Health gains from achieving optimal body mass index in Australia: a simulation study

Shweta Bohora,[a] Shiva Raj Mishra,[b,c,d] Tim Wilson,[a] and Tony Blakely[a,*]

[a]Centre for Epidemiology and Biostatistics, Melbourne School of Population and Global Health, University of Melbourne, Melbourne, Australia
[b]NHMRC Clinical Trials Center, Faculty of Medicine and Public Health, University of Sydney, Australia
[c]Westmead Applied Research Center, Faculty of Medicine and Public Health, University of Sydney, Australia
[d]Nepal Development Society, Bharatpur-6, Chitwan, Nepal

Summary

Background We estimated the health gains and health inequality impacts for the Australian population alive in 2021 (n = 25.0 million) in the next 20 years and over their remaining lifespan, from shifting everyone above a BMI of 25 kg/m² to 25 kg/m² compared to the BMI distribution in 2021 persisting into the future.

Methods National Health Survey 2017–2018 was used to estimate BMI distributions by sex, age and, socio-economic status (Socio-Economic Indexes for Areas; SEIFA). A proportional multistate life table linking BMI to 19 associated diseases and allowing for time lags and competing morbidity and mortality, was used to estimate the future stream of health adjusted life years (HALYs) gained from eradicating high BMI.

Findings Undiscounted health gains in the first 20 years and lifetime of the population were, respectively, 2.00 million (95% uncertainty interval 1.70–2.32) and 20.4 million (17.0–24.2) (at a 3% annual discount rate, HALY gains were 1.37 and 5.77 million, respectively). Reductions in the incidence of cardio metabolic diseases contributed 61% (95% UI: 54%–68%) of the undiscounted health gains in the first 20 years, musculoskeletal diseases contributed 26% (20%–32%) and cancer 5% (3%–8%). HALY gains in the first 20 years and lifetime, per person alive in 2021, were 2.5 (2.4–2.5) and 1.9 (1.9–2.0) times higher for the most compared to the least deprived SEIFA quintile.

Interpretation The total theoretical envelope of health gains, and health inequality reductions, through eradication of BMI is substantial. Our modeling infrastructure can be used to estimate the health impacts and cost effectiveness of many actual interventions.

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Introduction

Overweight and obesity is a global public health problem that contributes a significant health burden. Recent global estimates suggest nearly 2.5 billion adults aged 18 years and older were overweight, and 890 million were obese.[1] In Australia, with a population of 25 million, recent data from the Australian Institute of Health and Welfare (AIHW) indicates approximately 12.5 million adults are affected by overweight or obesity.[2] This is despite concerted efforts through various awareness programs and health interventions[3–5] on both individual and societal levels to reduce the prevalence.

Obesity (and to a lesser extent overweight) is causally associated with the incidence of cardiovascular disease, cancer and respiratory problems and may reduce life expectancy by 6–7 years.[6] Past modelling by AIHW suggests that nearly 7% of the total health burden in Australia in 2011 was due to people having a BMI greater than 25, and 53% of the diabetes and 45% of the osteoarthritis burden were due to high BMI. Nearly 2.3 times higher attributable disease burden due to high BMI was reported among lowest compared to high socio-economic group.[7] However, these estimates are based on comparative risk assessment that leverages cross-sectional burden of disease methodology and is

*Corresponding author. Population Interventions Unit, Melbourne School of Population and Global Health, University of Melbourne, Australia.
E-mail address: antony.blakely@unimelb.edu.au (T. Blakely).

Research in context

Evidence before this study
Obesity and overweight are a leading cause of fatal and non-fatal disease burden in Australia and globally. People from low socio-economic backgrounds (in high income countries) experience a disproportionate rate of obesity compared to those with higher socio-economic status.

Added value of this study
Our study expands on the previous findings by showing that achieving optimal body mass index is associated with substantial health gain, and reduction in health inequalities in Australia.

Implications of all the available evidence
Our findings strengthen the case for policy makers to prioritise public health interventions aimed at prevention and control of obesity and overweight in Australia and globally. A range of actual interventions (building on the hypothetical elimination of overweight and obesity in this study) require modelling for cost effectiveness, building on the Australian Cost Effectiveness (ACE-Obesity) modelling of interventions already conducted.

not an estimate of the *prospective* health gains (and health inequality impacts) of eradicating obesity allowing for time lags and competing morbidity and mortality.[8] Such prospective gains provide a more sound basis to policy making, including aligning with the targets set in the National Preventative Health Strategy 2021–2030.[9]

This current study aims to assess the predicted future health gain and inequality impacts (allowing for time lags, competing morbidity and mortality, and estimated future trends or forecasts in disease rates) from shifting people with a BMI of >25 kg/m^2 to 25 kg/m^2 in 2021. The health impacts were quantified as health adjusted life year (HALY) differences between the population with an instantaneous eradication of high BMI compared to a population with the BMI distribution in 2021 persisting into the future, with HALYs tallied up over the next 20 years and the remaining lifespan of the Australian population alive in 2021.

Methods
Model conceptualisation and intervention
A proportional multistate lifetable (PMSLT) is a macrosimulation model that simulates multiple birth cohorts of the population into the future (see[10] for a more detailed overview). Briefly, the PMSLT allows for the inclusion of multiple diseases simultaneously while accounting for independent co-morbidities. We modelled 19 BMI-related diseases (shown in Fig. 1) that, collectively, contributed to nearly 90% of total BMI attributable disability-adjusted life years (DALYs) in 2019 in the Global Burden of Disease.[11] DALYs are a cross-sectional or period estimate of the number of years of healthy life that individuals lose due to disability or premature death.[12]

For every modelled disease, the potential impact fraction (PIF; a function of the difference in BMI distribution between the business-as-usual[13] and intervention scenario (i.e. shifting everyone with a BMI >25 to 25 in 2021), and the rate ratios associating BMI with disease incidence) was used to calculate the proportional change in incidence. These PIFs were estimated for all sex-by-age-by-socioeconomic cohorts, in each future time step, allowing for time lags from change in BMI to change in disease incidence rates (detailed below). Over time in the PMSLT (as in reality) changes in incidence rate flow onto changes in disease prevalence and then mortality rate (see Fig. 1). In each future timestep, there is a resultant difference between the BMI eradication scenario and the BAU scenario in disease-specific prevalence and mortality rates, that are summed up across all diseases to allow estimation of HALYs gained under the BMI eradication scenario compared to BAU. The specifications applied in the model are shown in Table 1.

In our study, the World Health Organisation BMI method[1] was used to classify overweight at a cut-off of 25 kg/m^2 and obesity at a cut-off of 30 kg/m^2, with excess disease rates occurring above a BMI of 25 kg/m^2.

Business-as-usual characterisation
The BAU BMI distribution for each sex by age by SEIFA group was estimated using data from the National Health Survey (ABS 2018).[14] (See Supplementary Material 2 for BMI estimation methodology and results). The rate ratios associating BMI with disease incidence were taken from the GBD 2019 (ghdx. healthdata.org).[17] We also used GBD data[11] for sex by age disease incidence, prevalence and mortality rates from 1990 to 2019 to forecast future disease incidence and remission rates to 2040 (then no change), assuming log-linear trends on GBD estimates continue into the future. All-cause mortality rate forecasts were conducted similarly. These sex by age rates were then disaggregated by the socio-economic index for areas (SEIFA), using rate ratios (RRs) derived from the AIHW burden of disease study[18] and a previously published heterogeneity module.[10,19,20] The SEIFA RRs were estimated with log-link regression models on AIHW data, by sex, separately for mortality (Poisson error) and prevalence of disease (binomial error), with main effects
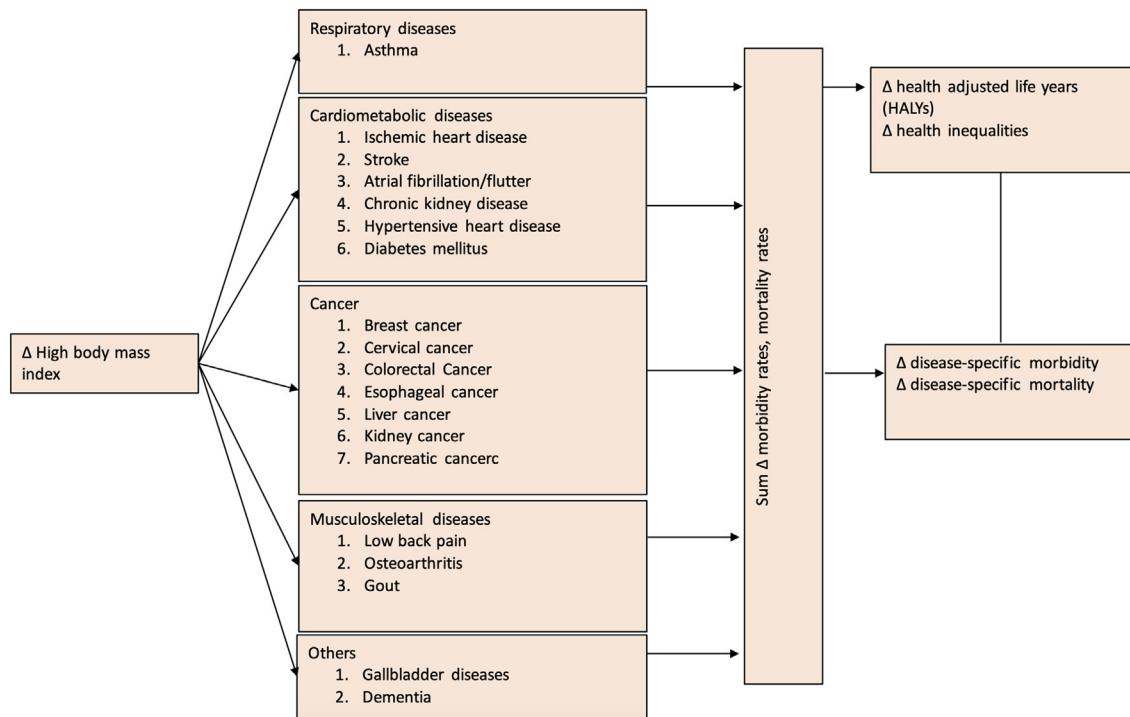
Fig. 1: Schematic showing disease modelling in the study.

for age (five-year age categories) and SEIFA (quintiles coded as integer continuous) and an interaction term of age (aggregated categories 20–24, 25–29, … 80–84 and 85+) with integer SEIFA. These SEIFA differences in disease mortality and prevalence were then used to secondarily estimate SEIFA RRs for incidence and case fatality rates. SEIFA differences in case fatality rates (CFR) were given by the ratio of mortality RRs to prevalence RRs. The incidence RR was [Prevalence RR] * [CFR RR] (see Table 1).

PIFs to link BMI eradication and PMSLT model

The study uses the RR (strictly speaking incidence rate ratio) shift method for calculating the population impact fraction (PIF),[10] whereby people stay in their 'starting state' of BMI but the mean BMI of their state shifts to 25 (if initially the mean > 25). The formula for the PIF cohort (sex by age by SEIFA) c and disease d, at time t, is:

$$PIF_{cdt} = \frac{\sum_{i=1}^{n} P_{ci} RR_{di} - \sum_{i=1}^{n} P_{ci} RR'_{di}}{\sum_{i=1}^{n} P_{ci} RR_{di}}$$

where P_{ci} is the proportion of people in cohort c in the ith BMI category, RR_{di} is the BMI incidence rate ratio for disease d, and RR'_{di} is the incidence rate ratio when the BMI of the category is shifted down to 25. P_{ci} is

assumed unchanging into the future under BAU (i.e. we assume that under BAU or the comparator the distribution of BMI by sex, age and SEIFA will be unchanged into the future). Thus, the PIFs do not vary by time in the future.

These PIFs are the percentage change in incidence rates for each BMI related disease, by sociodemographics. We applied a median lag time of zero to 3 years for cardiovascular diseases[21] and diabetes (upper limit of 3 distributed ln normal with SD of 0.2 on ln scale, equivalent to SD being 20% of the mean), and zero to 15 years for cancer (upper limit also SD on ln normal scale of 0.2). The 15 year lag was based on evidence on effects of surgical interventions on cancer incidence and mortality (BMI associated changes in cancer was seen as early as six years post intervention).[15] To operationalize these lags, the PMSLT used the *average* PIF in the last three and last 15 years (three and 15 are the median duration of time lag windows; actual values in each iteration of the simulation are random draws from above uncertainty intervals), meaning that for cancers the change in disease incidence rates was not maximal until a median of 15 years after the BMI shift.

Analysis

The PMSLT was run 2000 times, with each iteration using a different random draw on input parameter values from their specified input uncertainty distribution (see Table 1). The HALYs gained were estimated

Parameter	Data Source	Model assumptions
Hypothetical eradication of High BMI		
Distribution of individuals by BMI category, within strata of sex, age and SEIFA quintile	ABS (2017–2018)	ABS National Health Survey 2017–2018 data[14] was used for regression estimates of the ln mean and standard deviation of ln BMI by age, sex, SEIFA groups (see Supplementary Material 2). We then used these parameters to generate BMI distributions for all sex by age by SEIFA categories.
Actual intervention = Δ BMI (kg/m^2)	(Author specified)	For those with high BMI (>25 kg/m^2), the actual intervention was defined as shifting each groups mean BMI to 25 kg/m^2.
Time lags	Assumed	Because there are time lags from a change in risk factor to a change in disease incidence rates (and thence prevalence and mortality rates) in how diseases develop over time, eradicating BMI won't immediately affect the occurrence of diseases. Though we don't have precise information on the exact duration of these delays, prior evidence suggest that BMI associated changes in cancer incidence are seen as early as six years post intervention).[15] To address this uncertainty, we incorporated a time delay of 0–15 years (ln normal ±20%) for cancer, and 0–3 years for CHD (ln normal ±20%), stroke, diabetes and osteoarthritis.
BAU—epidemiological parameters		
All-cause mortality rates	GBD	Data on all-cause mortality rates by sex and age group were obtained from the Global Burden of disease results tool,[16] and used to generate future forecasts to 2040 then held constant. Data on SEIFA rate ratio differences in all-cause mortality was obtained from the Australian BDS, to specify mortality RRs for disaggregation by SEIFA within our heterogeneity module (see Methods text).
All-cause morbidity rates	GBD	Data on years of life lived with disability (YLD) were obtained from the Global Burden of Disease study for each sex and age group in 2019. No time trend was allowed. Data on SEIFA differences was taken from the Australian BDS, to specify morbidity RRs for disaggregation by SEIFA.

Disease specific incidence, prevalence, and case fatality rates	GBD	Sex by age: The disease-specific incidence rates, prevalence and mortality rates, and case fatality rates (mortality rate divided by prevalence), by sex and age, for all diseases included in our model were derived from regression-based forecast using GBD data for 1990 to 2019.
		To disaggregate disease rates by SEIFA, we used the following process:
		1) We sourced mortality and prevalence rates by SEIFA from the 2018 Australian BDS. We then fitted a simple log-link regression model by sex separately for mortality (Poisson error) and prevalence (binomial error) with main effects for age (five-year age categories) and SEIFA (quintiles coded as integer continuous) and an interaction term of age (aggregated categories 0–14, 15–24, 25–44, 45–64, 65–74, 75–84 and 85+) with integer SEIFA.
		2) If for most age-groups, the SEIFA gradient in mortality was between 0.8 and 1.25 of that for prevalence, we assumed:
		   i) no SEIFA differences in case fatality rates (CFR)
		   ii) the RRs for incidence were those observed for mortality.
		3) If for most age-groups, the SEIFA gradient in mortality was less than 0.8 or greater than 1.25 of that for prevalence, we assumed:
		   i) SEIFA differences in case fatality rates (CFR), given by the ratio of mortality RRs to prevalence RRs.
		   ii) The incidence RR was [Prevalence RR] * [CFR RR].
		Uncertainty: For rate ratios by SEIFA, we applied uncertainty ± 5% SD (log normal distribution for incidence), correlations 1.0 between sexes, age groups and SEIFA for all disease.
		Annual Percentage Change (APC) of sex by age rates (not of SEIFA RRs): the APC were estimated by fitting a least squares regression line to the natural logarithm of incidence rates and case fatality rates from 1990 to 2019 GBD data and included as inputs to the PMSLT out to year 2035, then rates held constant. (We assume the APC was constant across SEIFA.)
		Uncertainty: ± 0.5% SD (normal distribution), correlations 1.0 between sexes, age groups and SEIFA for all disease.

Disease specific morbidity	IHME/GBD	The sex and age specific disability rates were calculated as each disease's YLD obtained from GBD[16] divided by the prevalent cases. The same disability rate was assumed by SEIFA (i.e. those with disease are assumed to have same severity distribution across SEIFA). Uncertainty: ± 10% SD
Obesity-related disease	GBDx[16]	The 19 diseases (refer to Fig. 1 below) contributing to >90% of DALYs attributable to high BMI in 2019 (GBDx) were included, namely: • Asthma • Breast cancer • Cervical cancer • Colorectal cancer • Esophageal cancer • Kidney cancer • Liver cancer • Pancreatic cancer • Diabetes mellitus • Atrial fibrillation • Chronic kidney disease • Hypertensive heart disease • IHD • Stroke • Gout • Low back pain • Osteoarthritis • Dementia • Gallbladder disease
RRs for obesity-related disease	Global Burden of Disease.[17]	RRs for obesity related diseases were obtained from GBD 2019.

Table 1: Business-as-usual input parameter and epidemiological parameters and their sources for the base year (i.e. 2021) and projections.

both undiscounted and with a discount rate of 3% per annum (see Table 2 below). Analyses were conducted using Python version 3.9.5 (Delaware, USA). The GATHER checklist is provided in the Supplementary Material 1 to report on the modelling process.[22]

Results

The estimated undiscounted HALYs gained from eradicating high BMI in the first 20 years (by 2041) was 2.00 million (95% uncertainty interval UI: 1.70–2.32), and over the remaining lifetime of the population alive in 2021 was 20.4 million (95% UI: 17.0–24.2) (Table 2). The 3% per annum discounted HALY gains were less: 1.37 million (95% UI: 1.16–1.59) over the next 20 years and 5.77 million (95% UI: 4.87–6.75) over the lifetime.

Table 2 also shows HALY gains by socioeconomic position, expressed as the HALY gains per 1000 people alive in 2021. The undiscounted health gains were 2.47 times higher for the most deprived (95% UI: 2.40–2.54) compared to the least deprived quintile in first 20 years, and 2.47 time higher using a 3% discount rate (95% UI: 2.41–2.55).

The estimated health gains in the first 20 years and lifetime across nineteen BMI related diseases are illustrated in Fig. 2. Reductions in the incidence of cardio metabolic diseases contributed 61% (95% UI: 54%–68%) of the undiscounted health gains (i.e. HALYs) in the first 20 years, musculoskeletal diseases contributed 26% (20%–32%) and cancer 5% (3%–8%) respectively. Over a lifetime, nearly 69% (62%–74%) of the gains were through cardiometabolic diseases, 15% (11%–

19%) through musculoskeletal diseases and 11% (8%–14%) through cancers (see Figure 1 for disease grouping).

Discussion
Summary of main results
The study estimated large total health gains from shifting people with a BMI greater than 25 to 25 in Australia in the next 20 years and remaining lifetime of the population. Each Australian alive in 2021 stands to gain an average of 10 months of healthy life if high BMI was eradicated. Eradicating overweight and obesity can also lead to strong improvements in health inequalities, due to both a higher average BMI[23,24] and higher rates of BMI-related diseases (due to both high BMI and other reasons) among deprived compared to less deprived populations. We found that the per capita HALY gains for people in the most deprived quintile of small areas was two and a half times that for the least deprived quintile.

Thus, interventions addressing high body mass have the potential for substantial health gains and—if population wide or not preferentially taken up by higher socioeconomic groups—strong potential for reducing health inequalities.

Comparison of study results
The 20.4 million HALYs gained over the remaining lifespan of the population exceeds by 40-fold the DALYs lost due to COVID-19 in the Omicron BA.1/BA.2 wave in Australia in early 2022.[25] The health gain also exceeds the estimated per capita health gain from radical tobacco

	Undiscounted		Discounted at 3% per annum	
	2021–2041 (UI 2.5th–97.5th percentile)	Lifetime (UI 2.5th–97.5th percentile)	2021–2041 (UI 2.5th–97.5th percentile)	Lifetime (UI 2.5th–97.5th percentile)
Health adjusted life years (HALYs)				
Total HALYs (millions)	2.00 (1.70–2.32)	20.4 (17.00–24.2)	1.37 (1.16–1.59)	5.77 (4.87–6.75)
Total HALYs per 1000 people in 2021	80.4 (68.2–93.5)	819 (684–974)	54.9 (46.6–63.9)	232 (196–272)
By quintile of small area deprivation, per 1000 persons in 2021				
Most deprived quintile	117.8 (100.5–136.0)	1120 (939–1323)	80.6 (68.8–93.1)	323 (274–377)
2nd most deprived quintile	91.9 (78.2–106.8)	877 (734–1042)	62.9 (53.4–73.2)	254 (214–296)
3rd most deprived quintile	70.0 (59.3–81.6)	740 (615–884)	47.8 (40.4–55.8)	207 (174–244)
4th most deprived quintile	72.1 (61.1–84.4)	804 (670–958)	49.1 (41.6–57.5)	222 (187–260)
Least deprived quintile	51.0 (43.0–60.2)	563 (466–675)	34.8 (29.3–41.0)	156 (131–184)
RR for most vs least deprived[a]	2.47 (2.40–2.54)	na	2.48 (2.41–2.55)	na
By sex				
Males, per 1000 people in 2021	93.7 (79.8–109.0)	977 (815–1160)	64.0 (54.4–74.5)	276 (233–322)
Females, per 1000 people in 2021	66.8 (56.3–77.8)	659 (549–787)	45.8 (38.5–53.3)	187 (157–221)

BAU HALYs are shown in Supplementary 1 Table S1; the values in this table are incremental (due to hypothetical eradication of high BMI) to the BAU HALYs in Supplementary Table S1). Unless stated otherwise, non-age standardized. [a]Age standardized to WHO World population, using age at accrual of health gain. The central values reported are median (50th percentile) and the 95% UI (2.5th and 97.5th percentile).

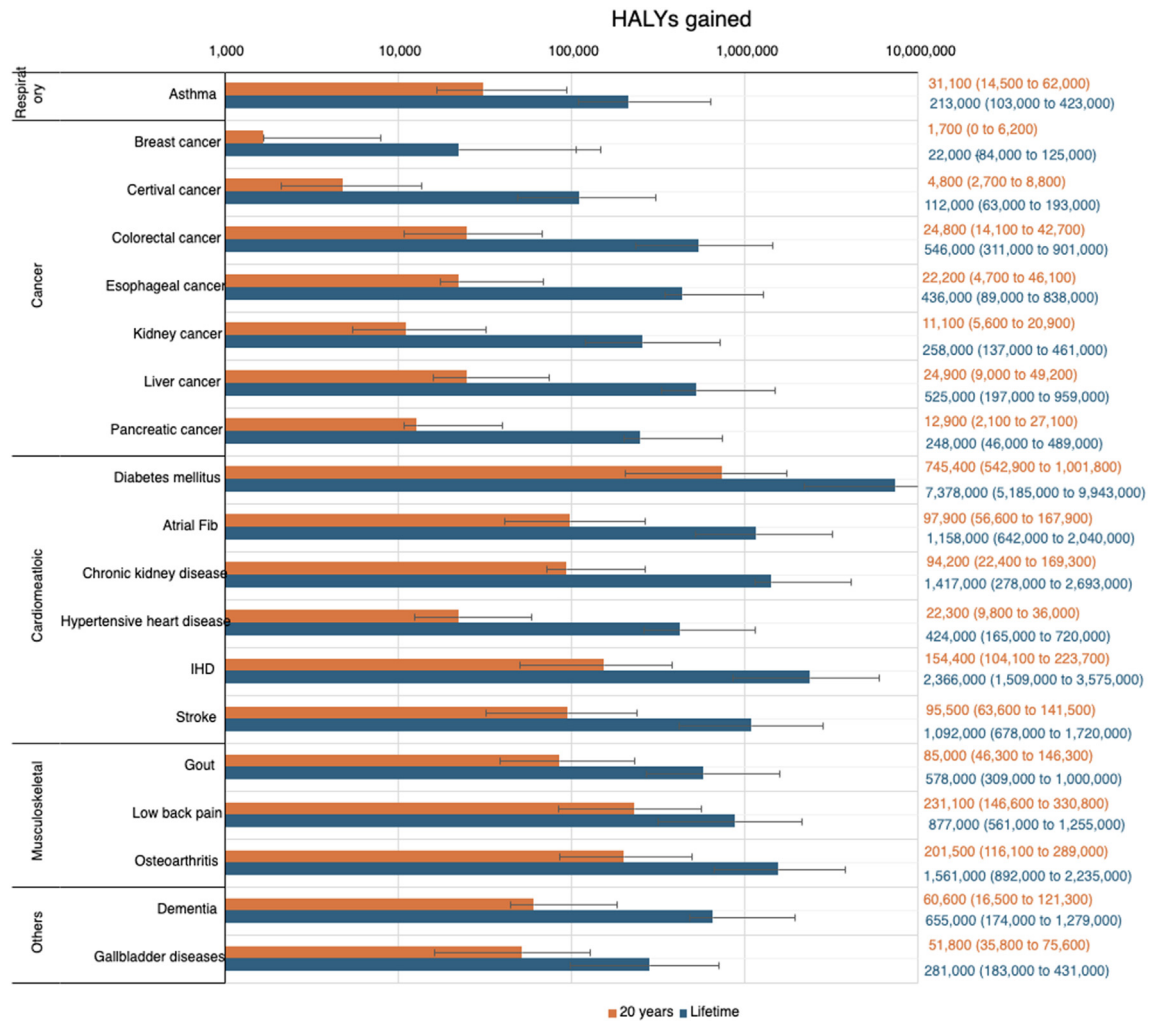*Table 2*: Future HALYs gained from achieving optimal BMI (<25 kg/m2) compared to BAU in Australia.

Fig. 2: Undiscounted HALYs gained by separate diseases across 20 years and lifetime horizon. Log scale, error bars are 95% UI, labels are median and 95% UI.

endgame policies modelled in New Zealand (a policy of denicotinising retail tobacco, 90% plus reduction in tobacco retail, and a tobacco-free generation—i.e. actually closely approximates eradication of tobacco). In a population a fifth the size of Australia, the 3% lifetime discounted HALY gains from the tobacco endgame were 594,000 (95% UI: 443,000–738,000),[26] compared to the 3% discounted lifetime gains from eradicating high BMI in our Australian study of 5.77 million (twice as much per capita).

The GBD estimates 525,000 DALYs of health loss due to high body weight in Australia in 2019[16] and the Australian Institute of Health and Welfare estimates 420,000 DALYs attributable in 2018.[18] These burden of disease studies use comparative risk assessment methodology that estimates the total health loss in a current year, compared to a counterfactual world where there

had been no overweight and obesity in the past. Accordingly, CRA methodology neither allows for time lags from changing disease incidence rates that over time lead to changing disease prevalence and deaths, nor does it allow for competing mortality and disease. Unsurprisingly, therefore, the prospective HALYs gained from eradicating overweight and obesity in our study over the next 20 years of 2.00 million HALYs gained is considerably less than (naively) multiplying 525,000 or 420,000 DALYs by 20. Put another way, an important added value of our study is that it simulates what we think the likely actual health gains would be in the future from changing body weight now—and lays the foundation for determining which actual interventions achieve much of this health gain (examples of potential interventions include food taxes[27] through to wide access to recently developed glucagon-like peptide-

1 (GLP-1) analogues (e.g. Semaglutide[28] and Tirzepatide[29]).

Our finding of two and a half times the health gain among more deprived people also accords with studies that have estimated the impact of actual interventions by socio-economic position. In Lal et al., 's 2017 study, implementing a tax on sugar-sweetened beverages in Australia (that largely, but not only, works through BMI reduction) was found to yield significant health benefits, with a 49.5% greater health gain observed among the most disadvantaged quintiles.[30]

As in many countries that have gone through the 'obesity transition',[31] there is a socioeconomic gradient in obesity in Australia. Therefore, any preventative actions aimed at redressing obesity (so long as uptake is at least as high among more deprived populations) will drive reductions in health inequalities.

Limitations
This study has several limitations. First, nearly 30% of BMI data was self-reported in the National Health Survey[14] from whence we estimated sex by age by SEIFA means and standard deviations. However, this should not bias the inputs to the model greatly, and moreover being a simulation model the RR estimates of changing BMI to disease incidence were taken from GBD meta-analyses. Second, our simulation model doesn't incorporate new births or migration. Whilst excluding births will make little difference to HALY gains in the next 20 years (as the disease impacts of high body mass are largely in middle and older ages), if the Australian population continues to grow due to migration then we will have underestimated the health gains in the next 20 years (the exact amount being a function of the age structure, BMI distribution and back ground disease rates of new migrants).[32] Third, the study does not include mental health gains that may result from reducing BMI. Whilst neither depression nor anxiety are included as outcomes associated with high BMI in either the GBD or the Australian burden of disease study, there is evidence that among children and young adults (at least) high body mass may be associated with mental health and disutility.[33,34] Fourth, our BAU scenario assumed the BMI distribution by sex, age and SEIFA in the 2018–19 Health Survey will persist into the future. If a greater proportion of the population were to become overweight and obese under the comparator BAU scenario (i.e. no intervention), then we will have underestimated the HALY gains from eradicating obesity and overweight.

Conclusions
Our study estimated very substantial health gains from achieving optimal body mass index in Australia over the next 20 years and remaining lifetime of the population. Further, these health gains were substantially higher in the most deprived compared to least deprived quintile.

Our model provides the basis for simulating actual interventions, and their cost-effectiveness, going forward.

References
1   World Health Organization. *Obesity and overweight*; 2024. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight#:~:text=Worldwide%20adult%20obesity%20has%20more,16%25%20were%20living%20with%20obesity. Accessed May 11, 2024.
2   Australian Institute of Health and Welfare. *Overweight and obesity*; 2023. https://www.aihw.gov.au/reports/overweight-obesity/overweight-and-obesity.
3   Allender S, Nichols M, Foulkes C, et al. The development of a network for community-based obesity prevention: the CO-OPS Collaboration. *BMC Publ Health*. 2011;11(1):132.
4   de Silva-Sanigorski AM, Bell AC, Kremer P, et al. Reducing obesity in early childhood: results from Romp & Chomp, an Australian community-wide intervention program. *Am J Clin Nutr*. 2010;91(4):831–840.
5   Nichols MS, Reynolds RC, Waters E, et al. Community-based efforts to prevent obesity: Australia-wide survey of projects. *Health Promot J Aust*. 2013;24(2):111–117.
6   Peeters A, Barendregt JJ, Willekens F, et al. Obesity in adulthood and its consequences for life expectancy: a life-table analysis. *Ann Intern Med*. 2003;138(1):24–32.
7   Australian Institute of Health and Welfare. *Impact of overweight and obesity as a risk factor for chronic conditions*; 2017. Accessed August 12, 2023.
8   Australian Institute of Health and Welfare. *Australian burden of disease study: methods and supplementary material 2018*; 2021. https://www.aihw.gov.au/reports/burden-of-disease/abds-methods-supplementary-material-2018.
9   Department of Health and Aged Care. *National preventative health Strategy 2021–2030*; 2021. https://www.health.gov.au/resources/publications/national-preventive-health-strategy-2021-2030.
10 Blakely T, Moss R, Collins J, et al. Proportional multistate lifetable modelling of preventive interventions: concepts, code and worked examples. *Int J Epidemiol*. 2020;49(5):1624–1636.
11 GBD 2019 Diseases and Injuries Collaborators. Global burden of 369 diseases and injuries in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet*. 2020;396(10258):1204–1222.
12 Australian Institute of Health and Welfare. *Australian burden of disease study 2023*; 2023. https://www.aihw.gov.au/reports/burden-of-disease/australian-burden-of-disease-study-2023.

13 Roth GA, Mensah GA, Johnson CO, et al. Global burden of cardiovascular diseases and risk factors, 1990–2019: update from the GBD 2019 study. *J Am Coll Cardiol*. 2020;76(25):2982–3021.

14 Australian Bureau of Statistics. National health survey: first results 2017-18. https://www.abs.gov.au/statistics/health/health-conditions-and-risks/national-health-survey-first-results/latest-release.

15 Aminian A, Wilson R, Al-Kurd A, et al. Association of bariatric surgery with cancer risk and mortality in adults with obesity. 2022;327(24):2423–2433.

16 Global Burden of Diseases Collaborative Network. *Global burden of disease study 2019 (GBD 2019) results*. Seattle, United States: Institute for Health Metrics and Evaluation (IHME); 2019.

17 Global Burden of Disease Collaborative Network. *Global burden of disease study 2019 (GBD 2019) relative risks*. Seattle, United States: Institute for Health Metrics and Evaluation (IHME); 2020.

18 Australian Institute of Health and Welfare. *Australian burden of disease study 2023*. Canberra: AIHW; 2023.

19 Andersen P, Mizdrak A, Wilson N, Davies A, Bablani L, Blakely T. Disaggregating proportional multistate lifetables by population heterogeneity to estimate intervention impacts on inequalities. *Popul Health Metrics*. 2022;20(1):6.

20 Blakely T, Cleghorn C, Petrović-van der Deen F, et al. Prospective impact of tobacco eradication and overweight and obesity eradication on future morbidity and health-adjusted life expectancy: simulation study. *J Epidemiol Community Health*. 2020;74(4):354–361.

21 WHO CVD Risk Chart Working Group. World Health Organization cardiovascular disease risk charts: revised models to estimate risk in 21 global regions. *Lancet Global Health*. 2019;7(10):e1332–e1345.

22 Stevens GA, Alkema L, Black RE, et al. Guidelines for accurate and transparent health estimates reporting: the GATHER statement. *Lancet*. 2016;388(10062):e19–e23.

23 Australian Institute of Health and Welfare. *Health across socioeconomic groups*; 2022. https://www.aihw.gov.au/reports/australias-health/health-across-socioeconomic-groups.

24 Australian Institute of Health and Welfare. *Overweight and obesity*; 2022. https://www.aihw.gov.au/reports/australias-health/overweight-and-obesity. Accessed October 10, 2022.

25 Howe S, Szanyi J, Blakely T. The health impact of long COVID during the 2021-2022 Omicron wave in Australia: a quantitative burden of disease study. *Int J Epidemiol*. 2023;52:677.

26 Ait Ouakrim D, Wilson T, Waa A, et al. Tobacco endgame intervention impacts on health gains and Maori:non-Maori health inequity: a simulation study of the Aotearoa/New Zealand Tobacco Action Plan. *Tobac Control*. 2023:tc-2022-057655.

27 Blakely T, Cleghorn C, Mizdrak A, et al. The effect of food taxes and subsidies on population health and health costs: a modelling study. *Lancet Public Health*. 2020;5(7):e404–e413.

28 Wilding JPH, Batterham RL, Calanna S, et al. Once-weekly semaglutide in adults with overweight or obesity. *N Engl J Med*. 2021;384(11):989–1002.

29 Jastreboff AM, Aronne LJ, Ahmad NN, et al. Tirzepatide once weekly for the treatment of obesity. *N Engl J Med*. 2022;387:1433.

30 Lal A, Mantilla-Herrera AM, Veerman L, et al. Modelled health benefits of a sugar-sweetened beverage tax across different socioeconomic groups in Australia: a cost-effectiveness and equity analysis. *PLoS Med*. 2017;14(6):e1002326.

31 Jaacks LM, Vandevijvere S, Pan A, et al. The obesity transition: stages of the global epidemic. *Lancet Diabetes Endocrinol*. 2019;7(3):231–240.

32 Wanjau MN, Aminde LN, Veerman JL. The avoidable disease burden associated with overweight and obesity in Kenya: a modelling study. *eClinicalMedicine*. 2022;50:101522.

33 van Vuuren CL, Wachter GG, Veenstra R, et al. Associations between overweight and mental health problems among adolescents, and the mediating role of victimization. *BMC Publ Health*. 2019;19(1):612.

34 Kokka I, Mourikis I, Bacopoulou F. Psychiatric disorders and obesity in childhood and adolescence-A systematic review of cross-sectional studies. *Children*. 2023;10(2).