Years of life lost and healthy life-years lost from diabetes and cardiovascular disease in overweight and obese people: a modelling study

Steven A Grover, Mohammed Kaouache, Philip Rempel, Lawrence Joseph, Martin Dawes, David C W Lau, Ilka Lowensteyn

Lancet Diabetes Endocrinol 2015; 3: 114–22

Published Online December 5, 2014 http://dx.doi.org/10.1016/S2213-8587(14)70229-3

See Comment page 93

Division of Clinical Epidemiology, Research Institute of the McGill University Health Centre, Montreal, QC, Canada (S A Grover MD, M Kaouache PhD, P Rempel MSc, I Lowensteyn PhD); **Faculty of Medicine, Department of Medicine** (S A Grover, L Joseph PhD), **and Faculty of Medicine, Department of Epidemiology, Biostatistics and Occupational Health** (L Joseph), **McGill University, Montreal, QC, Canada; Department of Family Practice, University of British Columbia, BC, Canada** (M Dawes MD); **and Diabetes and Endocrine Research Group, University of Calgary, Calgary, AB, Canada** (D C W Lau MD)

Correspondence to: Dr Steven Grover, Research Institute of the McGill University Health Centre, Montreal, QC H3A 1A1, Canada **steven.grover@mcgill.ca**

Summary

Background **Despite the increased risk of cardiovascular disease and type 2 diabetes associated with excess bodyweight, development of a clinically meaningful metric for health professionals remains a challenge. We estimated the years of life lost and the life-years lost from diabetes and cardiovascular disease associated with excess bodyweight.**

Methods **We developed a disease-simulation model to estimate the annual risk of diabetes, cardiovascular disease, and mortality for people with BMI of 25–<30 kg/m² (overweight), 30–<35 kg/m² (obese), or 35 kg/m² and higher (very obese), compared with an ideal BMI of 18·5–<25 kg/m². We used data from 3992 non-Hispanic white participants in the National Nutrition and Examination Survey (2003–10) for whom complete risk factor data and fasting glucose concentrations were available. After validation of the model projections, we estimated the years of life lost and healthy life-years lost associated with each bodyweight category.**

Findings **Excess bodyweight was positively associated with risk factors for cardiovascular disease and type 2 diabetes. The effect of excess weight on years of life lost was greatest for young individuals and decreased with increasing age. The years of life lost for obese men ranged from 0·8 years (95% CI 0·2–1·4) in those aged 60–79 years to 5·9 years (4·4–7·4) in those aged 20–39 years, and years lost for very obese men ranged from 0·9 (0–1·8) years in those aged 60–79 years to 8·4 (7·0–9·8) years in those aged 20–39 years, but losses were smaller and sometimes negligible for men who were only overweight. Similar results were noted for women (eg, 6·1 years [4·6–7·6] lost for very obese women aged 20–39 years; 0·9 years [0·1–1·7] lost for very obese women aged 60–79 years). Healthy life-years lost were two to four times higher than total years of life lost for all age groups and bodyweight categories.**

Interpretation **Our estimations for both healthy life-years and total years of life lost show the effect of excess bodyweight on cardiovascular disease and diabetes, and might provide a useful health measure for discussions between health professionals and their patients.**

Funding **Canadian Institutes of Health Research.**

Introduction

The health consequences of excess bodyweight are well described and their prevalence is increasing in most geographically western countries.[1,2] Strong and consistent data show the benefits of weight reduction on cardiovascular risk factors, such as hypertension and dyslipidaemia, and on the risk of type 2 diabetes.[3–6] Nonetheless, effective clinical interventions to help individuals maintain a healthy weight, or significantly reduce their bodyweight over the long-term, are elusive, as shown by the increasing prevalence of obesity.[7,8]

Cardiovascular risk assessment is used to guide health professionals when screening and treating individuals with hypertension or dyslipidaemia.[9] This information can also be discussed with the patient to engage them in health-care decision making, increasing the probability of patients reaching recommended treatment targets. Similarly, a composite health measure that captures the negative effect of excess bodyweight on health and longevity might prove useful in discussions about weight management, including adherence to lifestyle changes such as dietary modification and regular physical activity.

Although the negative effect of a raised BMI on cardiovascular risk factors such as impaired fasting glucose concentration, blood lipid concentrations, and blood pressure are well recognised, cardiovascular risk equations such as those produced by the Framingham Heart Study do not typically include excess bodyweight as an independent risk factor.[10] The presence of diabetes is a strong independent risk factor for cardiovascular disease, and risk of type 2 diabetes is positively associated with increasing BMI or waist circumference in many studies such as the Atherosclerosis and Risk in Communities Study (ARIC).[11] Accordingly, inclusion of the effect of bodyweight on diabetes risk, blood pressure, and blood lipid concentrations might provide the opportunity to develop a cardiometabolic risk[12] measurement that captures the combined effects of cardiovascular disease and type 2 diabetes outcomes on health and life expectancy. Investigators have previously calculated the reduced life expectancy or years of life lost associated with excess bodyweight.[13] Because years of life lost describes only a fraction of the clinical effect of obesity, calculation of healthy life-years free from the morbidity

associated with premature disease could provide another meaningful measurement.[13,14]

In this study, we aimed to develop and validate a Markov state-transition model to estimate the life expectancy and healthy life expectancy associated with commonly measured risk factors. We aimed to estimate the effect of excess bodyweight on years of life lost and healthy life-years lost, defined as the years free from cardiovascular disease and diabetes.

Methods

Design of cardiometabolic risk model

To calculate the annual risk of incident diabetes, cardiovascular disease, and their complications, we combined a previously published cardiovascular risk model with a newly developed diabetes risk model. In the resulting Markov state-transition cardiometabolic model, excess bodyweight (defined as a BMI of 25 kg/m² or higher) directly increased the risk of developing type 2 diabetes. Development of diabetes, in turn, increased the subsequent risk of developing cardiovascular disease. Excess body weight also indirectly increases cardiovascular risk if it is associated with raised blood pressure and an increased total cholesterol to HDL cholesterol ratio. We designed the model to calculate yearly transition probabilities between health states. Every year after entry into the model, the health status of a patient could remain unchanged, new diagnoses could be made, existing disorders could result in new complications, existing complications could progress, or the individual could die from the complications of diabetes, cardiovascular disease, or from non-specified other causes. The cycle was repeated until the patient died or reached 102 years of age, at which time all survivors were censored. We then calculated average life expectancy and healthy life expectancy free from diabetes or cardiovascular disease across all individuals included in the analyses. For additional details see appendix.

Cardiovascular risk model

For cardiovascular outcomes (non-fatal cardiovascular outcomes were coronary insufficiency, a non-fatal myocardial infarction, a transient ischaemic attack, or a nonfatal stroke; fatal cardiovascular outcomes were dying from cardiac disease or a stroke), we calculated the annual risk of developing cardiovascular disease with a Markov model designed to estimate the annual probability of specific fatal and non-fatal cardiovascular outcomes. This cardiovascular risk model, based on data from the Lipid Research Clinic Follow-Up Cohort, has been previously described in detail, and validated against the results of clinical trials[15–18] and published US national life tables[19] (appendix). In this cohort, patients were followed up for about 12 years. Briefly, this model includes a coronary heart disease submodel with baseline risk factors including age, sex, mean blood pressure, total cholesterol to HDL ratio, smoking status, diabetes diagnosis, and diagnosed cardiovascular disease (appendix). The cerebrovascular submodel is a function of risk factors including age, sex, mean blood pressure, smoking status, diabetes diagnosis, and total cholesterol to HDL ratio. Because this model was developed mainly with white patients, we restricted our analyses to white individuals only.

Diabetes risk model

We developed the diabetes risk model with data from ARIC, for which the study design and sampling procedures have been described in detail.[20] For this analysis, we excluded 1864 individuals who had diabetes at baseline as defined with the following criteria for incident diabetes. Individuals were classified as having developed diabetes when any of the following criteria were met at the first or second follow-up visit: use of antidiabetic drugs, fasting glucose concentrations of 7·0 mmol/L or higher, non-fasting glucose concentrations of 11·1 mmol/L or higher, or self-reported physician diagnosis. The data did not differentiate between type 1 and type 2 diabetes; however, given that the ARIC study enrolled individuals aged 45–64 years, it is reasonable to assume that newly diagnosed diabetes was type 2. We included 12 282 individuals in the analysis. Patients were followed up for about 6 years. For additional details see appendix.

We used the Bayesian Information Criteria to approximate Bayes factors within logistic regression modelling to identify risk factors predictive of the development of type 2 diabetes.[21] We calculated posterior model probabilities for all possible models from these approximate Bayes factors based on equal a-priori probability for all models. The posterior probabilities for each model represent the probability that the model is correct given the observed data and given that one model is indeed the correct model. We calculated the individual posterior probability of a candidate variable as the sum of posterior probabilities across all models that included the variable in question.

See Online for appendix

We included the following variables in the analysis: fasting glucose concentrations, age, sex, ethnic origin, parental history of diabetes, waist circumference, BMI, blood lipid concentrations (total and HDL cholesterol, and triglycerides), blood uric acid concentration, use of lipid-lowering drugs, blood pressure, use of drugs for hypertension, and smoking status. Although the optimum properties associated with Bayesian models theoretically depend on averaging all coefficients for each variable across all models, for practical reasons we did not use variables such as serum uric acid or triglycerides concentrations, which had weights lower than 50% and needed additional blood tests but seemed to add little predictive ability. The predictive performance of our final model, based on a parental history of diabetes, fasting glucose concentration, HDL cholesterol, BMI, and ethnic origin (African-American *vs* white), was compared with

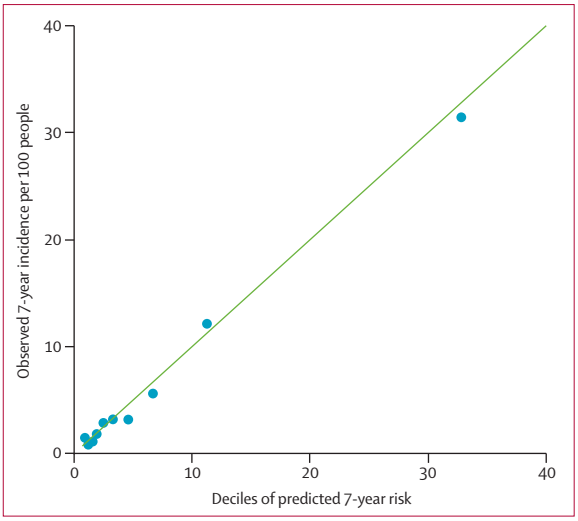

Figure 1: **External validation of our diabetes risk model with the observed Framingham offspring cohort data**
A plot of the observed versus predicted events in each decile of diabetes risk confirmed that the model was well calibrated. The events are the number of individuals who will develop diabetes during 7 years of follow-up.

that from full Bayesian model averaging to ensure that we did not lose an important degree of predictive performance when we used a more parsimonious model.

We externally validated the diabetes risk model with data from the Framingham offspring cohort, fifth examination cycle.[22] Because 99% of the Framingham offspring cohort was non-Hispanic white, we set the ethnic origin variable to white. A parental or family history of diabetes was also unavailable and therefore set to absent. Finally, the length of follow-up was, on average, about 7 years rather than the 6 years in the ARIC data set. Applying the ARIC model to the Framingham data resulted in excellent test discrimination (C=0·86) with good calibration across risk deciles (figure 1). We derived the annual incidence rates of specific complications of diabetes including retinopathy, nephropathy, and neuropathy from those reported by Eastman and colleagues.[23]

Validation of the full cardiometabolic model

We compared findings from the full cardiometabolic model with two previously published studies and reports. In these validation simulations, we used National Health and Nutrition Examination Survey (NHANES) data from 2003–10 in our model and compared estimates of life expectancy for white Americans with data from US national life tables,[19] and years of life lost to obesity from the Framingham Heart Study.[24]

Estimation of the effect of obesity on years of life lost

To estimate the years of life lost and healthy life-years lost due to excess bodyweight, we imputed NHANES data from 2003–10, which is representative of adults in the USA aged 20–79 years, into the full cardiometabolic model.[25] Individuals were stratified by sex and ethnic origin. In this Article, we focused on data from the subsample of non-Hispanic white participants with complete risk factor data for whom fasting glucose concentrations were measured (n=3992). We did all analyses with SAS (version 9.3).

After stratifying by sex, we used BMI to classify individuals into the following categories: 18·5 to less than 25 kg/m² (ideal bodyweight), 25 to less than 30 kg/m² (overweight), 30 to less than 35 kg/m² (obese), or 35 kg/m² and higher (very obese). For the primary analyses we stratified individuals into age ranges to ensure that resulting estimates were supported by adequate numbers in each group: 20–39, 40–59, and 60–79 years of age. This resulted in 65–293 individuals in each cell (see appendix for detailed tables stratified by age and sex). To estimate the years of life lost and healthy life-years lost we used the sampling weights provided by NHANES and adjusted for combination of data across multiple surveys as per NHANES guidelines.

Within each subgroup, we used the model to calculate each individual's life expectancy and life-years free from diabetes or cardiovascular disease if these diagnoses were absent when the individual was evaluated during the NHANES survey. The values within each subgroup were then compared with the reference subgroup with an ideal bodyweight. We calculated years of life lost as the difference in the mean forecasted life expectancy between BMI subgroups. These differences were due to the increased risk of a cardiovascular death due to excess weight adversely affecting blood pressure and blood lipids. The effect of diabetes on life expectancy was also due to an increased risk of fatal cardiovascular events. We similarly calculated healthy life-years lost as the remaining years of life free from diabetes or cardiovascular disease. Individuals who were diagnosed with diabetes or cardiovascular disease at baseline were assigned a value of zero for the healthy life-years lost, but still contributed to the years of life lost. We estimated 95% CI by taking 95% of the range of these averages.

In view of the recognised association between cigarette smoking and bodyweight, and between smoking and cardiovascular risk, combined analysis of smokers and non-smokers could affect the results in ways that are difficult to predict. We therefore completed a second analysis in which we stratified by smoking status, comparing current smokers with one another and non-smokers (defined as those who never smoked or had stopped smoking) likewise. Finally, we used the results for each individual in the cohort to calculate the years of life lost as a function of age (years), BMI (kg/m²), and the BMI multiplied by age interaction term to compare individuals with a BMI from 26–45 kg/m² to the ideal bodyweight reference.

Sensitivity analyses

We did several post-hoc analyses to establish the robustness of our results and summarise the effects of excess

For the **NHANES guidelines** see http://www.cdc.gov/nchs/tutorials/nhanes/SurveyDesign/Weighting/intro.htm

	Men					Women				
	Ideal body-weight (n=537)	Overweight (n=784)	Obese (n=432)	Very obese (n=258)	Overall (N=2011)	Ideal body-weight (n=702)	Overweight (n=578)	Obese (n=356)	Very obese (n=345)	Overall (N=1981)
Age (years)	42·4 (16·6)	47·5 (15·1)	48·9 (14·6)	48·1 (14·3)	46·5	44·5 (15·4)	49·0 (15·6)	50·5 (15·0)	48·7 (15·0)	47·5 (15·5)
Systolic blood pressure (mm Hg)	119·0 (14·4)	121·7 (13·7)	124·3 (14·2)	126·7 (16·3)	122·2	113·4 (16·4)	118·1 (16·8)	122·8 (17·3)	122·8 (16·6)	117·9 (17·2)
Diastolic blood pressure (mm Hg)	67·9 (10·9)	71·3 (11·1)	73·5 (11·4)	74·5 (11·4)	71·3 (11·4)	67·3 (10·2)	68·2 (10·8)	70·6 (11·3)	70·5 (11·1)	68·7 (10·8)
Total cholesterol (mmol/L)	4·8 (1·0)	5·1 (1·0)	5·1 (1·1)	4·8 (1·0)	5·0 (1·0)	5·1 (1·0)	5·5 (1·2)	5·3 (1·1)	5·2 (1·2)	5·2 (1·1)
HDL cholesterol (mmol/L)	1·4 (0·4)	1·2 (0·3)	1·1 (0·3)	1·1 (0·2)	1·2 (0·3)	1·7 (0·4)	1·5 (0·4)	1·4 (0·4)	1·3 (0·3)	1·5 (0·4)
Total cholesterol:HDL ratio	3·6 (1·4)	4·4 (1·5)	4·8 (1·4)	4·7 (1·4)	4·3 (1·4)	3·1 (1·0)	3·8 (1·3)	4·1 (1·6)	4·2 (1·3)	3·7 (1·3)
LDL cholesterol (mmol/L)	2·8 (0·9)	3·1 (0·9)	3·1 (0·9)	2·9 (0·9)	3·0 (0·9)	2·8 (1·0)	3·2 (0·9)	3·1 (0·9)	3·1 (0·9)	3·0 (0·9)
Triglycerides (mmol/L)	1·3 (0·8)	1·8 (1·5)	2·0 (1·6)	2·0 (1·6)	1·7 (1·4)	1·1 (1·2)	1·5 (1·0)	1·8 (1·7)	1·9 (1·2)	1·5 (1·3)
BMI (kg/m^2)	22·7 (1·6)	27·5 (1·5)	32·2 (1·4)	40·1 (6·8)	28·8 (6·1)	22·3 (1·8)	27·3 (1·4)	32·2 (1·4)	40·2 (4·6)	28·5 (6·8)
Waist circumference (cm)	87·0 (7·2)	100·0 (6·7)	112·0 (6·5)	129·2 (11·0)	102·8 (15·2)	80·8 (6·6)	93·8 (6·7)	104·8 (7·0)	119·9 (10·3)	95·3 (15·8)
Smoker	214 (42%)	186 (24%)	81 (20%)	49 (18%)	267 (27%)	193 (27%)	128 (20%)	76 (18%)	75 (21%)	472 (22%)
Cardiovascular disease	38 (2%)	73 (4%)	69 (6%)	33 (3%)	213 (4%)	29 (2%)	27 (3%)	34 (6%)	42 (6%)	105 (4%)
Glucose (mmol/L)	5·5 (1·1)	5·7 (1·1)	6·1 (1·9)	6·4 (1·8)	5·8 (1·5)	5·1 (0·6)	5·4 (1·0)	5·9 (1·5)	6·1 (1·7)	5·5 (1·2)
Family history of diabetes	177 (32%)	286 (37%)	170 (41%)	132 (50%)	765 (38%)	245 (36%)	224 (39%)	161 (49%)	170 (50%)	800 (41%)
Diabetes	46 (6%)	93 (6%)	78 (13%)	87 (25%)	304 (10%)	27 (1%)	37 (5%)	63 (13%)	79 (20%)	206 (8%)
Years with diabetes	10·8 (13·3)	5·9 (8·8)	6·6 (11·5)	6·9 (11·4)	7·2 (11·3)	11·2 (9·8)	6·8 (7·7)	8·0 (11·6)	9·1 (10·6)	8·5 (10·6)

Risk factors are presented as mean (SD) or n (%). Percentages in the table have been adjusted using the fasting sub-sampling weights provided by NHANES. Ideal bodyweight group is individuals with a BMI of 18·5 to <25 kg/m^2, overweight group is BMI 25 to <30 kg/m^2, obese group is a BMI of 30 to <35 kg/m^2, very obese group is BMI 35 kg/m^2 and higher. NHANES=National Health and Nutrition Examination Survey.

Table 1: **Cardiovascular and diabetes risk factors in non-Hispanic white adults aged 20–79 years in NHANES 2003–10**

	Life expectancy from US life tables (years)		Life expectancy in our model (years)	
	Men	Women	Men	Women
20–29 years	53·0	57·4	51·5	56·9
30–39 years	43·4	47·6	41·9	46·8
40–49 years	34·2	38·1	32·8	37·7
50–59 years	25·6	29·5	25·2	29·5
60–69 years	18·5	20·5	18·3	21·7
70–79 years	11·6	13·7	13·5	15·5

Table 2: **Validation of the cardiometabolic model by age group—US life tables[19]**

	Life expectancy from Peeters and colleagues[24] (years)		Life expectancy from our model (years)	
	Men	Women	Men	Women
Ideal bodyweight				
Non-smoker	43·4	46·3	43·0	46·6
Smoker	36·3	40·2	35·7	36·9
Overweight				
Non-smoker	40·3	43·0	38·9	44·8
Smoker	35·0	40·1	30·9	35·9
Obese and very obese				
Non-smoker	37·5	39·2	36·1	42·2
Smoker	29·7	33·0	28·2	33·0

Ideal bodyweight group is individuals with a BMI of 18·5 to <25 kg/m^2, overweight group is BMI 25 to <30 kg/m^2, obese and very obese group is a BMI of 30 kg/m^2 and higher. Population is men and women aged 30–49 years from Framingham study cohort, stratified by BMI and smoking status, as reported by Peeters and colleagues.[24]

Table 3: **Validation of the cardiometabolic model by BMI status—Peeters and colleagues[24]**

bodyweight from our model (appendix). First, because of the interest in central obesity as a risk factor for diabetes and cardiovascular disease, the primary analysis was re-calculated with NHANES data in which the definition of excess weight was based on waist circumference rather than BMI. Second, as a major determinant of life expectancy, age is an important potential confounder in our analyses because the average age in the groups with excess bodyweight was not the same as the reference group with ideal bodyweight. To adjust for these differences, we re-ran simulations with ages fixed at 30, 50, and 70 years for each participant aged 20–39, 40–59, 60–79 years, respectively. Finally, to highlight the importance of age, we calculated the estimated years of life lost (YLL) for men and women as a function of BMI, age, and the interaction between BMI and age.

Role of the funding source

The study funder did not have any input into the design or conduct of the study including the collection, management, analysis, and interpretation of the data; or the preparation, review, or approval of the manuscript. SAG, PR, and LJ had access to the raw data. The corresponding author had full access to all the data and the final responsibility to submit for publication.

Results

Compared with individuals with an ideal bodyweight, overweight, obese, and very obese individuals had increasingly raised blood pressure and concentrations of serum glucose and triglycerides; raised total and LDL cholesterol concentrations that tended to plateau in obese and very obese individuals; and increasingly lowered concentrations of HDL cholesterol (table 1). Presence of cigarette smoking was inversely related to increasing BMI, identifying this major cardiovascular risk factor as a potentially important confounder.

On the validation simulations, the model estimates were similar and consistent with previously reported results. With NHANES data (2003–10) for white individuals, the calculated life expectancy for men and women within specific age intervals matched closely those in the US national life tables (table 2).[19] Our results were also similar to those published by Peeters and colleagues[24] with data from Framingham study participants after stratification by sex, smoking status, and BMI (table 3).

Compared with individuals aged 20–39 years with an ideal bodyweight, we estimated that overweight men lost 2·7 years (95% CI 1·6–3·8), obese men lost 5·9 years (4·4–7·4), and severely obese men lost 8·4 years (7·0–9·8; figure 2). The years lost tended to be lower for older men than for younger men. For women, the years lost are as high as 6·1 years (95% CI 4·7–7·6; very obese women aged 20–39 years; figure 2). We estimated that women aged 20–39 years had the highest years of life lost whereas the effect of excess bodyweight was small or negligible in older women, especially for those who were only overweight (figure 2). The rare negative estimates in these figures are probably due to random variation within the smaller groups with respect to the prevalence of major risk factors including age, diabetes diagnosis, smoking status, or currently diagnosed cardiovascular disease.

Increased bodyweight was associated not only with reduced life expectancy but also with early development of diseases such as type 2 diabetes and cardiovascular disease. Accordingly, healthy life-years lost were substantially greater than the years of life lost for all groups of overweight and obese individuals, with the largest values noted in young adults aged 20–39 years, including 18·8 years (95% CI 16·8–20·8) for very obese men and 19·1 years (16·7–21·5) for very obese women (figure 2). Even in older individuals who are only overweight, the healthy life-years lost were substantial despite small or negligible years of life lost. After stratification by smoking status (figures 3, 4), and comparison of smokers across BMI categories, the years

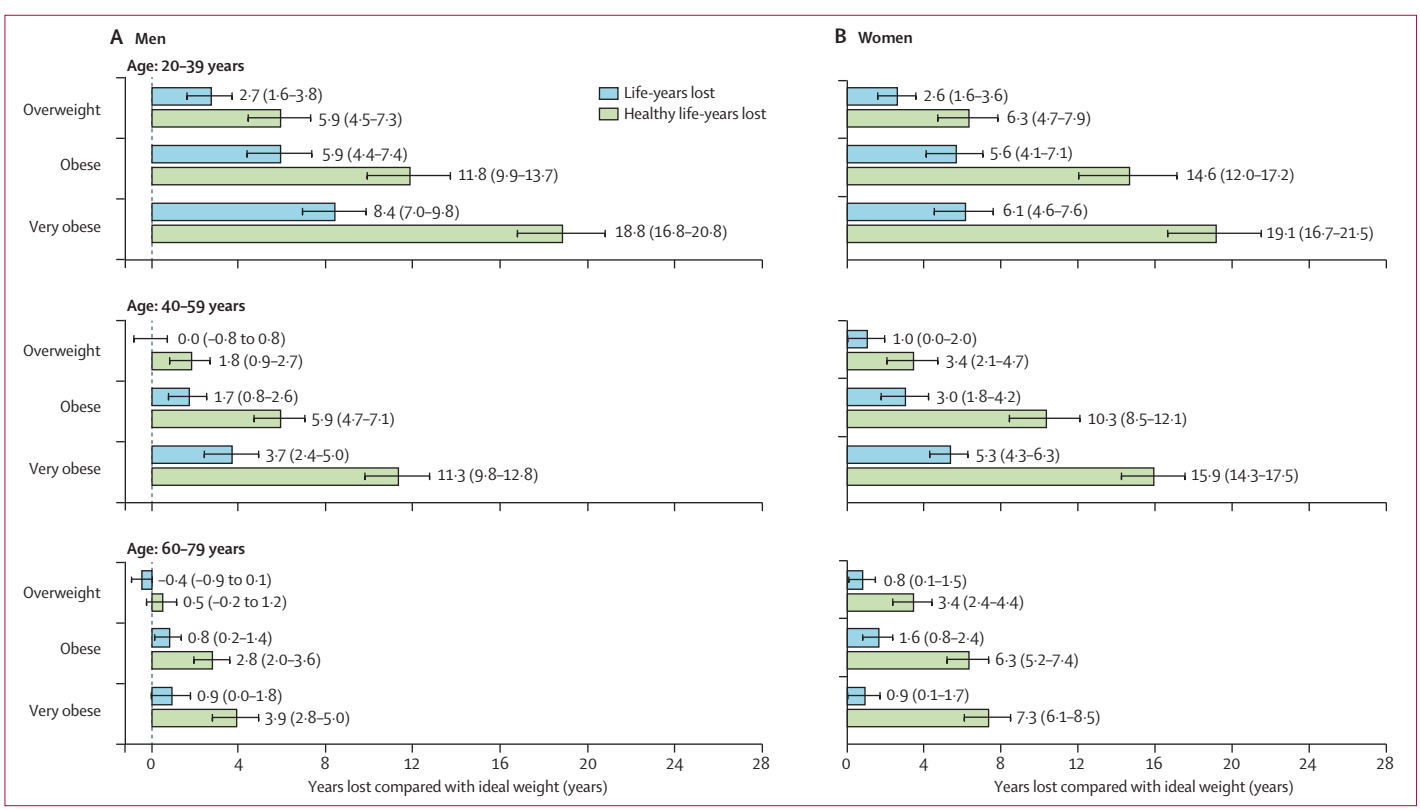

Figure 2: **Calculated years of life lost and healthy life-years lost in men (A) and women (B) compared with those with an ideal bodyweight**
Bodyweight categories are ideal (BMI 18·5 to <25 kg/m²), overweight (25 to <30 kg/m²), obese (30 to <35 kg/m²), or very obese (≥35 kg/m²). Data are based on cardiometabolic risk factors in US adults in the National Health Examinations and Nutrition Survey data from 2003–10.[25] Error bars show the 95% CI for each estimate.

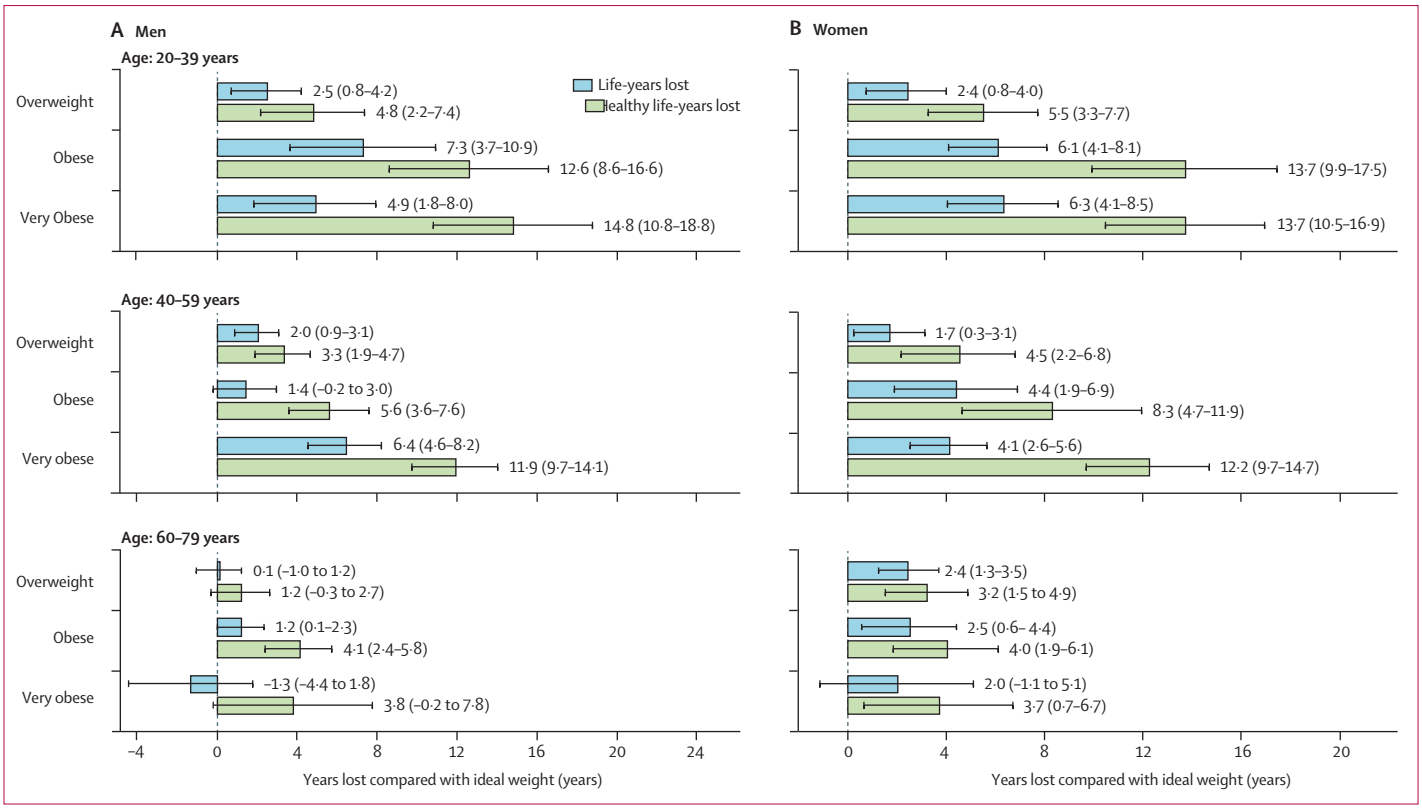

Figure 3: **Calculated years of life lost and healthy life-years lost in male smokers (A) and female smokers (B) compared with smokers with an ideal bodyweight**
Bodyweight categories are ideal (BMI 18·5 to <25 kg/m²), overweight (25 to <30 kg/m²), obese (30 to <35 kg/m²), or very obese (≥35 kg/m²). Data are based on cardiometabolic risk factors in US adults in the National Health Examinations and Nutrition Survey data from 2003–10.[25] Error bars show the 95% CI for each estimate.

of life lost and healthy life-years lost were greatest for young non-smokers.

The findings of our analyses remained unchanged when the NHANES data were stratified by waist circumference rather than BMI (appendix) or when age was adjusted to be exactly the same for the groups with ideal body weight versus those with excess weight (appendix). Finally, the decreasing effect of excess bodyweight associated with increasing age was shown when the years of life lost were calculated as a function of BMI, age, and the interaction between BMI and age (appendix).

Discussion

Our results, calculated with 2003–10 NHANES data, show the distribution of diabetes and cardiovascular risk factors in adults with varying BMIs and show the substantial clinical burden associated with excess bodyweight (panel). When only the increased risks of developing diabetes or cardiovascular disease were considered, excess bodyweight was associated with a substantial reduction in life expectancy. However, focusing only on years of life lost might substantially underestimate the effect of excess weight on an individual's health.[14] When the effect of living with a chronic illness such as type 2 diabetes or cardiovascular disease is considered, healthy life-years lost were two to four times greater than total years of life lost and, in some instances, as much as eight times greater.

These estimates, based on a disease modelling approach, are consistent with several studies that used mortality data (linkage to death certificate records or mortality files) to calculate the effect of excess bodyweight on life expectancy. Our results stratified by smoking status are very similar to those of Peeters and colleagues[24] who used Framingham cohort data (table 2). In the Prospective Studies Collaboration, based on 66 552 deaths among 894 576 participants in 57 prospective studies, the observed reduction in median survival was 0–2 years, 2–4 years, and 8–10 years for those who were overweight, obese, and very obese, respectively. Our estimated years of life lost are similar: 0–3 years (overweight), 1–6 years (obese), and 1–8 years (very obese), dependent on an individual's age and sex.[2]

Fontaine and colleagues,[13] in a mortality study using a NHANES dataset from 1998–94, showed a small or negligible years of life lost (≤1 year) for men and women whose BMIs were between 25 and 30 kg/m². For those with a BMI of 31–35 the years lost were 1–3 years, whereas those with a BMI higher than 35 kg/m² were estimated to lose 1–12 years of life expectancy. Years of

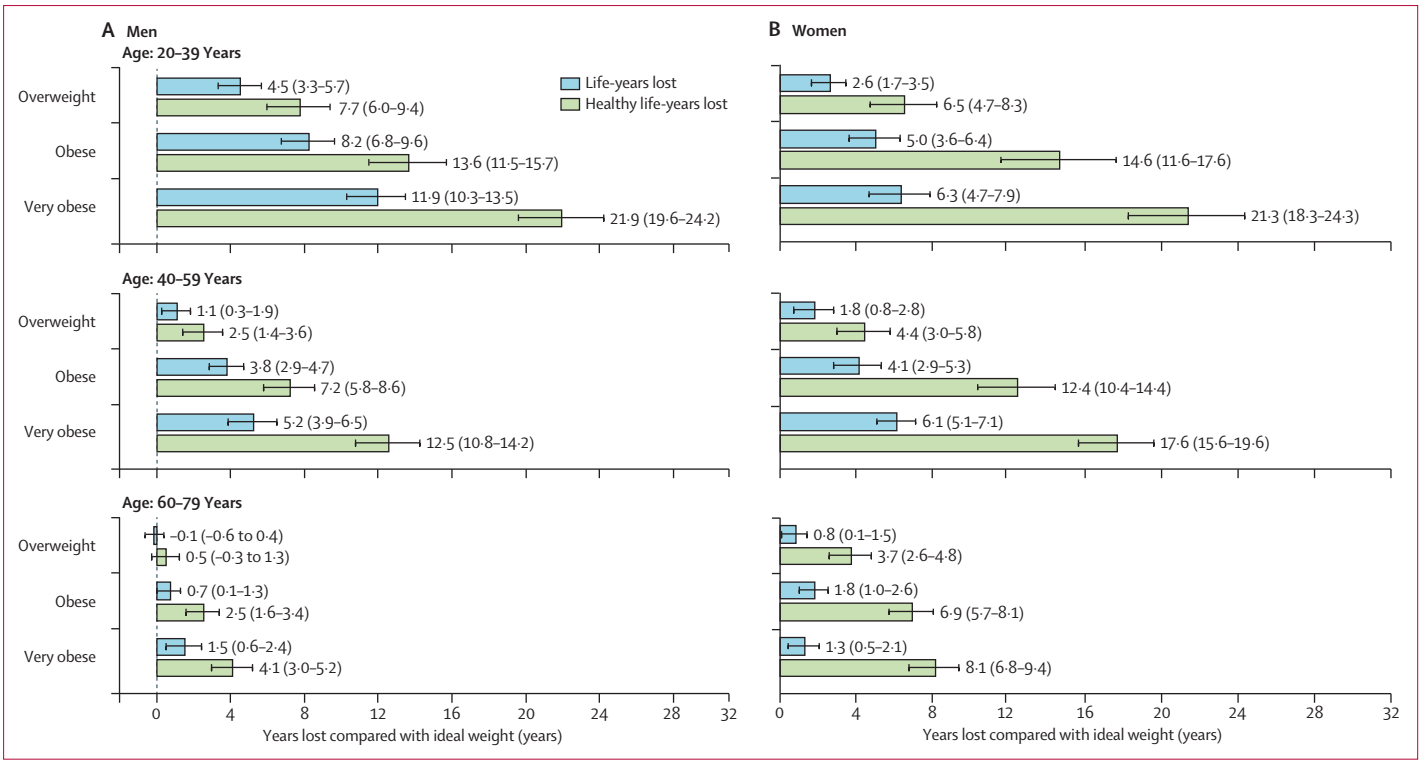

Figure 4: **Calculated years of life lost and healthy life-years lost in men (A) and women (B) who do not currently smoke compared with those with an ideal bodyweight**
Bodyweight categories are ideal (BMI 18·5 to <25 kg/m^2), overweight (25 to <30 kg/m^2), obese (30 to <35 kg/m^2), or very obese (≥35 kg/m^2). Data are based on cardiometabolic risk factors in US adults in the National Health Examinations and Nutrition Survey data from 2003–10.[25] Error bars show the 95% CI for each estimate.

life lost were inversely related to age, and were greater for men than for women aged 60 years. Above this age, years of life lost became greater for women than for men. Our results with more recent NHANES data are similar. The results of Finkelstein and colleagues,[26] who used National Health Survey-linked mortality files, also showed increased mortality associated with obesity, but no reduction in life expectancy associated with overweight status.[26] years of life lost decreased with increasing age, as we have shown with our findings.

We are not aware of other studies that estimate healthy life-years lost due to obesity. However, Pardo Silva and colleagues[27] used Framingham study data to estimate the effect of excess weight on both life expectancy and years lived without cardiovascular disease.[27] The analysis was restricted to only cardiovascular outcomes in individuals free of disease at baseline. Similar to our results, the reduction in years free of disease due to excess bodyweight was generally greater than was the reduction in life expectancy.

Our results are conservative because we estimated the effect of excess bodyweight on only the risk factors associated with type 2 diabetes or cardiovascular disease. Although prospective cohort studies also show that excess bodyweight is associated with increased mortality due to cancer, non-malignant respiratory disease, hepatic disease, and renal disease, there is no evidence from clinical trials that risks of mortality from these causes are modifiable with weight reduction.[2] Accordingly, the years of life lost are mainly due to an increased risk of cardiovascular deaths, whereas the healthy life-years lost are due to the development of type 2 diabetes or cardiovascular disease at an earlier age. Our focus on cardiometabolic risk factors was intentional. Although secular trends to actively treat hypertension and dyslipidaemia might reduce the risk of cardiovascular disease in obese individuals, cardiovascular deaths remain the main cause of mortality.[2,28,29] Clinical trial data clearly indicate that the prevalence of cardiovascular risk factors such as dyslipidaemia and hypertension can be reduced by weight reduction, as can the risk of developing type 2 diabetes.[30–32]

We acknowledge that any use of model estimates to inform individual patients needs to be done with caution. Although the 95% CIs provided in each figure acknowledge some of the uncertainty around each point estimate, these intervals are average values and do not capture the full extent of the uncertainty at the individual level. One approach would be to describe how excess bodyweight is associated with an increased risk of cardiovascular disease and type 2 diabetes that will, on average, reduce an individual's life expectancy and their healthy life-years free from diabetes and cardiovascular disease. Similar approaches with metrics such as 10 year cardiovascular risk scores or

Panel: Research in context

Systematic review

We searched PubMed for articles published in English from Jan 1, 2000 to Nov 1, 2014, with the search terms "cardiometabolic risk and life expectancy", "diabetes risk and life expectancy", "cardiovascular risk and life expectancy", and "obesity and healthy life expectancy". Although several studies have estimated the effect of excess bodyweight on premature mortality,[13,24,26,27] we found no information on the morbidity (healthy life-years lost) due to the increased risk of cardiovascular disease and diabetes in adults who are overweight or obese at various ages across the lifetime.

Interpretation

We developed and validated a disease-simulation model to estimate the risk of developing diabetes and cardiovascular disease. We then estimated the mortality (years of life lost) and morbidity (healthy life-years lost) associated with excess bodyweight in white US individuals within specific age groups. Overall, healthy life-years lost were two to four times greater than were years of life lost. These results might provide useful measures for health professionals and patients to discuss the clinical effect of being overweight or obese.

cardiovascular age estimates have improved management of dyslipidaemia and hypertension to prevent cardiovascular disease.[9,33] Our results provide an order of magnitude of effect, on average, for groups of a particular age, sex, and BMI, compared with similar groups with an ideal bodyweight. The pattern is clear: the more an individual weighs and the younger their age, the greater the effect of excess weight on health.

Our calculated measurement of years of life lost associated with excess weight provides a clinically relevant health measure to focus disease-prevention efforts of both health professionals and patients. Estimates for healthy life-years lost might also prove useful because they magnify the effect of excess bodyweight beyond mortality through inclusion of morbidity associated with living with type 2 diabetes or cardiovascular disease. These results might help health professionals to more actively encourage weight loss in their overweight and obese patients, and also provide such patients with additional motivation to adhere to healthier lifestyles.

Contributors

All authors were involved in the study design, data analysis, and preparation of the manuscript.

Declaration of interests

SAG acts as a consultant to Merck, Roche, AstraZeneca, and Amgen. MD is a board member of North American Primary Care Research Group Program Chair and receives grant support from Pfizer, AstraZeneca, Roche, GlaxoSmithKline, Janssen, and Health Research Foundation for genetics research. DCWL receives consultancy fees from Abbott, Allergan, Amgen, AstraZeneca, Bristol-Myers Squibb, Boehringer-Ingelheim, Eli Lilly, Janssen, Novo Nordisk, Merck, Roche, Novartis, Sanofi, and Valeant. DL provides expert testimony to the Canadian Medical Protective Association and to United Nurses of Alberta. MK, LJ, IK, and PR declare no competing interests.

Acknowledgments

SG, LJ, DCWL, and MD received funding from the Canadian Institute of Health Research (grant GIR-86935).

References

1 WHO. Global status report on noncommunicable diseases 2010. Geneva: World Health Organization, 2010: 1–160.
2 Whitlock G, Lewington S, Sherliker P, et al. Body-mass index and cause-specific mortality in 900 000 adults: collaborative analyses of 57 prospective studies. *Lancet* 2009; **373:** 1083–96.
3 Knowler WC, Barrett-Connor E, Fowler SE, et al. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *N Engl J Med* 2002; **346:** 393–403.
4 Tuomilehto J, Lindstrom J, Eriksson JG, et al. Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. *N Engl J Med* 2001; **344:** 1343–50.
5 Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults. Executive Summary of The Third Report of The National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, And Treatment of High Blood Cholesterol In Adults (Adult Treatment Panel III). *JAMA* 2001; **285:** 2486–97.
6 Chobanian AV, Bakris GL, Black HR, et al. The Seventh Report of the Joint Nationa Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure. *JAMA* 2003; **289:** 2560–72.
7 Flegal KM, Carroll MD, Ogden CL, Curtin LR. Prevalence and trends in obesity among US adults, 1999–2008. *JAMA* 2010; **303:** 235–41.
8 Finucane MM, Stevens GA, Cowan MJ, et al. National, regional, and global trends in body-mass index since 1980: systematic analysis of health examination surveys and epidemiological studies with 960 country-years and 9·1 million participants. *Lancet* 2011; **377:** 557–67.
9 Cooney MT, Dudina AL, Graham IM. Value and limitations of existing scores for the assessment of cardiovascular risk: a review for clinicians. *J Am Coll Cardiol* 2009; **54:** 1209–27.
10 D'Agostino RB, Vasan RS, Pencina MJ, et al. General cardiovascular risk profile for use in primary care: the Framingham Heart Study. *Circulation* 2008; **117:** 743–53.
11 Schmidt MI, Duncan BB, Bang H, et al. Identifying individuals at high risk for diabetes: The Atherosclerosis Risk in Communities study. *Diabetes Care* 2005; **28:** 2013–18.
12 Després JP, Lemieux I. Abdominal obesity and metabolic syndrome. *Nature* 2006; **444:** 881–87.
13 Fontaine KR, Redden DT, Wang C, Westfall AO, Allison DB. Years of life lost due to obesity. *JAMA* 2003; **289:** 187–93.
14 Manson JE, Bassuk SS. Obesity in the United States: a fresh look at its high toll. *JAMA* 2003; **289:** 229–30.
15 Grover SA, Coupal L, Paquet S, Zowall H. Cost-effectiveness of 3-hydroxy-3-methylglutaryl-coenzyme A reductase inhibitors in the secondary prevention of cardiovascular disease: forecasting the incremental benefits of preventing coronary and cerebrovascular events. *Arch Intern Med* 1999; **159:** 593–600.
16 Grover SA, Paquet S, Levinton C, Coupal L, Zowall H. Estimating the benefits of modifying risk factors of cardiovascular disease: a comparison of primary vs secondary prevention. *Arch Intern Med* 1998; **158:** 655–62.
17 Grover SA, Coupal L, Kaouache M, Lowensteyn I. Preventing cardiovascular disease among Canadians: what are the potential benefits of treating hypertension or dyslipidemia? *Can J Cardiol* 2007; **23:** 467–73.
18 Grover SA, Coupal L, Gilmore N, Mukherjee J. Impact of dyslipidemia associated with highly active antiretroviral therapy (HAART) on cardiovascular risk and life expectancy. *Am J Cardiol* 2005; **95:** 586–91.
19 Arias E. United States life tables, 2007. *Natl Vital Stat Rep* 2011; **59:** 1–60.
20 The ARIC investigators. The Atherosclerosis Risk in Communities (ARIC) Study: design and objectives. *Am J Epidemiol* 1989; **129:** 687–702.
21 Kass RE, Raftery AE. Bayes Factors. *J Am Stat Assoc* 1995; **90:** 773–95.
22 Wilson PWF, Meigs JB, Sullivan L, Fox CS, Nathan DM, D'Agostino RB. Prediction of incident diabetes mellitus in middle-aged adults—The Framingham Offspring Study. *Arch Intern Med* 2007; **167:** 1068–74.

23 Eastman RC, Javitt JC, Herman WH, et al. Model of complications of NIDDM. I. Model construction and assumptions. *Diabetes Care* 1997; **20:** 725–34.

24 Peeters A, Barendregt JJ, Willekens F, Mackenbach JP, Al Mamun A, Bonneux L. Obesity in adulthood and its consequences for life expectancy: a life-table analysis. *Ann Intern Med* 2003; **138:** 24–32.

25 CDC/National Center for Health Statistics. Third National Health and Nutrition Examination Survey (NHANES III), 2003–2010. Atlanta: CDC/National Center for Health Statistics, 2012.

26 Finkelstein EA, Brown DS, Wrage LA, Allaire BT, Hoerger TJ. Individual and aggregate years-of-life-lost associated with overweight and obesity. *Obesity (Silver Spring)* 2010; **18:** 333–39.

27 Pardo Silva MC, de Lact C, Nusselder WJ, Mamun AA, Peeters A. Adult obesity and number of years lived with and without cardiovascular disease. *Obesity (Silver Spring)* 2006; **14:** 1264–73.

28 Mehta T, Fontaine KR, Keith SW, et al. Obesity and mortality: are the risks declining? Evidence from multiple prospective studies in the United States. *Obes Rev* 2014; **15:** 619–29.

29 Gregg EW, Cheng YJ, Cadwell BL, et al. Secular trends in cardiovascular disease risk factors according to body mass index in US adults. *JAMA* 2005; **293:** 1868–74.

30 Thomas DE, Elliott EJ, Baur L. Low glycaemic index or low glycaemic load diets for overweight and obesity. *Cochrane Database Syst Rev* 2007; CD005105.

31 Norris SL, Zhang X, Avenell A, et al. Long-term non-pharmacologic weight loss interventions for adults with type 2 diabetes. *Cochrane Database Syst Rev* 2005; CD004095.

32 Siebenhofer A, Jeitler K, Berghold A, et al. Long-term effects of weight-reducing diets in hypertensive patients. *Cochrane Database Syst Rev* 2011; CD008274.

33 Grover SA, Lowensteyn I, Joseph L, et al. Patient knowledge of coronary risk profile improves the effectiveness of dyslipidemia therapy: the CHECK-UP study: a randomized controlled trial. *Arch Intern Med* 2007; **167:** 2296–303.