life-years saved. The model used Australian Bureau of Statistics Australian and Victorian demography data[20] from campaign years (those eligible for screening in 2017 for Scenario 1, those born between 1945 and 1972 inclusive for Scenarios 2 and 3) as a reference population to calculate outcomes. Outcomes are calculated over the lifetime of the modelled cohort, that is, 40 years from the final year of the campaign.

All costs are presented in 2015 Australian dollars (AUD$1 =US$ 0.7706 as at June 20, 2015). The cumulative discounted lifetime cost and life-years were calculated with a discount rate of 5% per annum from 2017 (Scenario 1) or 2019 (Scenarios 2 and 3). This discount rate has previously been used in a predicate Medical Services Advisory Committee evaluation of the National Cervical Screening Program in Australia.[21,22] The cost-effectiveness ratio (CER) of each campaign, presented as cost in AUD per life-years saved (LYS), was calculated versus the comparators (NBCSP with no campaign). This quantifies the amount of additional expenditure associated with saving a year of life. There is no official willingness-to-pay (WTP) threshold for cost-effectiveness evaluation for cancer prevention in Australia. Thresholds of AUD$30,000–50,000/LYS have been used in previous studies.[5,23,24] In this study, CERs are compared with a nominal WTP threshold of AUD$30,000/LYS.

We also calculated the return on investment (ROI), which expresses the return in terms of health outcomes and costs for every additional dollar invested in the campaign (beyond the cost of running the NBCSP itself). This was calculated by associating an AUD$30,000 value per discounted LYS (determined by WTP threshold), subtracting the additional discounted costs, and dividing the total by initial campaign investment, as shown in the below equation..

$$ROI = \frac{Life\ Years\ Saved\ \times\ AUD\$30,000\ -\ Additional\ Costs}{Direct\ Campaign\ Costs}$$

A time horizon for all costs and LYS of 2060 was used. Note that the ROI is sensitive to methodological changes, such as value per LYS, discounting, time horizon used, and which costs are included.[25]

Sensitivity analyses

One-way sensitivity analyses on selected model parameters were completed to study the impact on the cost-effectiveness. These included 20% higher and 20% lower campaign costs than the base case, waning campaign effectiveness in the third and fourth years of the campaign to capture possible campaign fatigue in Scenarios 2 and 3, and 15% higher 5-year survival for all CRC patients.

We also completed sensitivity analysis on more aggressive and less aggressive precancer natural histories which represent the range of parameter values found in the calibration of *Policy1-Bowel*.[5] The more aggressive natural history assumes a slightly higher prevalence of adenoma/sessile serrated polyps (SSP) in the population and a slightly faster progression of adenoma/SSP to CRC than the base case natural history assumption. By contrast, the less aggressive natural history assumes a slightly lower prevalence of adenoma/SSP in the population and a slightly slower progression of adenoma/SSP to CRC. Therefore, the model predicts a higher CRC incidence rate when assuming a more aggressive natural history, and predicts a lower CRC incidence rate when assuming a less aggressive natural history.

Full details of these scenarios are available in Appendix B.

Results

Resource utilisation

During the respective campaign periods, an additional 12,300 iFOBT kits would be returned versus the comparator in Scenario 1, 283,000 in Scenario 2, and 1,250,000 in Scenario 3 (Table 1; numerical results are presented to three significant figures).

During the respective campaign periods, an additional 768 colonoscopies would be required in Scenario 1, 16,300 in Scenario 2, and 73,000 in Scenario 3 (Table 1, Fig. 1). After campaign, colonoscopy demand would remain higher than the comparator.

Health outcomes

The short-term impact of the campaign would be the detection of non-symptomatic cancers and adenomas that would otherwise be undetected without the improvements to screening participation. An estimated 36 additional cancers would be detected during the campaign period in Scenario 1, 310 additional cancers in Scenario 2, and 1,710 in Scenario 3 (Table 1). In the longer term, an additional 319, 1,750, and 8,100 CRC cases and 183, 987, and 4,330 CRC deaths would be prevented over the 40 years after the campaign in Scenarios 1–3, respectively, versus the comparator (Table 1), because of the early detection of colorectal cancers and precancerous adenomas. Fig. 2 illustrates the estimated cumulative discounted LYS by the campaigns for Scenarios 1–3.

Costs, cost-effectiveness, and return on investment

Cumulative additional discounted costs for Scenarios 1–3 versus the comparator are shown in Table 1 and Fig. 3. For all scenarios, high annual upfront costs occurred during the campaigns because of campaign costs and additional costs associated with increased NBCSP participation. In later years, annual costs were predicted to drop lower than the comparators. The cumulative discounted additional costs over the 40 years after the campaign are AUD$1,160,000, AUD$9,800,000, and AUD$40,100,000 for Scenarios 1–3, respectively, versus the comparator (Table 1).

All scenarios were found to be highly cost-effective versus the comparator; the estimated CERs are AUD$3,440/LYS, AUD$2,770/LYS, and AUD$2,470/LYS for Scenarios 1–3, respectively, all under the nominal WTP threshold of AUD$30,000/LYS. The estimated ROIs are AUD$10.50, AUD$12.90, and AUD$15.80 per dollar invested in Scenarios 1–3, respectively (Table 1), including a value of AUD$30,000 per life year saved in the return.

Participation ranges

The three scenarios were also modelled at the low and high NBCSP participation increases. All outcomes for the scenarios with lower and higher participation increases are shown alongside the observed rates in Table 1. Over the 40 years after the campaign, Scenario 1 was predicted to be associated with an additional 133 (low participation increase) to 525 (high

Table 1 – Outcomes for Scenarios 1, 2, and 3.

	Observed participation increase (base case)	Low participation increase	High participation increase
Scenario 1 (2017 campaign, Victoria)			
Additional iFOBT kit returns in 2017	12,300	5,130	20,200
Additional colonoscopy services in 2017	768	320	1,260
Additional polypectomies 2017	328	137	537
Additional CRC cases detected in 2017	36	15	59
Additional CRC cases prevented, cohort lifetime	319	133	525
Additional CRC deaths prevented, cohort lifetime	183	76	300
Additional discounted costs, cohort lifetime (AUD) [a]	$1,160,000	$1,100,000	$1,220,000
Cost-effectiveness ratio (AUD/LYS) [b]	$3,440	$7,470	$2,310
Return on investment (AUD per AUD) [c]	$10.50	$4.35	$17.20
Scenario 2 (2019–2022 campaign, Victoria)			
Additional iFOBT kit returns, 2019–2022	283,000	114,000	461,000
Additional colonoscopy services, 2019–2022	16,300	6,360	26,600
Additional polypectomies, 2019–2022	7,050	2,720	11,600
Additional CRC cases detected, 2019–2022	310	83	538
Additional CRC cases prevented, cohort lifetime	1,750	836	2,700
Additional CRC deaths prevented, cohort lifetime	987	490	1,490
Additional discounted costs, cohort lifetime (AUD) [a]	$9,800,000	$7,200,000	$14,200,000
Cost-effectiveness ratio (AUD/LYS) [b]	$2,770	$3,510	$2,600
Return on investment (AUD per AUD) [c]	$12.90	$7.24	$19.70
Scenario 3 (2019–2022 campaign, Australia)			
Additional iFOBT kit returns, 2019–2022	1,250,000	504,000	2,030,000
Additional colonoscopy services, 2019–2022	73,000	29,400	119,000
Additional polypectomies, 2019–2022	32,500	13,000	52,500
Additional CRC cases detected, 2019–2022	1,710	821	2,880
Additional CRC cases prevented, cohort lifetime	8,100	3,700	11,900
Additional CRC deaths prevented, cohort lifetime	4,330	2,110	6,420
Additional discounted costs, cohort lifetime (AUD) [a]	$40,100,000	$42,900,000	$54,000,000
Cost-effectiveness ratio [CER] (AUD/LYS) [b]	$2,470	$4,990	$2,310
Return on investment [ROI] (AUD per AUD) [c]	$15.80	$7.29	$22.00

All results are versus the comparator (no change to NBCSP participation) and are presented to three significant figures.
NBCSP, National Bowel Cancer Screening Program; iFOBT, immunochemical faecal occult blood test; CRC, colorectal cancer; AUD, Australian Dollars; LYS, life-years saved.

[a] Cumulative discounted costs are discounted at a rate of 5% annually from 2017 (Scenario 1) or 2019 (Scenarios 2 and 3).

[b] Cost-effectiveness ratio was calculated using discounted lifetime cost and LYS versus the comparator, which were accumulated over the lifetime of the modelled cohort (the 40 years after the campaign) and discounted at a rate of 5% per annum from 2017 (Scenario 1) or 2019 (Scenarios 2 and 3).

[c] Return on investment in discounted dollars saved and discounted life-years saved valued at AUD$30,000/LYS, per dollar invested.

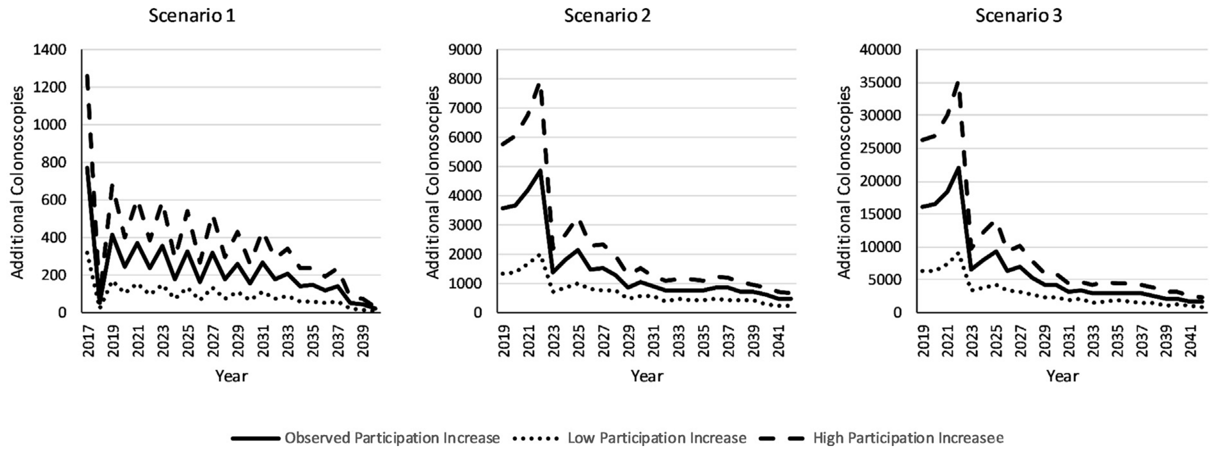

Fig. 1 – Absolute number of additional colonoscopies by year in (left to right) Scenario 1 (the 2017 campaign run in Victoria), Scenario 2 (the 2019–2022 4-year campaign in Victoria), and Scenario 3 (the 2019–2022 4-year campaign in Australia). Shown at the observed increase to participation rate, as well as the high and low participation increases modelled.

participation increase) CRCs prevented, 76–300 additional CRC deaths prevented, and AUD$1.1–1.2 million additional costs. In Scenarios 2 and 3, similar ranges were observed at higher and lower participation increases; see Table 1. At all modelled participation rates, all scenarios were estimated to remain very cost-effective.

Sensitivity analyses

Findings of the sensitivity analyses are summarised in Fig. 4. Given the nominal WTP threshold of AUD$30,000/LYS, all scenarios were predicted to remain highly cost-effective (associated with CER less than AUD$7,600/LYS vs no campaign) in all sensitivity analyses assessed in this study, including at higher costs, lower campaign effectiveness, higher CRC survival rates, and with the effects of the campaigns waning by 50% or completely in the third and fourth years for Scenarios 2 and 3. The campaigns were found to remain cost-effective under these alternative assumptions. Full cost-effectiveness results and descriptions can be found in Appendix B.

Discussion

To our knowledge, this is the first comprehensive evidence-based cost-effectiveness evaluation that considers all downstream health benefits and costs of a real-world mass-media campaign to promote participation in an organised CRC screening program. Our analysis found that the one-off 2017 campaign costing AUD$1.06 million was highly cost-effective and could prevent 183 CRC deaths in Victoria. If run three times a year over 4 years, this would increase to 1,750 deaths prevented if the campaign ran in Victoria only, and 4,330 deaths prevented if run Australia-wide. All modelled campaigns were found to be highly cost-effective, even

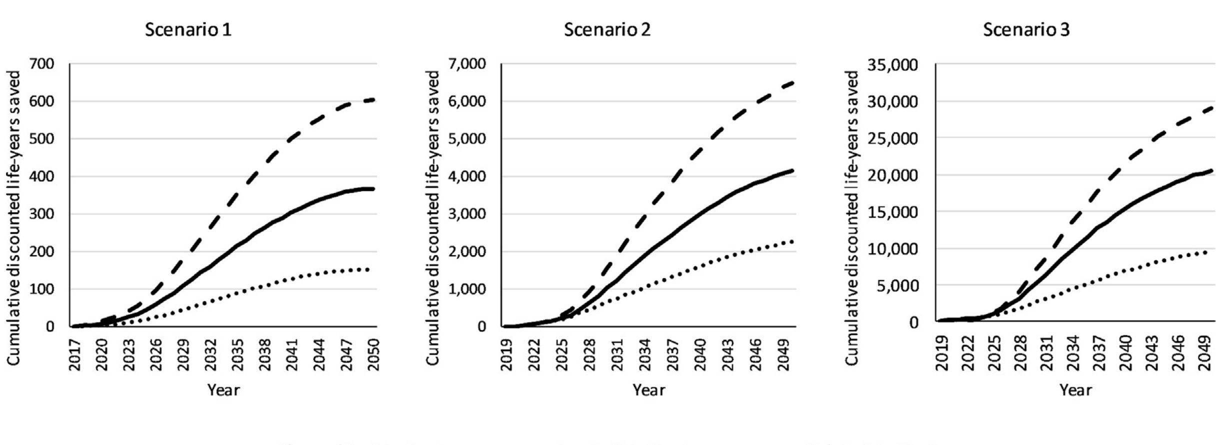

Fig. 2 – Model-estimated cumulative discounted life-years saved after the campaign for (from left to right) Scenario 1 (the 2017 campaign run in Victoria), Scenario 2 (the 2019–2022 4-year campaign in Victoria), and Scenario 3 (the 2019–2022 4-year campaign in Australia). Shown at the observed increase to participation rate, as well as the high and low participation increases modelled.

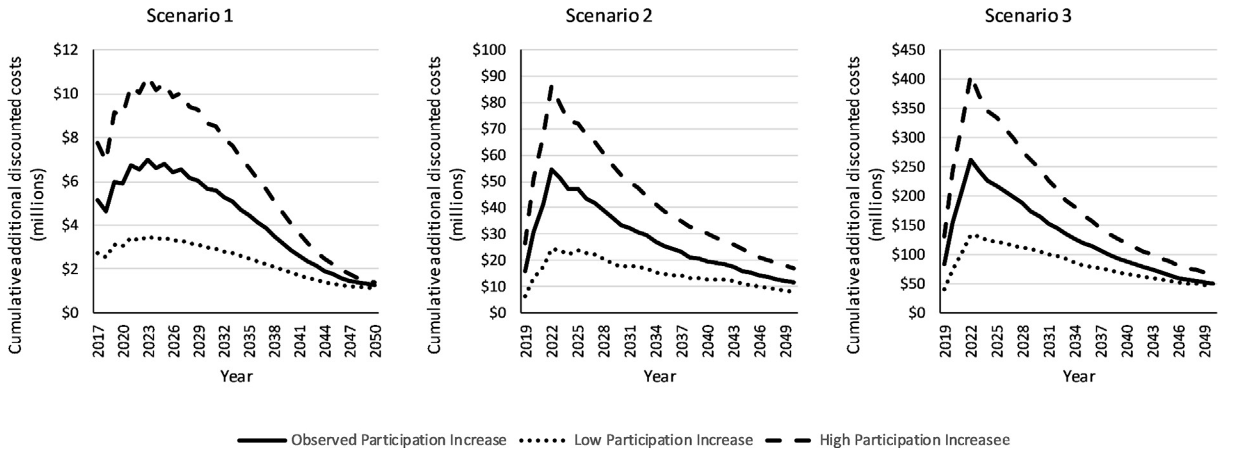

Fig. 3 – Model-estimated cumulative discounted additional costs after the campaign for (from left to right) Scenario 1 (the 2017 campaign run in Victoria), Scenario 2 (the 2019–2022 4-year campaign in Victoria), and Scenario 3 (the 2019–2022 4-year campaign in Australia). As the net effect of the campaign will decrease costs to the NBCSP after the initial investment, the cumulative additional costs decrease after the campaign period is completed. Shown at the observed increase to participation rates, as well as the high and low participation increases modelled.

considering a wide range of increases to participation, campaign costs, and alternative natural history assumptions. The results of the analysis provide a suite of outputs covering resource utilisations, health impact, and cost-effectiveness which could inform planning and investment, particularly around colonoscopy demand. By calculating the cost-effectiveness ratio, the utility of a mass-media campaign can be directly compared with other interventions.[26]

Improvement to screening participation is key to effective CRC control. Internationally, organised screening programs can vary substantially by recruitment method, screening test technology used, and return method,[11] and are therefore not always directly comparable. However, interventions used in other countries can highlight facilitators for CRC screening participation which could be transferred to other settings. For instance, evaluations have studied the effect of interventions including mass-media campaigns, reminder letters, and screening aids to improve CRC screening participation[13,27,28] or symptom recognition,[29] and the benefits of improved feedback and monitoring tools for physicians to engage patients in screening.[12] However, there are fewer complete cost-effectiveness analyses for general population awareness campaigns and their impact on cancer outcomes.[28,29] Combining cost-effectiveness analyses with explorations into the effectiveness of new interventions to improve cancer screening participation is important for selecting the best investment for public funding and could inform funding priorities for future and ongoing interventions to improve NBCSP coverage.

A key strength of this study is that a well-calibrated and validated comprehensive microsimulation model, *Policy1-Bowel*, was used to simulate the campaigns. *Policy1-Bowel* incorporates detailed and current data for the NBCSP participation rate, follow-up colonoscopy compliance, colonoscopy surveillance management, test accuracy of iFOBT and colonoscopy, and CRC treatment costs observed in Australia.[5–7] Furthermore, in this study, the model has incorporated costs and improvements to NBCSP participation attributable to the campaign based on real-world data observed in the 2017 campaign.[14] This allows us to generate well-supported predictions for long-term health outcomes, resource utilisation, and cost-effectiveness. Sensitivity analyses on key model parameters (including the campaigns' costs and effectiveness) were performed, and the cost-effectiveness findings for all campaigns analysed were found to be robust with respect to the parameters tested.

Another strength of this study is that it used a multiple-cohort approach to estimate long-term health benefits, resource utilisation, and cost-effectiveness of the campaign. Compared with the commonly used single-cohort approach which focuses on the outcomes of a single age cohort,[6,7] the multiple-cohort approach allows the study to account for the variation in the long-term impact for people who experience the campaign at different ages and have different life expectancies.

As is typical for simulation models, there are uncertainties associated with the model parameters. Particularly relevant for this study is uncertainty around future screening participation rates. The modelled screening participation rates from 2016 were estimated based on the data observed in 2015–2016 (latest data) and earlier.[4] Changes to screening behaviours in the future, whether as a result of interventions or a natural effect of the full rollout of the program, may affect the improvement in screening participation achievable by the mass-media campaign and, hence, the results of our analysis. However, it is unlikely that the NBCSP participation rate has changed considerably from the observed rates in 2015–2016 by 2019. We took a whole-of-government perspective for this analysis, but in practice costs in this analysis are borne by different levels or sections of government. For example, costs related to hospitalisation and treatment for colorectal cancer are split between state jurisdictional governments and federal government, whereas central costs of running the NBCSP and the mass media campaign are borne by the federal

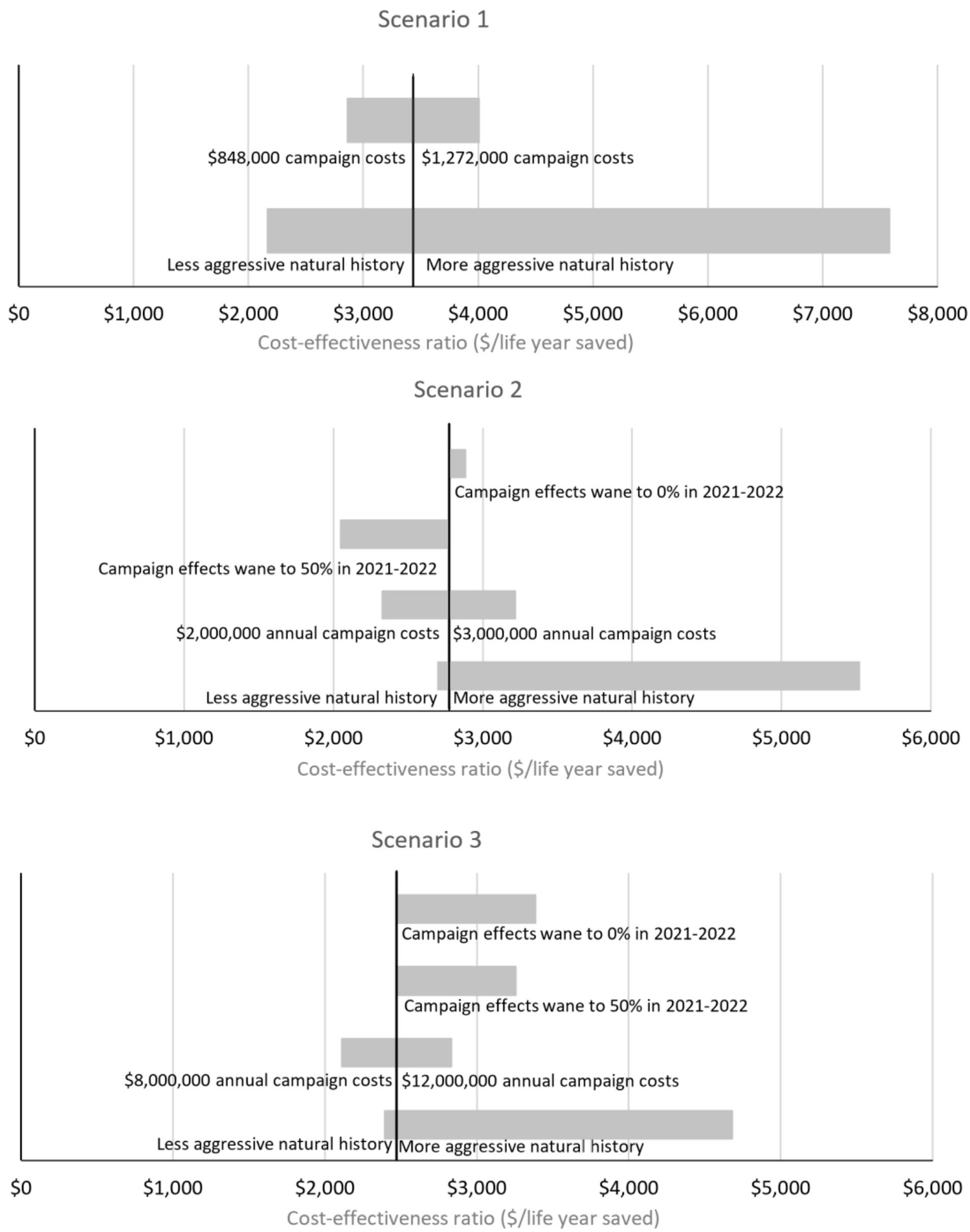

Fig. 4 – Cost-effectiveness of Scenario 1 (the 2017 campaign run in Victoria), Scenario 2 (the 2019–2022 4-year campaign in Victoria), and Scenario 3 (the 2019–2022 4-year campaign in Australia) under various sensitivity analyses. Detailed discussion can be found in Appendix B.

government. Therefore, our analysis must be viewed as taking an overarching perspective on government costs rather than adopting the perspective of any one government agency.

There is also a possibility of future changes to the costs and effectiveness of CRC screening and treatment due to the advancements in technology – these changes may alter the benefit and cost-effectiveness of screening, and will need to be tracked to perform updated evaluations as necessary. Advancements in immunotherapy have proven effective for some specific CRC subtypes, and there have been calls for further research into several new immune agents and other therapies for CRC treatment that could potentially improve outcomes.[30] In future, evaluations of treatment options and their associated outcomes could be conducted. Our sensitivity analysis which assumed higher survival rates showed that these campaigns would still be very cost-effective even if CRC treatments were significantly more effective (15% higher 5-year survival).

As more cohorts become eligible, loosely targeted media campaigns could have a larger impact as messaging would be relevant to a higher proportion of viewers. There may also be less confusion around eligibility for screening after full rollout is complete. However, it is possible that improvements in screening participation could be tempered by effects such as message fatigue or desensitisation,[31] and could vary widely by changes to campaign messaging and methodology.[32] We have explored the potential impact of desensitisation on the study's findings in the sensitivity analyses; both the 4-year Victoria (Scenario 2) and Australia-wide (Scenario 3) campaigns were predicted to remain highly cost-effective even if the campaign's effect was assumed to be completely diminished in the third and fourth years of the campaign. The impact of mass-media campaigns on behavioural change can vary widely.[33] We have explored a range of increases to program participation in the study; all scenarios were predicted to be highly cost-effective even when assuming screening participation increased by 1.18-fold during campaign weeks.

Another limitation of our study is that we have not considered health disutilities such as quality-adjusted life years or similar measures in the cost-effectiveness analysis. We have therefore not captured quality-of-life effects associated with screening, colonoscopy, cancer diagnosis, and cancer treatment. Health disutility assumptions are very sensitive to uncertainty and setting-specific data are limited; previous comparable studies have also used unweighted life-years as a primary output.[5] Future studies which address quality-of-life concerns could also address the psychosocial issues associated with screening, especially false-positive iFOBT screening and adverse events after a colonoscopy. It should also be noted that there is significant out-of-program screening for CRC in Australia, including both non-NBCSP iFOBT and screening colonoscopies.[34] Some of this screening is for individuals who are at a higher risk of CRC, or who believe they are at a higher risk; the current NBCSP does not discriminate by risk group. This is not captured in the model currently; any effects the campaigns may have on out-of-program screening is not captured.

The predictions of previous modelling studies[35] indicate that improving NBCSP participation is key to reducing the burden of CRC in Australia. Participation rates remain disparate among population subgroups, notably by age, gender, location, language spoken at home, and Aboriginal and Torres Strait Islander status.[4] The potential benefit of interventions targeted at population subgroups should be explored by future research.

An analysis of Australian incidence trends indicated a rise in CRC in people under 50 years.[36] A focus on CRC prevention through healthy lifestyles from an early age is increasingly important to maintain the decreasing incidence observed in people over 50 years. Mass-media campaigns can support this behavioural change.[33]

Combined with previous evidence showing that increased participation among the NBCSP's 50–74-year-old cohort should be prioritised to further reduce the burden of CRC in Australia,[6,7] this study shows that mass-media screening interventions can be cost-effective investments to achieve this goal. In acknowledgement of this, the Australian Government has recently awarded a grant of AUD$10 million to improve NBCSP participation through a national mass-media campaign for one year which will allow for further analyses of the longer-term effects of a rolling campaign.[10] Continual evaluation and monitoring of this campaign's impact on NBCSP participation in and ongoing estimates of longer term impact *Policy1-Bowel* is currently planned. The need for continued and robust monitoring of any organised CRC screening program is illustrated by this study, as small changes to participation could have a considerable long-term impact.

Author statements

Authors' contributions

JW led the participated in study design and drafted the manuscript. JBL, EF, KB, and SD participated in the study design, results analyses, interpretations, and manuscript preparation. MW, TH, and PG participated in the study design. KC oversaw the project. All authors reviewed the study's findings and read and approved the final manuscript.

Ethical approval

Not required; modelling study with no human participants.

Funding

This work is funded by National Health and Medical Research Council Australia Career Development Fellowship (CDFs APP1007994 and APP1082989) for Karen Canfell. The funder had no role in study design, data collection, or data analysis.

Conflicts of interest

KC is co-PI of unrelated investigator-initiated trial of cervical screening in Australia ('Compass') conducted by the Victorian Cytology Service, which has received a funding contribution from Roche Molecular Systems and Ventana Inc., USA.

REFERENCES

1. Australian Institute of Health and Welfare. *Australian Cancer Incidence and Mortality (ACIM) books: colorectal cancer*. Canberra: AIHW; 2018.
2. Australian Government Department of Health. *National bowel cancer screening progam quality framework*. http://www.cancerscreening.gov.au; October 2016.

3. Schreuders EH, Ruco A, Rabeneck L, Schoen RE, Sung JJ, Young GP, et al. Colorectal cancer screening: a global overview of existing programmes. *Gut* 2015;**64**(10):1637–49.
4. Australian Institute of Health and Welfare. *National bowel cancer screening program: monitoring report 2018. Cat. No. CAN 112*. Canberra: AIHW; 2018.
5. Lew JB, St John DJB, Xu XM, Greuter MJE, Caruana M, Cenin DR, et al. Long-term evaluation of benefits, harms, and cost-effectiveness of the National Bowel Cancer Screening Program in Australia: a modelling study. *The Lancet Public health* 2017;**2**:e331–40.
6. Lew JB, St John DJB, Macrae FA, Emery JD, Ee HC, Jenkins MA, et al. Benefits, harms, and cost-effectiveness of potential age extensions to the national bowel cancer screening program in Australia. *Cancer Epidemiol Prev Biomark* 2018;**27**(12):1450–61.
7. Lew JB, St John DJB, Macrae FA, Emery JD, Ee HC, Jenkins MA, et al. Evaluation of the benefits, harms and cost-effectiveness of potential alternatives to iFOBT testing for colorectal cancer screening in Australia. *Int J Cancer* 2018;**143**(2):269–82.
8. Cancer Council Australia Colorectal Cancer Guidelines Working Party. *Clinical practice guidelines for the prevention, early detection and management of colorectal cancer*. 2017. Sydney.
9. Cenin DR, St John DJB, Ledger MJ, Slevin T, Lansdorp-Vogelaar I. Optimising the expansion of the national bowel cancer screening program. *Med J Aust* 2014;**201**(8):456–61.
10. Australian Government Department of Health. *$10 million to boost bowel cancer screening participation [press release]*. 2019. 2019 18th January.
11. Martini A, Morris JN, Preen D. Impact of non-clinical community-based promotional campaigns on bowel cancer screening engagement: an integrative literature review. *Patient Educ Couns* 2016;**99**(10):1549–57.
12. Jonah L, Pefoyo AK, Lee A, Hader J, Strasberg S, Kupets R, et al. Evaluation of the effect of an audit and feedback reporting tool on screening participation: the Primary Care Screening Activity Report (PCSAR). *Prev Med* 2017;**96**:135–43.
13. White B, Power E, Ciurej M, Lo SH, Nash K, Ormiston-Smith N. Piloting the impact of three interventions on guaiac faecal occult blood test uptake within the NHS bowel cancer screening programme. *BioMed Res Int* 2015;**2015**:928251.
14. Durkin SJ, Broun K, Spittal MJ, et al. Impact of a mass media campaign on participation rates in a National Bowel Cancer Screening Program: a field experiment. *BMJ Open* 2019;**9**(10):e024267.
15. Lich KH, Cornejo DA, Mayorga ME, Pignone M, Tangka FK, Richardson LC, et al. Cost-effectiveness analysis of four simulated colorectal cancer screening interventions, North Carolina. *Prev Chronic Dis* 2017;**14**.
16. Australian Institute of Health and Welfare. *GRIM (general record of incidence of mortality) books 2013: all causes combined*. Canberra: AIHW; 2015.
17. Australian Institute of Health Welfare. *National Bowel Cancer Screening Program: monitoring report 2013–14. Cancer series no. 94. Cat. no.* CAN 92. Canberra: AIHW; 2015.
18. Australian Cancer Network Colorectal Cancer Guidelines Revision C. *Clinical practical guidelines for the prevention, early detection and management of colorectal cancer*. Sydney: The Cancer Council Australia and Australian Cancer Network; 2005.
19. Barclay K, Cancer Council Australia Surveillance Colonoscopy Guidelines Working Party. *Algorithm for colonoscopic surveillance intervals - adenomas*. New South Wales: Cancer Council Australia; 2013.
20. Australian Bureau of Statistics. 3222.0 - population Projections, Australia, 2012 (base) to 2101 2013 [The population projections presented in this publication cover the period 2012 to 101 for Australia and to 61 for the states and territories, and capital cities and balance of state regions.]. Available from: http://www.abs.gov.au/ausstats/abs@.nsf/mf/3222.0.
21. Australian Government Department of Health. *The pharmaceutical benefits advisory committee*. PBAC) Guidelines; 2016.
22. Lew JB, Simms KT, Smith MA, Hall M, Kang YJ, Xu XM, et al. Primary HPV testing versus cytology-based cervical screening in women in Australia vaccinated for HPV and unvaccinated: effectiveness and economic assessment for the National Cervical Screening Program. The Lancet Public Health.2(2):e96-e107.
23. Simms KT, Laprise J-F, Smith MA, Lew J-B, Caruana M, Brisson M, et al. Cost-effectiveness of the next generation nonavalent human papillomavirus vaccine in the context of primary human papillomavirus screening in Australia: a comparative modelling analysis. *The Lancet Public Health* 2016;**1**(2):e66–75.
24. Medical Services Advisory Committee. *Application No. 1276 – renewal of the national cervical screening program*. 2014.
25. Masters R, Anwar E, Collins B, Cookson R, Capewell S. Return on investment of public health interventions: a systematic review. *J Epidemiol Community Health* 2017;**71**(8):827–34.
26. Vos T, Carter R, Barendregt J, Mihalopoulos C, Veerman L, Magnus A, et al. *Assessing cost-effectiveness in prevention: ACE–prevention September 2010 final report*. University of Queensland; 2010. Report No.: 1742720064.
27. Cooper CP, Gelb CA, Hawkins NA. How many "Get Screened" messages does it take? Evidence from colorectal cancer screening promotion in the United States, 2012. *Prev Med* 2014;**60**:27–32.
28. Ekwueme DU, Howard DH, Gelb CA, Rim SH, Cooper CP. Analysis of the benefits and costs of a national campaign to promote colorectal cancer screening: CDC's Screen for Life—national Colorectal Cancer Action Campaign. *Health Promot Pract* 2014;**15**(5):750–8.
29. Whyte S, Harnan S. Effectiveness and cost-effectiveness of an awareness campaign for colorectal cancer: a mathematical modeling study. *Cancer Causes Control* 2014;**25**(6).
30. Kruger S, Ilmer M, Kobold S, Cadilha BL, Endres S, Ormanns S, et al. Advances in cancer immunotherapy 2019–latest trends. *J Exp Clin Cancer Res* 2019;**38**(1):268.
31. Cho H, Salmon CT. Unintended effects of health communication campaigns. *J Commun* 2006;**57**(2):293–317.
32. Young B-R, Gwede CK, Thomas B, Vazquez-Otero C, Ewing A, Aguado Loi CX, et al. A systematic review of US-based colorectal cancer screening uptake intervention systematic reviews: available evidence and lessons learned for research and practice. *Frontiers in Public Health* 2019;**7**:145.
33. Wakefield MA, Loken B, Hornik RC. Use of mass media campaigns to change health behaviour. *Lancet* 2010;**376**(9748):1261–71.
34. Australian Government Department of Health. *Review of the National Bowel Cancer Screening Program*. Canberra: Australia Government Department of Health; 2012.
35. Lew JB, Feletto E, Wade S, Caruana M, Kang Y-J, Nickson C, et al. Benefits, harms, and cost-effectiveness of cancer screening in Australia: an overview of modelling estimates. *Public Health Research & Practice* 2019;**29**(2).
36. Feletto E, Yu XQ, Lew JB, St John DJB, Jenkins MA, Macrae FA, et al. Trends in colon and rectal cancer incidence in Australia from 1982 to 2014: analysis of data on over 375,000 cases. *Cancer Epidemiol Biomark Prev* 2019;**28**(1):83–90.

Appendix Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2019.10.003.

PUBLIC HEALTH 179 (2020) 68–75

Available online at www.sciencedirect.com

Public Health

journal homepage: www.elsevier.com/puhe

Original Research

Mid-upper arm circumference as a substitute of the body mass index for assessment of nutritional status among adult and adolescent females: learning from an impoverished Indian state

A. Das, G. Saimala, N. Reddy, P. Mishra, R. Giri, A. Kumar, A. Raj, G. Kumar, S. Chaturvedi, S. Babu, S. Srikantiah, T. Mahapatra*

CARE India Solutions for Sustainable Development, H No. 14, Patliputra Colony, Patna, Bihar, 800013, India

ARTICLE INFO

Article history:
Received 20 September 2018
Received in revised form
17 May 2019
Accepted 11 September 2019
Available online 14 November 2019

Keywords:
Anthropometry
Body mass index
Mid-upper arm circumference
Malnutrition
Women's health

ABSTRACT

Objectives: For population-level screening of malnutrition among adults—especially in developing-country settings—the body mass index (BMI) can be impractical because of logistical requirements for weight and height measurement. We analyzed anthropometric data collected from a large-scale nutritional survey on women of rural Bihar to determine the mid-upper arm circumference (MUAC) cutoffs corresponding to standard BMI cutoffs and the predictive accuracies of the determined cutoffs.
Study design: It was a cross-sectional study using multistage cluster sampling.
Methods: The current analysis used anthropometric data from a study on dietary practices of rural women (adolescents, lactating mothers, and women in the interpregnancy period). The MUAC (cm) cutoffs corresponding to four standard BMI (kg/m^2) values were determined using receiver operating characteristic (ROC) curve analysis.
Result: We detected a significant positive correlation between BMI and MUAC ($r = 0.81$, $P < 0.0001$). In ROC curve analysis, the MUAC cutoffs corresponding to BMI cutoffs of 18.5, 23, 25, and 30 kg/m^2 were estimated to be 23.2, 26.0, 27.3, and 30.5 kg/m^2, respectively. The predictive accuracy of the determined cutoffs was good, as indicated by the area under the ROC curve for the four different cutoffs—which ranged between 88% and 97%. Other than the cutoff for 'obese' (BMI, 30 kg/m^2), the *Kappa* coefficients for the rest of the MUAC cutoffs showed 'substantial' agreement (>0.6) with their BMI counterparts.
Conclusion: The results suggest that the cutoffs based on MUAC—a less resource-intensive measure than BMI—can be used for community-based screening of malnutrition among women of Bihar.

© 2019 CARE India Solutions for Sustainable Development, Bihar Technical Support Program. Published by Elsevier Ltd on behalf of The Royal Society for Public Health. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

* *Corresponding author.*
E-mail address: tanmay@careindia.org (T. Mahapatra).
https://doi.org/10.1016/j.puhe.2019.09.010
0033-3506/© 2019 CARE India Solutions for Sustainable Development, Bihar Technical Support Program. Published by Elsevier Ltd on behalf of The Royal Society for Public Health. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Introduction

Nutrition is one of the key determinants of the quality of life both among children and adults.[1] Malnourishment among adult women is associated with a variety of subsequent illnesses that lead to increased risk of morbidity and mortality and affect the country's economy by increasing the burden on state-funded and out-of-pocket expenditure and also by affecting productive life years.[2–4] From public health perspective, nutritional status of adolescent and adult women, especially those of reproductive age, is an important parameter to assess the overall health status of a nation.[5] However, only a few community-based studies in India have assessed the nutritional status of adult women as most of such studies have focused on ‘infants and young children’.[6]

Various anthropometric measurement techniques are used to assess nutritional status such as body mass index (BMI), mid-upper arm circumference (MUAC), measurement of the thickness of triceps or subscapular skinfolds, and calf circumference.[7] Although these anthropometric assessments are considered to be less reliable for assessing malnutrition than sophisticated but expensive body composition assessment techniques such as hydrodensitometry, electronic bioimpedance, dual-energy X-ray absorptiometry, and so on,[8–10] simplicity of usage and low cost of implementation make these assessments the ideal choice for population-based evaluations.[10,11] BMI, a marker for generalized adiposity and measured as body weight (in kg) divided by height (in meter^2) squared, is the most widely used anthropometric measure as it is inexpensive and non-invasive and can be collected by evaluators with minimal training.[12,13] Therefore, assessment of BMI became popular not only as individual-level clinical and nutritional assessments but also as a survey tool, especially for assessment of undernutrition in developing nations.[13,14] A BMI of <18.5 kg/m^2 is widely accepted as a sign of chronic energy deficiency, where the energy intake equals the energy expenditure, regardless of body weight and body energy stores.[15] Moreover, prior research studies suggest that BMI, besides being a sensitive marker for nutritional deficiencies/surplus and a crucial determinant of morbidities associated with malnutrition,[16] can also serve as a surrogate for the socio-economic status of a community.[13,14,17] Nevertheless, in large-scale population-based surveys and for regular monitoring, assessment of BMI is often impractical because of logistical reasons as the equipment for assessment of weight and height often proves unwieldy in the field. Moreover, it is difficult to measure weight and height for non-ambulatory participants/patients.

Under these circumstances, MUAC, a popular anthropometric measure for assessing the nutritional status of children younger than 5 years, has been suggested as an alternative for nutritional status evaluation of adults as well—especially in resource-limited settings.[18,19] MUAC has long been used as a tool for anthropometric measurement as it is easier to implement than BMI, with minimum requirement of equipment and acceptable sensitivity and specificity for detecting underweight.[19,20] During recent times, MUAC has been used for evaluation of adult nutritional status as well, especially in resource-limited settings, including India.[11,16,18,20–22] Prior studies also suggest that MUAC can be an efficient indicator of adult undernutrition—comparable or even better than BMI.[16,23] Thus, given its simplicity and attribute of being less resource intensive, MUAC could be an ideal choice for community-based assessment of undernutrition among rural Indian women. Against this background, the present study sets out to determine the MUAC cutoffs equivalent to BMI cutoffs among adolescent and married women of reproductive age in Bihar.

Methods

Study objectives

The Concurrent Measurement and Learning unit of CARE India's Bihar Technical Support Program conducted the ‘Women's Nutrition Study’ in August–September 2016 with the following key objectives:

- To assess the adequacy of food and nutrient (both macronutrients and micronutrients including dietary diversity) intake among women
- To estimate the coverage of iron folic acid supplementation and anthelmintics and determine consumptions of the same
- To evaluate the anthropometric indicators in the study population
- To understand the knowledge level and practices regarding various women's nutritional parameters

Study design

The present study used a cross-sectional design implemented using multistage cluster sampling.

Study sample

The study collected data from the following groups of women (representative of women of rural Bihar)—(1) pregnant; (2) lactating; (3) non-pregnant and non-lactating women (women in the interpregnancy period [WIPP]); and (4) adolescent women (married or unmarried) who did not belong to any of the aforementioned categories. The four groups of participants were decided based on the four key beneficiary groups under the current nutrition program: adolescent women, pregnant women, lactating women, and also WIPP (as these women are likely to be pregnant again). Given the low age of marriage and first pregnancy in rural Bihar,[24] the sampled adolescents were also expected to be representative of the women who have never been pregnant. The selection criteria of different groups of women were as follows:

Selection criteria for the different groups of women.			
Pregnant women	Lactating women	Non-pregnant, non-lactating women	Adolescent women
• In the 2nd or 3rd trimester of pregnancy • Adult (≥18 years)	• Biological mothers of up to 6-month-old living children • Ever breastfed the last born child • Adult (≥18 years)	• Mothers who have had at least one live birth and intend to have another child • Adult (≥18 years)	• Between 15 and 17 years old (married or unmarried), lowest age encountered in the sample was 15 years • Non-pregnant and non-lactating

To ensure statewide representativeness, respondents were selected from all 534 blocks (subdistricts) in Bihar. For within-block sampling, a list of Anganwadi centers (AWCs)—village-level institutions providing basic healthcare services—was used. From each block, two AWC catchment areas were selected by cluster random sampling. This sampling strategy resulted in selection of 1068 (534*2) AWC catchment areas across Bihar. In the selected AWC catchment areas, one index household was selected using a random number table. Then, following a 'Right-hand (clockwise)' rule (and excluding first five households from the index household), the enumerators went around the village until they came across a household containing an eligible, consenting participant from any of the four target groups. Once a successful interview was conducted, the next five households were excluded to lower possible neighborhood effect regarding knowledge/behavior, and search for next eligible participant was continued using the 'Right-hand' rule. As many of the nutritional parameters and proximal outcomes such as knowledge may depend largely on the quality of services provided by the designated Anganwadi workers (AWWs), only a single participant from each group was interviewed in each of the selected AWC catchment areas to minimize the effect of intracluster correlation in the overall sample.

Measurements

From each of the sampled AWC catchment areas, interviews on dietary intake pattern and food availability were conducted with one eligible participant belonging to each of the four categories, resulting in 1068 respondents per category. For selection of eligible women from within the selected AWC catchment areas, a systematic sampling methodology similar to that used in earlier studies[25,26] was used.

Standard anthropometric measurements—standing height and weight—were carried out for approximately 25% of the consenting respondents (25% from each target group—the AWC catchment areas for measurement were selected beforehand using simple random sampling). MUAC was measured for all participants. In the subsample selected for anthropometric measurement, if the interview was not completed (or if the participant provided consent for interview only but not for measurement), then a replacement interview was conducted in the same village with a participant belonging to the same target group. Standing height, weight, and MUAC were measured using portable stadiometers (SECA code 213), digital weighing flat scales (SECA code 874), and non-stretchable measuring tapes, respectively. The weighing machine was calibrated to measure differences of up to 10 g, whereas one millimeter was the minimum measurement possible for height and MUAC. For measuring height, it was ensured that the participant neither was wearing any footwear/socks nor had any buns/hair ornaments. The participants were instructed to stand with the back of their head, scapula, buttocks, and back of heels making contact with the back plate of the stadiometer and the toes pointing outward. The head was positioned so that the infraorbital ridge and upper border of the external auditory meatus was in the same horizontal plane (Frankfort's plane). During weight measurement, the participants were requested to remove any heavy removable items/clothing/shoes, as far as culturally appropriate, and stand on the center of the weighing machine with hands at their sides and looking straight ahead. MUAC measurement was performed in the left arm at the midpoint of the acromion process and olecranon process. Each of the anthropometric measurement was conducted twice, and both the values were recorded. At the analysis level, the arithmetic mean of the two measures was calculated. Other than pregnant women, anthropometric data from the rest of the three categories of women were used for the current analysis.

Overall, 310 enumerators, who underwent standardized training in different batches, conducted data collection and MUAC measurements. From these enumerators, 80 were selected for further training on anthropometric assessments, i.e., assessment of height and weight.

Statistical analysis

Descriptive analyses were carried out to determine the distribution of sociodemographic and anthropometric characteristics of the study population. The nature of relationship (linear/curvilinear) between BMI and MUAC was assessed using Box–Cox transformation and identity function (Transreg procedure in SAS). After establishment of a linear relationship (based on the 'lambda' value), we performed Pearson's correlation between BMI and MUAC to assess if a statistically significant positive or negative association existed between these two variables. Simple linear regression analysis was performed to determine the strength of association (and statistical significance) between BMI and MUAC. The MUAC values corresponding to four standard BMI cut points,[27] namely, 18.5, 23, 25, and 30 kg/m^2, were determined using receiver operating characteristic (ROC) curve analysis. Three methods were used to estimate the optimal cutoff values from the ROC curves: (1) Youden's J statistic; (2) minimized distance to the (0,1) point in the ROC curve; and (3) sensitivity-specificity equality.[28–31] In case of discordance between these three methods, the cutoff value determined by Youden's J statistic was chosen. Furthermore, the predictive accuracy of each cutoff point for MUAC was assessed by determining the sensitivity, specificity, and total misclassification percentage against the corresponding BMI cutoff. We also assessed Cohen's *Kappa* statistic to determine the agreement between the standard BMI cutoffs and MUAC cutoffs estimated by the aforementioned process. SAS version 9.4 was used to conduct all statistical analyses. The confidence interval was set at 95%, and the significance level, at 5%.

Results

In total, we had complete anthropometric information on 618 women; of which, 213 were adolescents, 212 were lactating mothers, and 193 belonged to the WIPP group. The mean age of the adolescent participants was 16 years (standard

Table 1 – Sociodemographic and anthropometric characteristics of the study participants. Women's nutrition study, Bihar, 2016.

Characteristics	Adolescents (N = 213)	Lactating mothers (N = 212)	Women in the interpregnancy period (N = 193)
	Percentage[a]	Percentage[a]	Percentage[a]
Religion			
Hindu	84.5	85.4	87.6
Muslim	15.5	14.6	11.9
Others	0.0	0.0	0.5
Caste			
Scheduled caste	18.3	20.3	21.8
Scheduled tribe	2.4	1.9	2.6
Other backward castes	64.3	67.0	63.7
Others/general caste	15.0	10.9	11.9
Type of family			
Nuclear family	64.3	50.5	59.6
Joint family	35.2	48.6	40.4
Type of house[b]			
Kaccha	23.9	26.4	25.9
Semi-pucca	56.8	59.9	56.5
Pucca	19.3	13.7	17.6
Source of drinking water			
Piped water (own/community tap)	4.3	1.9	2.6
Hand pump (own/community)	94.3	95.3	94.3
Others (dug well, pond, river, and so on)	1.4	2.8	3.1
Type of toilet			
Own flush toilet	21.1	17.9	17.1
Own pit toilet	8.5	6.1	7.8
Community/public toilet	0.5	0.5	0.0
No facility/open defecation	70.0	75.5	75.1
Education			
No formal education	0.0	1.82	2.0
Studied up to 8th standard	34.04	48.18	41.0
Studied higher than 8th standard	65.96	50.0	57.0
Husband's education[c]			
No formal education	0.0	0.7	0.0
Studied up to 8th standard	29.41	33.57	40.6
Studied higher than 8th standard	70.59	65.73	59.4
Family's asset index[d]			
1st tertile (low wealth)	23.47	33.49	32.12
2nd tertile (middle wealth)	36.62	35.85	35.75
3rd tertile (high wealth)	39.91	30.66	32.12
	Mean (±SD)	Mean (±SD)	Mean (±SD)
Age (years)	16 (1.2)	24 (4.6)	25 (4.7)
Weight (kg)	42 (5.6)	45 (7.5)	45 (7.9)
Height (cm)	150 (8.8)	149 (5.6)	150 (5.8)
Body mass index (kg/m^2)	19 (8.7)	20 (2.9)	20 (3.2)
Mid-upper arm circumference (cm)	23 (2.2)	24 (3.0)	23 (3.9)

SD, standard deviation.
[a] Observations with missing values excluded as applicable.
[b] Type of house: ‘kaccha’—house made of mud, grass, bamboo, thatch, and other low-quality materials; ‘pucca’—structure made of brick; ‘semi-pucca’—any combination of the components of ‘kaccha’ and ‘pucca’ houses.
[c] Only for married adolescents (N = 27).
[d] Based on possession of 25 different household items.

deviation [SD], 1.2), whereas that of lactating mothers and WIPP was 24 (SD, 4.6) and 25 (SD, 4.7) years, respectively. In all study groups, Hindus were an overwhelming majority, whereas in terms of caste, women from 'other backward castes' comprised about two-thirds of the participants. Approximately, four of five women lived in a non-pucca (not entirely built of brick) house, and about one-fifth of them had access to a flush toilet. In terms of education, the adolescent women fared much better than the other two groups; 58% of them completed more than eight years of school education as against less than 30% in rest of the groups. The socio-economic and sociodemographic characteristics of the study participants are presented in Table 1.

Using Box–Cox power transformation for the simple linear regression model with BMI as the dependent variable and MUAC as the sole independent variable, we obtained a lambda value of 1.1 and an adjusted R-squared value of 0.74. Based on the lambda value of close to 1, it was determined that a linear relationship existed between BMI and MUAC.[32] From the results of linear regression analysis, it was determined that the linear relationship between BMI and MUAC could be expressed by the following equation: $\boldsymbol{BMI = -3.24 + 0.96^{*}MUAC} + \varepsilon$ (P-value for slope < 0.0001). Furthermore, a statistically significant positive relationship between BMI and MUAC was also established by a high Pearson's correlation coefficient ($r = 0.81$, $P < 0.0001$). The linear relationship between BMI and MUAC with 95% prediction limits is depicted in Fig. 1. In the ROC curve analysis, the area under the curve for the four different cutoffs for BMI ranged between 88% and 97% (Fig. 2). Based on the findings of ROC curve analysis, the MUAC cutoffs corresponding to the BMI cutoffs of 18.5, 23, 25, and 30 kg/m^2 were estimated to be 23.2, 26.0, 27.3, and 30.5 kg/m^2, respectively (Table 2). The extent of misclassification of the nutritional status of the study participants by using MUAC cutoffs instead of standard BMI cutoffs is presented in Table 3. Table 3 also depicts the sensitivity and specificity of MUAC cutoffs (considering BMI cutoffs as the gold standard) and the extent of agreement between different MUAC and BMI cutoffs. Other than the cutoff for 'obese' (BMI, 30 kg/m^2), the *Kappa* coefficients for the rest of the MUAC cutoffs showed 'substantial' agreement (>0.6) with their BMI equivalents.[33] The cutoff for 'obese' ($k = 0.58$) showed 'moderate' agreement with the corresponding BMI cutoff.

Discussion

As per the fourth iteration of the National Family Health Survey (NFHS-4), about 32% of the 15- to 49-year-old women in rural Bihar were underweight.[34] Therefore, addressing the issue of undernutrition among women in this state is a public health priority. Furthermore, obesity is slowly becoming a public health problem in India, though it is yet to reach the magnitude of developed world.[35] Prior studies reported that obesity is not only more prevalent among women of reproductive age, compared to males, but also increasing at a faster rate among women.[36] Therefore, the nutritional problems among Indian women are bifold.[37] Assessment of nutritional status of adolescent and adult women is thus essential to determine the extent of this problem and to track the effectiveness of different measures to address malnutrition in this demographic stratum.

The present study collected anthropometric data on adolescent and adult women of rural Bihar, a socially and economically less developed state in India, and found that not only BMI and MUAC are strongly correlated but also a linear relationship exists between the anthropometric parameters. This corroborates the findings from earlier studies conducted in neighboring states of West Bengal and Jharkhand and other South-East Asian countries.[11,16,20,38] Rather than the actual BMI value, public health programs tend to rely more on different BMI cutoffs as they allow for easier decision-making regarding intervention. Therefore, current analysis also focused on determining the MUAC cutoffs that corresponded to the standard BMI limits. The MUAC cutoffs determined using ROC curve analysis were found to have good agreement with BMI and showed excellent classification properties.

Our results therefore suggest that the MUAC cutoffs can serve as an effective screening tool for detection of malnutrition—both undernutrition and obesity—among women of Bihar and possibly other parts of India and neighboring countries with demographic characteristics similar to those of this impoverished Indian state. This constitutes an important finding from the public health nutrition perspective as MUAC is a far simpler measure, requiring less logistical (can be measured using inexpensive color-coded tapes) and intellectual (technical training) resources than BMI assessment (comparatively more sophisticated and difficult-to-carry instruments for weight and height measurement). A screening mechanism based on MUAC could be essential for early detection of malnutrition among women, who usually have poorer access to health care than men, and to bring them under care. Being a simpler measure, MUAC assessments can be implemented by frontline health workers such as AWWs and accredited social health activists (ASHAs) for community-level detection of malnutrition among women, especially in rural

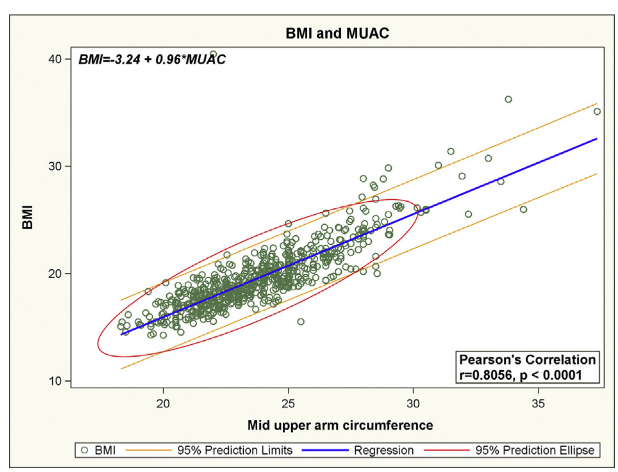

Fig. 1 – The linear relationship between Body Mass Index and Mid Upper Arm Circumference with 95% prediction limits. BMI, body mass index; MUAC, mid upper arm circumference.

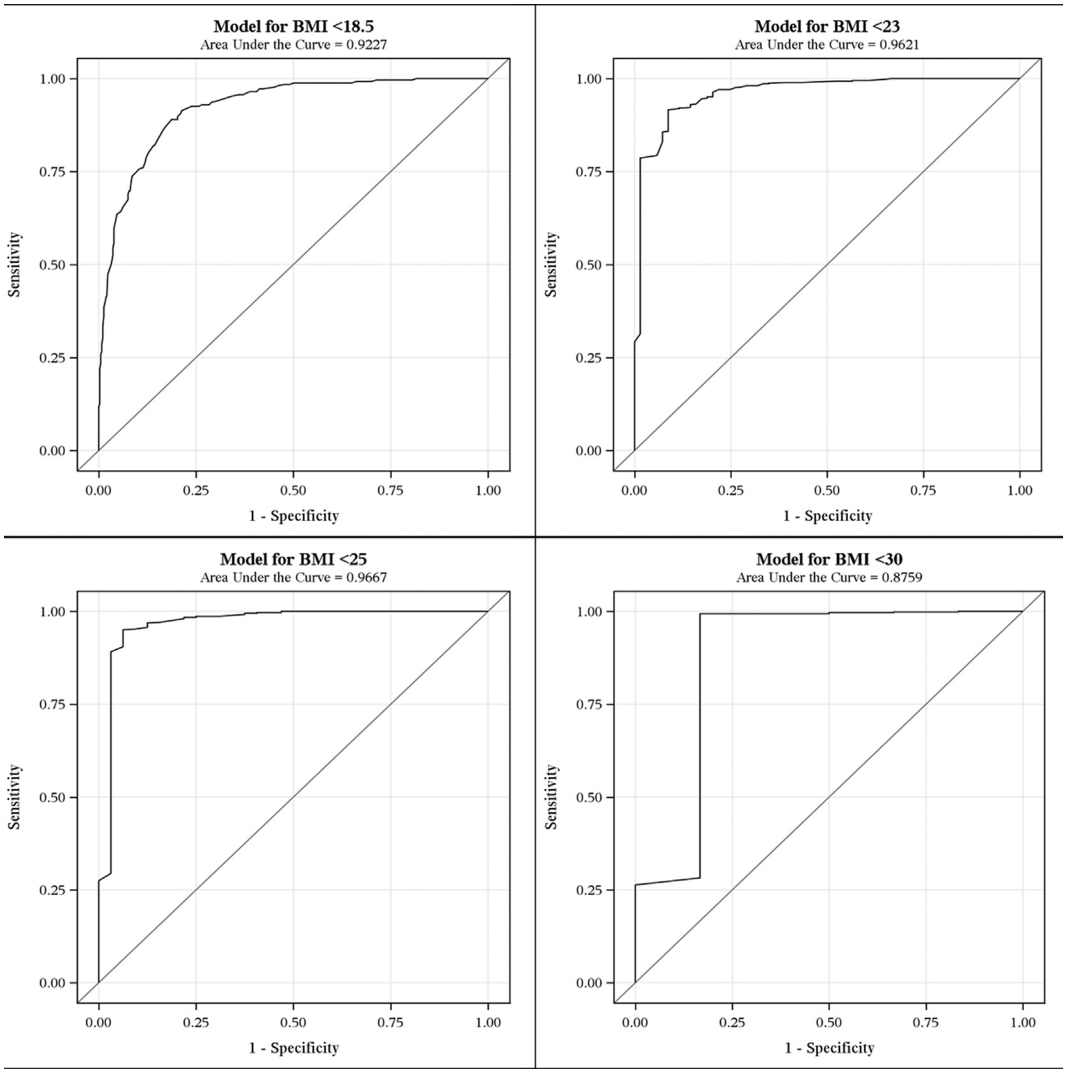

Fig. 2 – The area under the curve for the four different cutoffs for Body Mass Index. BMI, body mass index; MUAC, mid upper arm circumference.

areas. The malnutrition cases detected this way can then be managed using simple community-based intervention under public health nutrition programs such as Integrated Child Development Services or, if found severe, by referral to health facilities. The present study also demonstrates the feasibility of measuring MUAC in study setting. To ensure compliance from rural women regarding anthropometric measurements, during enumerators' training, special emphasis was given on proper consent taking and explanation of the procedure to the study participants. The fact that there was no refusal toward measurement of MUAC by the study participants who provided consent for interview and anthropometric assessment, i.e., there was no refusal for MUAC measurement among the women who agreed to be interviewed, provides evidence that MUAC of rural women can be successfully measured by properly trained enumerators without much difficulty.

The current assessment suffered from a few limitations. Although the study had representation of women from across Bihar, a few important categories of women might have been left out. As the survey participants had to respond to a detailed interview and undergo anthropometric measurements, the probability of participation of sick women (who were also more likely to be malnourished) was low. Thus, the cutoff

Table 2 – MUAC cutoffs corresponding to BMI cutoffs, determined by different methods of ROC curve analysis. Women's nutrition study, Bihar, 2016.

Body mass index (kg/m^2) cutoff	Mid-upper arm circumference (cm) cutoff (from different methods)		
	Youden's *J* statistic	Minimized distance to (0,1) point in the ROC curve	Sensitivity-specificity equality
18.5	23.2	23.2	23.0
23	26.0	26.0	26.0
25	27.3	27.3	27.0
30	30.5	30.5	26.0

ROC, receiver operating characteristic; MUAC, mid-upper arm circumference.

Table 3 – Extent of misclassification on using different MUAC cutoffs as against the corresponding BMI cutoffs. Women's nutrition study, Bihar, 2016.

Body mass index (kg/m^2)	Mid-upper arm circumference (cm)		Sensitivity and specificity of the chosen cutoff value	Total misclassification (%)	Kappa coefficient (95% CI)
	<23.2	**≥23.2**			
<18.5	193 (31.23)	53 (8.58)	0.89, 0.82	18.94	0.68 (0.62–0.73)
≥18.5	64 (10.36)	308 (49.84)			
	<26	**≥26**			
<23	494 (79.94)	59 (9.55)	0.91, 0.91	11.33	0.61 (0.53–0.69)
≥23	11 (1.78)	54 (8.74)			
	<27.3	**≥27.3**			
<25	565 (91.42)	24 (3.88)	0.95, 0.94	4.85	0.60 (0.48–0.72)
≥25	6 (0.97)	23 (3.72)			
	<30.5	**≥30.5**			
<30	608 (98.38)	4 (0.65)	0.99, 0.83	0.97	0.58 (0.30–0.86)
≥30	2 (0.32)	4 (0.65)			

MUAC, mid-upper arm circumference; BMI, body mass index; CI, confidence interval.

determined in the present study might have been based on the measurements taken from relatively healthier women, which might not comprehensively represent the scenario in the community. Exclusion of malnourished women would mean that at the population level, the sensitivity for screening of overweight and obese women might be lower, whereas that for underweight women would be higher than that obtained in the current analysis. As the burden of underweight among women of rural Bihar is much higher than that of overweight, from the perspective of public health nutrition programs, the measurement error might not be of much significance. Another obvious limitation of the present study is that because of its cross-sectional design, the health outcomes among women belonging to various anthropometric categories could not be assessed. Thus, we may not comment on whether the MUAC cutoffs can successfully identify women who are at higher risk of negative health outcomes. Furthermore, the extent of misclassification is the highest for the underweight cutoff (18.5 kg/m^2). However, even for this cutoff, sensitivity of the corresponding MUAC cutoff for diagnosis of underweight is much higher than specificity. Therefore, despite some misclassification, being an easier measure and given the emphasis of the current nutrition program on identifying the underweight (even at the cost of some overdiagnosis), it may still be beneficial to the program. Finally, as the present study recruited women from rural Bihar, replicability of the cutoffs in urban settings and in other Indian states with varying sociodemographic characteristics remains to be evaluated.

The limitations notwithstanding, the present study is the first in India to assess the MUAC cutoffs corresponding to the standard BMI limits from a large and representative sample of women. The results suggest that it is possible to conduct community-level screening of malnourishment among adult/adolescent women using less resource-intensive techniques such as MUAC. Nevertheless, further work would be essential to estimate the MUAC standards for more granular age and physiological categories among women. In addition, longitudinal studies to understand the causal association between different MUAC levels and health outcomes would be immensely beneficial for nutrition programs.

Author statements

Acknowledgments

The authors are grateful to the study participants for their time in engaging with this study. They would also like to acknowledge the administrative support provided by State Health Society, Government of Bihar, India.

Ethical approval

The present study was approved by the Ashirwad Ethics Committee, Ashirwad Hospital and Research Center, Ulhasnagar, India (ashirwadethicscommittee@gmail.com). Informed consent was collected from each agreeing participant before the interview and measurements, after explaining the details of the study in a language that the participant could understand.

Funding

The study was funded by Bill and Melinda Gates Foundation (grant ID# OPP1084426). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing interests

The authors declare that they have no competing interests to disclose.

REFERENCES

1. Kennedy ET. Evidence for nutritional benefits in prolonging wellness. *Am J Clin Nutr* 2006;**83**. 410s-4s.
2. Leandro-Merhi VA, de Aquino JL. Determinants of malnutrition and post-operative complications in hospitalized surgical patients. *J Health Popul Nutr* 2014;**32**:400–10.
3. Green C. Existence, causes and consequences of disease-related malnutrition in the hospital and the community, and clinical and financial benefits of nutritional intervention. *Clin Nutr* 1999;**18**:3–28.
4. Luma HN, Eloumou S, Mboligong FN, Temfack E, Donfack OT, Doualla MS. Malnutrition in patients admitted to the medical wards of the Douala General Hospital: a cross-sectional study. *BMC Res Notes* 2017;**10**:238.
5. Islam MZ, Akhtaruzzaman M, Lamberg-Allardt C. Nutritional status of women in Bangladesh: comparison of energy intake and nutritional status of a low income rural group with a high income urban group. *Asia Pac J Clin Nutr* 2004;**13**:61–8.
6. Bhan N, Rao KD, Kachwaha S. Health inequalities research in India: a review of trends and themes in the literature since the 1990s. *Int J Equity Health* 2016;**15**:166.
7. Woodruff BA, Duffield A. Anthropometric assessment of nutritional status in adolescent populations in humanitarian emergencies. *Eur J Clin Nutr* 2002;**56**:1108–18.
8. Laskey MA. Dual-energy X-ray absorptiometry and body composition. *Nutrition* 1996;**12**:45–51.
9. Kyle UG, Genton L, Pichard C. Body composition: what's new? *Curr Opin Clin Nutr Metab Care* 2002;**5**.
10. Sánchez-García S, García-Peña C, Duque-López MX, Juárez-Cedillo T, Cortés-Núñez AR, Reyes-Beaman S. Anthropometric measures and nutritional status in a healthy elderly population. *BMC Public Health* 2007;**7**:2.
11. Nguyen P, Ramakrishnan U, Katz B, Gonzalez-Casanova I, Lowe AE, Nguyen H, et al. Mid-upper-arm and calf circumferences are useful predictors of underweight in women of reproductive age in northern Vietnam. *Food Nutr Bull* 2014;**35**:301–11.
12. Lee R, Nieman D. *Nutritional assessment*. New York: Mc Graw Hill; 2003.
13. Nube M, Asenso-Okyere WK, van den Boom GJ. Body mass index as indicator of standard of living in developing countries. *Eur J Clin Nutr* 1998;**52**:136–44.
14. Shetty PS, James WP. Body mass index. A measure of chronic energy deficiency in adults. *FAO Food Nutr Pap* 1994;**56**:1–57.
15. FAO. *Defining chronic energy deficiency*. FAO; July 29, 2017. Available from: http://www.fao.org/docrep/T1970E/t1970e02.htm#P67_15391.
16. Sultana T, Karim MN, Ahmed T, Hossain MI. Assessment of under nutrition of Bangladeshi adults using anthropometry: can body mass index be replaced by mid-upper-arm-circumference? *PLoS One* 2015;**10**:e0121456.
17. Ferro-Luzzi A, Sette S, Franklin M, James WP. A simplified approach of assessing adult chronic energy deficiency. *Eur J Clin Nutr* 1992;**46**:173–86.
18. James WP, Mascie-Taylor GC, Norgan NG, Bistrian BR, Shetty PS, Ferro-Luzzi A. The value of arm circumference measurements in assessing chronic energy deficiency in Third World adults. *Eur J Clin Nutr* 1994;**48**:883–94.
19. Briend A, Garenne M, Maire B, Fontaine O, Dieng K. Nutritional status, age and survival: the muscle mass hypothesis. *Eur J Clin Nutr* 1989;**43**:715–26.
20. Chakraborty R, Bose K, Koziel S. Use of mid-upper arm circumference in determining undernutrition and illness in rural adult Oraon men of Gumla District, Jharkhand, India. *Rural Remote Health* 2011;**11**:1754.
21. Akhter N, Sondhya FY. Nutritional status of adolescents in Bangladesh: comparison of severe thinness status of a low-income family's adolescents between urban and rural Bangladesh. *J Educ Health Promot* 2013;**2**:27.
22. Chakraborty R, Bose K, Bisai S. Mid-upper arm circumference as a measure of nutritional status among adult Bengalee male slum dwellers of Kolkata, India: relationship with self reported morbidity. *Anthropol Anzeiger* 2009;**67**:129–37.
23. Wijnhoven HA, van Bokhorst-de van der Schueren MA, Heymans MW, de Vet HC, Kruizenga HM, Twisk JW, et al. Low mid-upper arm circumference, calf circumference, and body mass index and mortality in older persons. *J Gerontol Ser A, Biol Sci Med Sci* 2010;**65**:1107–14.
24. National Family Health Survey (NFHS-4). Mumbai: International Institute for Population Sciences (IIPS) and ICF; 2015-16 2017.
25. Das A, Mahapatra S, Sai Mala G, Chaudhuri I, Mahapatra T. Association of frontline worker-provided services with change in block-level complementary feeding indicators: an ecological analysis from Bihar, India. *PLoS One* 2016;**11**:e0166511.
26. Das A, Chatterjee R, Karthick M, Mahapatra T, Chaudhuri I. The influence of seasonality and community-based health worker provided counselling on exclusive breastfeeding - findings from a cross-sectional survey in India. *PLoS One* 2016;**11**:e0161186.
27. Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. *Lancet* 2004;**363**:157–63.
28. Youden WJ. Index for rating diagnostic tests. *Cancer* 1950;**3**:32–5.
29. Pandey M, Jain A. *ROC Curve: making way for correct diagnosis2016*. SP11 - PharmaSUG; 2016. Available from: https://www.pharmasug.org/proceedings/2016/SP/PharmaSUG-2016-SP11.pdf.
30. Reiser B. Measuring the effectiveness of diagnostic markers in the presence of measurement error through the use of ROC curves. *Stat Med* 2000;**19**:2115–29.
31. Faraggi D. The effect of random measurement error on receiver operating characteristic (ROC) curves. *Stat Med* 2000;**19**:61–70.
32. Box GE, Cox DR. An analysis of transformations. *J R Stat Soc Ser B* 1964:211–52.
33. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977;**33**:159–74.
34. *State fact sheet: Bihar; national family health survey 4*. Delhi: Government of India; Ministry of Health and Family Welfare; 2016.
35. Arnold F, Parasuraman S, Arokiasamy P, Kothari M. Nutrition in India. National Family Health Survey (NFHS-3) India 2005-062009.,
36. Gouda J, Prusty RK. Overweight and obesity among women by economic stratum in urban India. *J Health Popul Nutr* 2014;**32**:79–88.
37. Kennedy G, Nantel G, Shetty P. *Assessment of the double burden of malnutrition in six case study countries*. FAO Food and Nutrition Paper (FAO); 2006.
38. Chakraborty R, Bose K, Bisai S. Mid-upper arm circumference as a measure of nutritional status among adult Bengalee male slum dwellers of Kolkata, India: relationship with self reported morbidity. *Anthropol Anzeiger* 2009;**67**:129–37.