Changes in BMI and waist circumference in Scottish adults: Use of repeated cross-sectional surveys to explore multiple age groups and birth-cohorts

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Abstract

Objective: To document changes in body mass index (BMI) and waist circumference (WC) over a 10-year period 1998-2008, in representative surveys of adults.

Subjects: Adults aged 18-72 in the Scottish Health Surveys conducted in 1998, 2003 and 2008 were divided, separately for men and women, into eleven 5-year age bands. 'Synthetic birth-cohorts' were created by dividing participants into thirteen 5-years-of-birth bands (n=20,423). Weight, height and waist circumference were objectively measured by trained observers.

Results: Subjects with data available on BMI/waist circumference were 7743/6894 in 1998, 5838/4437 in 2003 and 4688/925 in 2008 with approximately equal gender distributions. Mean BMI and waist were both greater in successive surveys in both men and women. At most specific ages, people were consistently heavier in 2008 than in 1998 by about 1-1.5 BMI units, and waist circumferences were greater, by about 2-6 cm in men and 5-7 cm in women. Greater increases were seen at younger ages between 1998 and 2003 than between 2003 and 2008, however increases continued at older ages, particularly in waist. All birth-cohorts observed over the 10 years 1998-2008 showed increases in both BMI and waist, most marked in the younger groups. The 10-year increases in waist within birth-cohorts (mean 7.4 cm (8.1%) in men and 8.6 cm (10.9%) in women) were more striking than BMI (mean 1.8 kg/m^2 (6.6%) in men and 1.5 kg/m^2 (6.4%) in women) were particularly steep in older women.

Conclusion: People were heavier and fatter in 2003 than those of the same age in 1998, with less marked increases in WC between 2003 and 2008 than 1998 and 2003. There were proportionally greater increases in waist circumference than BMI, especially in older women. This suggests a disproportionate increase in body fat, compared to muscle, particularly among older women.

Keywords: Body fat, obesity, sarcopenia, ageing

Introduction

Obesity, the "disease process characterised by excessive body fat accumulation with multiple organ-specific consequences"[1] is a critical public health problem, for all ages, ethnic and socio-economic groups. For epidemiological purposes Body Mass Index (BMI) is widely used to characterise adults body composition (≥25 kg/m^2 = overweight, ≥30 kg/m^2 = obese)[2] but waist circumference (WC) is a marginally better indicator of total body fat[3] and of health risks (>94 cm men, >80 cm women = increased risk; >102 cm men, >88 cm women = high risk for Caucasian adults).[4,5] Obesity at age 40 shortens life expectancy by about 7 years,[6] and its numerous health consequences have major negative impacts, potentially avoidable, on quality of life, healthcare and social support costs. Obese individuals spend 30% more than normal-weight on medical care.[7] Total healthcare costs of people with BMI 40 are about double those at BMI 20-21 ("ideal body weight").[8,9]

Obesity prevalence has increased dramatically globally and it is predicted to increase furhter.[10] Over 30% of US adults have BMI ≥30.[11] European prevalences vary from 15-26% in men and 11-27.5% in women, with Scotland well above UK and European averages, reaching 26.0% for men and 27.5% for women in 2008, when BMI 35 kg/m^2 was exceeded by 6% of men and 11.2% of women.[12] Understanding time-trends in prevalence and distribution of obesity is important to inform appropriate policies and interventions. Time-related variations in markers, such as BMI and WC, can be attributed to *age*, *period* or *cohort effects*. Data from the 1990s showed that BMI increased most rapidly in early adulthood, levelled off by age 60 to 70 years and decreased slightly in older ages.[13] In US, BMI now continues to increase up to 80 years.[14] Obesity prevalence has also increased remarkably over time, especially among developed countries. [11,15,16] This increase is evident both in total populations and in different groups, younger adults showing significantly larger weight-gains over time compared to older adults.[17,18]

The few published data on age-related changes in BMI in birth-cohorts suggest that men have recently been gaining weight more rapidly than previously, while women gain more weight with age than men, but at similar rates across different birth-cohorts.[19.20,21] A recent English study confirmed this, and suggested that obesity prevalence is plateauing.[22] Longitudinal NHANES data showed how consequences of obesity can be seriously underestimated if based on BMI trends alone.[23] Despite its stronger associations with total body fat and with diabetes and cardiovascular disease risk, in most but not all studies (Vazquez 2007) little is known about time-trends in WC. [24,25,26] The present study was designed to document and compare time-trends in both BMI and WC, over a 10-year period (1998-2008) in the Scottish population, one of the highest obesity prevalences in Europe.

Methods

A "synthetic birth-cohort" approach was used for secondary analyses of successive cross-sectional national surveys, to quantify both changes with 10-year age increases and also differences between people of the same age, 10 years apart.

Design and setting

Data were accessed through the UK Data Archive from the Scottish Health Survey (SHS), a series of cross-sectional surveys designed to provide nationally representative data on health-related variables and risk factors, commissioned by the Scottish Government.[27] Each survey uses multistage stratified random sampling of private households from the Postcode Address File. During the first stage, personal interviews are conducted by a trained interviewer, to collect information on socio-demographic factors, self-assessed health, disability, eating habits, health conditions, lifestyle factors such as smoking and drinking behaviours, and health services use. Subsequently, a trained nurse collects further information on prescribed drugs and vitamin supplements, blood, saliva and urine samples, and makes anthropometric measurements including body weight, height, waist and hip circumference. Detailed information on sampling procedures, survey design and content and response rates which range from 76% in 1998 to 54% in 2008 are published.[28] Overall, records were available for 12,939, 11,472 and 8,215 subjects in 1998, 2003 and 2008 SHS surveys respectively. From 2008, the survey design was modified, to be conducted annually, with body weight and height measurement during the personal interview, and only a sub-sample allocated a nurse visit for waist and hip measurements.

Data from three SHS surveys (1998, 2003, 2008), were combined into a single database, organising respondents firstly by age-groups, and secondly by constructing "synthetic birth-cohorts", by grouping individuals according to their years of birth. Categorical variables were created for periods, age and birth-cohort. Participants' ages at last birthday were grouped into eleven 5-year bands, identified by the middle year from 20 (i.e. ages 18 to 22) to 70 (ages 68 to 72) years. Thirteen synthetic birth-cohorts were constructed, each for 5 birth-years, identified by the middle year from 1928 (i.e. born 1926-1930) to 1988 (born 1986-1990). For each birth-cohort, data on BMI and WC were available from the 3 surveys and at 3 different ages. For example, respondents from the 1978 cohort (born 1976-1980) were interviewed at the ages of 20, 25 and 30 years, in 1998, 2003 and 2008 respectively. For the youngest birth-cohorts of 1988 and 1983, data were only available at age 20 years and 20, 25 years respectively. Similarly, data for the eldest 1928 to 1933 birth-cohorts were only available at age 70 years and 65, 70 years respectively.

Variables and measurements

All anthropometric measurements followed a specified protocol using calibrated scales and inextensible plastic tapes. Height was measured to the nearest even millimetre, without shoes, head in the Frankfort Plane position. Weight was measured with light clothing without shoes, to the nearest 0.1 kg. Waist circumference was measured with an inelastic tape, to the nearest 0.1 cm, mid-way between the lowest (10^{th}) rib and the iliac crest. Mean of two measurements was used: if they differed by 3 cm or more, a third measurement was recorded.

Participants and study size

Data for the present analyses included adults aged 18 to 72 years, excluding pregnant women, with measured data available on weight, height and waist circumference. Anthropometric measurements were available for the present study for 92%, 85% and 87% of subjects in 1998, 2003 and 2008 respectively (Figure 1).

Statistical methods

All analyses were conducted separately for men and women. Simple exploratory statistical techniques were used to describe 10-year changes in BMI and WC for each birth-cohort and age group. Statistical significance was assessed with one-way analysis of variance (ANOVA) with post-hoc Bonferroni correction. Change in the prevalence of overweight and obesity over time were assessed using chi-square test. Differences in age and percentage of male and female participants between respondents and non-respondents were compared using chi-square test and t-tests or Mann-Whitney test for parametric and non-parametric data respectively. Statistical significance was set to 0.05. All analyses were performed with SPSS statistical software package version 15.

Results

Participants

Response rates for weight and height measurements were 91%, 84% and 86% for 1998, 2003 and 2008 respectively. Respondents were more likely to be women in 1998 and 2008 and older in 1998, compared to those who refused anthropometric measurements. Differences in respondents are unlikely to have biased analyses for specific age groups: variables were compared between participants who responded for weight, height and WC and those who provided weight and height but not WC measurements. In 1998 and 2003, men without WC measurements had marginally lower mean BMI (26.4 kg/m^2 vs. 26.9 kg/m^2, p=0.016 in 1998; 27.2 kg/m^2 vs. 27.6 kg/m^2, p=0.031 in 2003).

Table 1 provides descriptive statistics. Data were available for 18,269 and 12,256 subjects for analyses of BMI and WC trends respectively. Mean age, weight, height, BMI and WC all increased significantly over time ($p<0.001$).

Body Mass Index

Table 2 shows estimated prevalences of BMI 25-<30, ≥30 and ≥35 kg/m^2. The total with BMI 25-30 kg/m^2 rose successively among women at 32.6%, 34.7%, 35.1% in the respective surveys of 1998, 2003, 2008. Men had a higher prevalence of BMI 25-30 kg/m^2 than women in all surveys ($p<0.001$), increasing between 1998 and 2003 from 44.6% to 45.8% and then decreasing to 44.0% in 2008. Prevalence of BMI ≥30 kg/m^2 increased steeply over the 10 year period, in men from 20.8% to 30.3%, in women from 23.4% to 30.3% (both $p<0.001$), More women than men had BMI ≥30 kg/m^2 in 1998 and 2003 (p=0.003 and p=0.02 respectively), but in 2008, obesity prevalence was equal between the sexes. A BMI ≥35 kg/m^2 was seen in 3.8%, 6.1%, 6.2% of men and in 7.9%, 10.6%, 11.7% of women in 1998, 2003 and 2008 respectively: prevalence of BMI 30-35 kg/m^2 increased by 40% in men, and 20% in women, while BMI >35 kg/m^2 increased by 63% in men, and 48% in women.

Age effects

Mean BMI, from all surveys, along with the 10 year change in BMI, stratified by sex and age-band are presented in Table 3. In 1998, mean BMI of men increased until the age of 45 years, whereas in 2003 and 2008 BMI continued to increase until age 60 and declined between 60-70. In women, mean BMI rose until age 60-65 in all three surveys, falling only above age 65

Age-specific and birth-cohort period trends

Over the 10 year period, a trend to a greater mean BMI was observed at all ages in both sexes. Among men, the increase varied from 0.1 to 1.8 kg/m^2, in women, from 0.5 to 2.0 kg/m^2. Age-specific BMI within 5-year bands showed more statistically significant rises between 1998 and 2003, than between 2003 and 2008, particularly in older women, but no consistent pattern was evident.

Both men and women were taller in 2008 than 1998, significantly for men aged 45, 50 and 70 years and women aged 20, 40, 45 and 65, compared to those of the same age in 1998 (data not shown). BMI was higher in all age groups and both sexes in 2008 compared to 1998. However weight increases were large enough to overcome increases in height, to result in an overall higher BMI.

Ten-year changes in mean BMI with age between the three surveys, for each birth-cohort in men and women, are shown in Figure 2. BMI increased with age in all birth-cohorts ($p<0.001$), more steeply in younger cohorts, particularly among young men. Figure 2 illustrates how more recent birth-cohorts attain any specific BMI at an earlier age than their predecessors. For example, men in the 1968 cohort reached a mean BMI 28 kg/m^2 at age 40 years, while those in the 1943 cohort only reached mean BMI 28 kg/m^2 at 55 years of age.

Waist Circumference

Age effects

Mean WC increased with age until 55-60 years in 1998 and 2003, but in 2008 it rose up to 70 years

Age-specific and birth-cohort period trends

Mean WC increased significantly over time, significantly in almost all age-bands of both men and women. Ten-year differences in age-specific WC were 2 to 6 cm in men, and 4 to 8 cm in women (Table 4).

WC also increased within all birth-cohorts (p<0.001) over the 10 years (Figure 3). In men, younger birth-cohorts showed more a pronounced increases in mean WC, whereas older women also a showed marked rises. More recent birth-cohorts reached a given WC at younger age than those born earlier. For example those born 1971-1975 reached mean WC above 80 cm in women, or 94 cm in men, at age 35 years, while those who were born 10-20 years earlier did not attain the same level until 40 or 45 years of age.

Relative changes in BMI and waist circumference

Age- and cohort-specific ten-year changes in BMI and WC were compared by expressing the 10-year difference (in 2008) as a percentage of the 1998 value (Table 5). Mean BMI increased 4.5% between 1998 and 2008, in both men and women, while mean WC increased 5.7% for men and 7.5% for women. The increase in WC over time was most marked in older women: those over 50 had significantly larger waists in 2008 compared to those of the same age in 1998.

Discussion

The present study was conducted to describe the distribution of BMI and WC, and any changes by age and birth-cohort over 1 10-year period 1998-2008, in a European country with a particularly high prevalence of obesity. This study was not primarily concerned with explaining any effects. It would be possible in future research to examine in detail the socio-economic and behavioural factors, e.g. smoking, occupation, physical activity, alcohol consumption, which might influence BMI or WC differentially with age. We did not consider it appropriate to adjust the data for any such factors, but present a descriptive analysis. The data demonstrate striking increases in both BMI and WC over a 10-year period in the population as a whole. We demonstrate higher BMI and WC in 2008 than in 1998 as people of specific ages, and 10-year increases which appear proportionally greater for WC than for BMI within birth-cohorts. The patterns indicate increasing weight gain in most population subgroups, and suggest either a disproportionate increase in body fat, relative to muscle (sarcopenia) or an exaggerated shift towards more central fat distribution in older people. Whichever of these is responsible, and whatever the socio-economic and behavioural influences, this shift in body composition is likely to herald poorer health.

The increasing mean BMI in population surveys over the last 30-40 years could indicate three possibilities: (i) greater weight increases in those already obese (while the non-obese do not change), (ii) more rapid weight-increases in younger people, or (iii) continued weight-gain into older age bands where previously weight and BMI had become stable or fell. Our analyses suggest that both (ii) and (iii) may apply. Other evidence suggests that most of the changes in BMI are seen in people, or families, who have a predisposition towards obesity,[29] although we found that the proportion with normal weight (BMI 18.5 – 25) has declined. The mean BMI of women aged 20 was already 2 kg/m^2 greater in 2008 than 1998, illustrating the influence of increased adolescent weight-gain. At age 18-22 in 2008 8.8% of men and 23.5% of women exceeded BMI 30. Continued rises of weight and BMI into older ages appear more marked in 2008 than in the earlier surveys for men, while for women there is some suggestion of a decline in mean BMI in older age groups. The greatest shifts between categories were out of the normal-weight, and into the obese, with BMI 25-30 (overweight) fairly constant. These observations are somewhat different from data from England, where between 1993/1994 and 2002/2003 lean people remained fairly stable, while people at the upper end of the distribution experienced greater changes.[29] We observed sharp increases in prevalences of BMI ≥35 between 1998 and 2008, of 48% in women and 63% in men, to reach 11.7% and 6.2% of adults. These data, with the decline in those with BMI <25, point to a generalised upwards shift in the whole population distribution.

The methodological approach used in the present study is little used. When multiple birth-cohorts, followed longitudinally, are not available for comparisons, conclusions about time trends must be drawn from cross-sectional surveys. The design of the SHS series offered the opportunity to construct “synthetic birth-cohorts” from the data in three surveys 10 years apart. Similar approaches were used, for BMI time-trends, by Lahti-Koski et al (2001) in Finland and by Howel (2010) in England. Their results similarly showed that individuals born more recently were consistently heavier than those of the same age who were born in earlier decades.[20,22] Moreover, Howel et al found that the increase in overweight and obesity prevalence between periods was greater in older men than it was in younger men.[22] This agrees with the findings of the present study suggesting that age-specific BMI increased significantly in men aged over 50 years.

No earlier study has used a birth-cohort approach to examine time-trends in waist circumference. Although WC is closely correlated with BMI, it is a somewhat better predictor of total body fat,[3] and of health risks[24,25] and disability in the elderly.[30] The present results consistently show greater relative increases in WC than BMI between surveys 10 and 5 years apart. There is no reason to expect the percentage change in WC and BMI to be equivalent because these measures are not directly proportional to each other nor are they directly proportional to percentage body fat.[3] However, other cross-sectional population studies have shown larger increases in WC, in relation to BMI.[17,24,31] If WC is increasing more rapidly than what might be expected from changes in BMI this is likely to indicate greater body fat, with some loss of lean body mass (i.e. loss of muscle mass). It could also include a change in fat distribution of people of the same ages, with a greater intra-abdominal fat mass.[32,33,34] Studies with MRI scanning would be necessary to identify changing intra-abdominal fat, but a greater WC, whatever its cause, indicates greater risks of many serious disease outcomes. WC was greater in 2008 than 1998 at all ages, by about 2-6 cm in men, 4-8 cm in women. Synthetic cohort analyses show 10-year age-related rises of around 7 cm in men and up to 11 cm in women. The increase in WC above the age of 50 now continuing into older age, is of particular concern for health care planning for an aging population, as it probably indicates relative sarcopenia.

Age effects

Existing evidence supports our finding that both BMI and WC are increasing with age, at least up to a certain age.[13,14] A BMI increase with age, levelling off at a younger age in men than in women, has been observed previously.[20] Our data suggest that in the period 2003-2008, weight-gains continued until the age of 70 years, among men, suggesting that BMI trends have shifted towards more prolonged weight-gain, while BMI appears to change less among older women (Table 3).

Period effects

While an increasing BMI over time has been well documented. In Germany, over 5-years between 1989/90 – 1994/95, mean BMI increased 0.3-0.4 kg/m^2, and waist by 1 cm, with some suggestion of a greater increases among older women.[35] The Swedish MONICA study reported increases in BMI at every age of men and women over 18 years, greater among the youngest groups.[36] In the present study, age-specific BMI was significantly greater at 2008 than 1998 in many 5-year age-groups, particularly the older ones, but our study lacked power for this purpose. Additionally, Sweden had the lowest obesity prevalence in Europe.[37] Our results are more in agreement with a Finnish study, which found a stronger upward trend in BMI among men over 50 years and, also similarly to the present study, marked BMI increase in the youngest women.[20] Changes in waist circumference have had less attention. In the US, NHANES analyses documented rising waist circumferences between surveys of 1988-94 and 1999-2000, i.e. 8-9 years, of about 3.5 cms in men.[38] Elobeid et al (2007) analysed US national survey data from 1959 to 2004, and found no compelling evidence for any changes in the relationship between the rising BMI and waist circumferences with both rising over time.[39]

Interestingly, pair-wise comparisons of age-specific period effects revealed that for both BMI and WC, increases were significant only for the period between 1998 and 2003, whereas between 2003 and 2008, few significant changes were seen. These findings could suggest that secular trends in BMI and WC are decelerating, but the 2008 sample was considerably smaller, reducing power to detect changes. English data between 1995 and 2006 also showed less increase in prevalence of obesity in the second half of the examination period, Intriguingly, the only exception in this study too, was in BMI of men aged around 60 years,[22] around the age of retiral.

Birth-cohort effects

Later birth-cohorts were heavier and experienced greater increases in BMI and WC over time. There were limited age-ranges available for data in different birth-cohorts, so that later birth-cohorts were also younger. Thus, the observed cohort effect is partly confounded by age effects. However, where data were available on subjects of the same age, for example, at ages 35 to 60 years, later birth-cohorts had higher BMIs and WCs. The effect was more clearly and consistently seen in men than women. Below 35 years and above 55 years, there was no consistent relationship between birth-cohort and BMI in women but a consistent trend toward increasing WC when age-specific birth-cohorts were compared. Thus women could be less susceptible to birth-cohort effects than men, as with the BMI changes found in Finland.[20]

Interpretation

Previous studies investigating age, period and cohort effects on BMI trends, have consistently pointed towards an independent effect of birth-cohort membership on the risk of overweight or obesity.[17,19,20,21,22,40,41] However, these studies varied widely in populations and statistical methods, and self-reporting biases render such studies unreliable. European studies, using measured weight and height, reported a greater increase in BMI with age in subjects born more recently,[19,20] particularly among men.[20] Obesity prevalence was consistently greater at all ages in more recent English cohorts[22] and in the United States,[17,40,41] although two of these studies used self-reported data[40,41] and birth-cohort and period effects were not distinguished in one.[40] Discrepancies in the designs of the existing studies render comparisons difficult, but they all suggest an independent birth-cohort effect, on BMI.

Several hypotheses can be made to explain the observed trends in BMI and WC. Birth-cohort effects may describe common behavioural characteristics – such as food preferences, exercise patterns – or metabolic differences determined by fetal or early-life factors. Declining smoking, in more recent birth-cohorts,[42] could account for greater BMI, but other studies have concluded that smoking cessation does not account for rising BMI or obesity prevalence,[43] and WC is greater among smokers.[43] Changes in educational and socio-economic status might possibly contribute at least for women, who show closer associations between socio-economic status and BMI,[45] but, there is no evidence for such changes, and the present obesogenic environment affects all educational segments rather uniformly,[46] such that proportional differences in BMI among socio-economic groups might reduce.[47]

It seems reasonable to hypothesize that adverse changes in dietary habits and physical activity, both with age and over time, are the primary causes of the observed trends. Greater WC indicates either increased body fat and reduced lean mass, or a more central fat distribution. Physical inactivity is a likely cause of both, and correlates inversely with WC.[48] No specific dietary factors cause more central fat distribution. Physical activity has a small effect in reducing intra-abdominal fat in some studies but not others.[49] Smoking cessation and a non-smoking state, which has become more frequent in Scotland is associated with lower, not higher, WC,[44] although a greater BMI. Thus the large increases in WC probably reflect greater total body fat, with less muscle mass, especially in older people. Other studies have found that age-specific WC has increased over time among both men and women.[23,37,38]

Increasing BMI and WC are of considerable clinical and public health significance, since even modest increases in BMI and WC are associated with increased risk of cardiovascular disease (CVD), diabetes and overall mortality.[13,50,51] A disproportionate increase in WC is of particular concern. We have not found previous publications with an analysis of relative BMI and WC changes, similar to that in table 5. An increase over time in WC, independent of changes in BMI, has been reported previously[23,30] and indicates either a more centrally distributed fat, or greater total body fat with declining muscle mass (i.e. sarcopenia), so the overall health-burden of obesity might be underestimated if only BMI trends are monitored.[23,51,52] As newer cohorts reach higher BMI and WC values at younger ages, future generations will face medical consequences of weight-gain and obesity earlier in life.

Limitations

The present study used measured anthropometric data, from a nationally representative database, to assess contemporary trends in BMI and WC at different ages, which are likely to be representative, sooner or later, of many Western populations. Data were only available for a 10-year period, 1998-2008, and the reduced numbers with measured WC in 2008 limited study power. The resulting sample was somewhat different from the entire SHS database, obesity prevalence appearing greater than in the entire surveys (in 2008, 26% of men and 27.5% of women had BMI >30 kg/m^2). Analysing 5-year bands of age and birth-date allowed a view of the patterns and consistency of changes: using 10-year bands, increasing power but reducing definition, led to very similar overall conclusion (Appendix). Un-weighted data were used, since weighting variables to adjust for selection probability and non-response were available only for 2003 and 2008 datasets. We repeated the analyses employing these sampling-weights, with essentially identical findings, although standard errors increased by about 10%. Since changing in height over time could have affected BMI trends, trends in weight and height were also assessed separately. Respondents with all measurements were included in both BMI and WC analyses, but those without WC only in BMI analysis. Since men without WC data in 1998 and 2003 had marginally lower mean BMI, it is possible that this altered the apparent relationship of WC to BMI. However, this theoretical possibility would be unlikely to account for the observed trends. Changing the structure and content of national surveys, as happened in 2008, limits the scope for longitudinal analyses.

Conclusion

The present study thus conclude that there are clear trends of rapid increases in BMI, with even more worrying disproportionate increases in WC, which is particularly clear using a "synthetic birth-cohort" approach.

Future consideration should be given to discriminating the effects of age, period and birth-cohort membership on body composition and health risks, to inform public health policies. Analyses of socio-economic and behavioural determinants are needed. The present data indicate the need to collect more complete WC data in future, as the current trends are worrying. Future longitudinal outcome studies should examine the influence of relative increases in WC over BMI on physical outcomes, such as falls and hip fractures, as well as metabolic consequences of sarcopenia, such as diabetes and heart disease.

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Conflict of interest

ML has received departmental funding for unrelated research from Novo Nordisk and Cambridge Weight plan, and has received lecture fees from Eli Lilly and conference attendance paid by Novo Nordisk and Cambridge Weight Plan. All other authors declared no conflict of interest.

Supplementary information is available at IJO's website.

References

1. Management of Obesity – A national clinical guideline No 115. Scottish Intercollegiate Guidelines Network 2010 http://www.sign.ac.uk/pdf/sign115.pdf [accessed March 2010]

2. WHO (2006) Obesity fact sheet No 311: World Health Organisation.

3. Lean ME, Han TS, Deurenberg P. Predicting body composition by densitometry from simple anthropometric measurements. *Am J Clin Nutr* 1996; **63**: 4-14.

4. Lean ME, Han TS, Seidell JC. Impairment of health and quality of life in people with large waist circumference. *Lancet* 1998; **351**: 853-856.

5. WHO (2000) Obesity: Preventing and Managing the Global Epidemic. Geneva.

6. 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.

7. Withrow D, Alter DA. The economic burden of obesity worldwide: a systematic review of the direct costs of obesity. *Obes Rev* 2011; **12**: 131-141.

8. Lean M, Tigbe W, Briggs A. A patient-centred approach to estimate total annual healthcare costs by BMI in the UK Counterweight Programme (abstract). *Obes Reviews* 2011; **12(S1)**: 105.

9. www.counterweight.org [accessed March 2012]

10. Kelly T, Yang W, Chen CS, Reynolds K, He J. Global burden of obesity in 2005 and projections to 2030. *Int J Obes* 2008; **32**: 1431-1437.

11. Flegal KM, Carroll MD, Ogden CL, Curtin LR. Prevalence and trends in obesity among US adults, 1999-2008. *JAMA* 2010; **303**: 235-241.

12. Scottish Health Survey: The Scottish Government Statistics. 2008.

13. Whitlock G, Lewington S, Sherliker P, Clarke R, Emberson J, Halsey J, *et al*. Body-mass index and cause-specific mortality in 900 000 adults: collaborative analyses of 57 prospective studies. *Lancet* 2009; **373**: 1083-1096.

14. Stevens J, Katz EG, Huxley RR. Associations between gender, age and waist circumference. *Eur J Clin Nutr* 2010; **64**: 6-15.

15. Rennie KL, Jebb SA. Prevalence of obesity in Great Britain. *Obes Rev* 2005; **6**: 11-12.

16. Berghofer A, Pischon T, Reinhold T, Apovian CM, Sharma AM, Willich SN. Obesity prevalence from a European perspective: a systematic review. *BMC Public Health* 2008; **8**: 200.

17. Juhaeri, Stevens J, Jones DW, Arnett D. Associations of aging and birth-cohort with body mass index in a biethnic cohort. *Obes Res* 2003; **11**: 426-433.

18. Kahn HS, Cheng YJ. Longitudinal changes in BMI and in an index estimating excess lipids among white and black adults in the United States. *Int J Obes* 2008; **32**: 136-143.

19. Jacobsen BK, Njolstad I, Thune I, Wilsgaard T, Lochen ML, Schirmer H. Increase in weight in all birth-cohorts in a general population: The Tromso Study, 1974-1994. *Arch Intern Med* 2001; **161**: 466-472.

20. Lahti-Koski M, Jousilahti P, Pietinen P. Secular trends in body mass index by birth-cohort in eastern Finland from 1972 to 1997. *Int J Obes Relat Metab Disord* 2001; **25**: 727-734.

21. Allman-Farinelli MA, Chey T, Bauman AE, Gill T, James WP. Age, period and birth-cohort effects on prevalence of overweight and obesity in Australian adults from 1990 to 2000. *Eur J Clin Nutr* 2008; **62**: 898-907.

22. Howel D. Trends in the prevalence of obesity and overweight in English adults by age and birth-cohorts, 1991-2006. *Pub Health Nutr* 2011; **14**: 27-33.

23. Walls HL, Stevenson CE, Mannan HR, Abdullah A, Reid CM, McNeil JJ *et al*. Comparing Trends in BMI and Waist Circumference. *Obesity* 2011; **19**: 216-219.

24. Dalton M, Cameron AJ, Zimmet PZ, Shaw JE, Jolley D, Dunstan DW et al. Waist circumference, waist-hip ratio and body mass index and their correlation with cardiovascular disease risk factors in Australian adults. *J Intern Med* 2003;254:555-563.

25. Zhu S, Heshka S, Wang Z, Shen W, Allison DB, Ross R *et al*. Combination of BMI and Waist Circumference for Identifying Cardiovascular Risk Factors in Whites. *Obes Res* 2004; **12**: 633-645.

26. Vazquez G, Duval S, Jacobs DR Jr, Silventoinen K. Comparison of body mass index, waist circumfernce, and waist/hip ratio in predicting incident diabetes: a meta-analysis. *Epidemiol Rev* 2007; **29**: 115-128.

27. SHS (2010b) SHeS 2008 - Data documentation (user guide/variable list).

28. SHS (2010a) Scottish Health Survey Publications: The Scottish Government.

29. Wardle J, Boniface D. Changes in the distributions of body mass index and waist circumference in English adults, 1993/1994 to 2002/2003. *Int J Obes* 2008; **32**: 527-532.

30. Guallar-Castillon P, Sagardui-Villamor J, Banegas JR, Graciani A, Fornes NS, Lopez Garcia E *et al*. Waist circumference as a predictor of disability among older adults. *Obesity* 2007; **15**: 233-244.

31. Lissner L, Sjoberg A, Schutze M, Lapidus L, Hulthen L, Bjorkelund C. Diet, obesity and obesogenic trends in two generations of Swedish women. *Eur J Nutr* 2008; **47**: 424-431.

32. Han TS, McNeill G, Seidell JC, Lean ME. Predicting intra-abdominal fatness from anthropometric measures: the influence of stature. *IJO* 1997; **21(7)**: 587-593.

33. Kamel EG, McNeill G, Van Wijk MC. Change in intra-abdominal adipose tissue volume during weight-loss in obese men and women: correlation between magnetic resonance imaging and anthropometric measurements. *IJO* 2000; **24(5)**: 607-613.

34. Lemieux S, Prud'homme D, Tremblay A, Bouchard C, Despres JP. Anthropometric correlates to changes in visceral adipose tissue over 7 years in women. *IJO* 1996; **20(7)**: 618-624.

35. Liese AD, Doring A, Hense H, Keil U. Five year changes in waist circumference, body mass index and obesity in Augsburg, Germany. *Eur J Nutr* 2001; **40**: 282-288.

36. Lilja M, Eliasson M, Stegmayr B, Olsson T, Soderberg S. Trends in obesity and its distribution: data from the Northern Sweden MONICA Survey, 1986-2004. *Obesity* 2008; **16**: 1120-1128.

37. Seidell JC. Time trends in obesity: an epidemiological perspective. *Horm Metab Res* 1997; **29**: 155-158.

38. Ford ES, Mokdad AH, Giles WH. Trends in waist circumference among US adults. *Obes Res* 2003; **11(10)**: 1223-1231.

39. Elobeid MA, Desmond RA, Thomas O, Keith SW, Allison DB. Waist circumference values are increasing beyond those expected from BMI increases. *Obesity* 2007; **15**: 2380-2383.

40. Reynolds SL, Himes CL. Cohort differences in adult obesity in the United States: 1982-2002. *J Aging Health* 2007; **19**: 831-850.

41. Reither EN, Hauser RM, Yang Y. Do birth-cohorts matter? Age-period-cohort analyses of the obesity epidemic in the United States. *Soc Sci Med* 2009; **69**: 1439-1448.

42. Rosengren A, Eriksson H, Hansson PO, Svardsudd K, Wilhelmsen L, Johansson S, *et al*. Obesity and trends in cardiovascular risk factors over 40 years in Swedish men aged 50. *J Intern Med* 2009; **266**: 268-276.

43. Akbartabartoori M, Lean ME, Hankey CR. Relationships between cigarette smoking, body size and body shape. *Int J Obes* 2005; **29**: 236-243.

44. Lewis CE, Jacobs DR, Jr., McCreath H, Kiefe CI, Schreiner PJ, Smith DE *et al*. Weight-gain continues in the 1990s: 10-year trends in weight and overweight from the CARDIA study. Coronary Artery Risk Development in Young Adults. *Am J Epidemiol* 2000; **151**: 1172-1181.

45. McLaren L. Socioeconomic status and obesity. *Epidemiol Rev* 2007; **29**: 29-48.

46. Sturm R. Stemming the global obesity epidemic: what can we learn from data about social and economic trends? *Public Health* 2008; **122**: 739-746.

47. Zhang Q, Wang Y. Trends in the association between obesity and socioeconomic status in US adults: 1971 to 2000. *Obes Res* 2004; **12**: 1622-1632.

48. Akbartabartoori M, Lean MEJ, Hankey CR. The associations between current recommendation for physical activity and cardiovascular risks associated with obesity. *Eur J Clin Nutr* 2008; **62**: 1-9.

49. Kay SJ, Fiatarone Singh MA. The influence of physical activity on abdominal fat: a systematic review of the literature. *Obes Rev* 2006; **7**: 183-200.

50. Seidell JC, Andres R, Sorkin JD, Muller DC. The sagittal waist diameter and mortality in men: the Baltimore Longitudinal Study on Aging. *Int J Obes Relat Metab Disord* 1994; **18**: 61-67.

51. de Koning L, Merchant AT, Pogue J, Anand SS (2007) Waist circumference and waist-to-hip ratio as predictors of cardiovascular events: meta-regression analysis of prospective studies. *Eur Heart J* 2007; **28**: 850-856.

52. Yusuf S, Hawken S, Ounpuu S, Dans T, Avezum A, Lanas F, *et al*. Effect of potentially modifiable risk factors associated with myocardial infarction in 52 countries (the INTERHEART study): case-control study. *Lancet* 2004;**364**: 937-952.

Table 1: Characteristics of respondents in each survey. Numbers are mean values with standard deviations unless otherwise indicated

		1998		2003		2008	
Respondents with valid BMI	Sample size (n)	7743		5838		4688	
	Men (%)	44.2		45.0		44.8	
	Age (sd); *years*	45.2	(14.9)	46.6	(14.3)	47.4	(14.6)
	men	*45.0*	*(14.7)*	*46.8*	*(14.4)*	*48.0*	*(14.7)*
	women	*45.4*	*(15.1)*	*46.4*	*(14.2)*	*46.9*	*(14.6)*
	Weight (sd); *kg*	74.7	(15.5)	76.9	(16.1)	78.6	(17.0)
	men	*81.7*	*(14.1)*	*83.8*	*(14.7)*	*85.8*	*(15.5)*
	women	*69.1*	*(14.2)*	*71.3*	*(15.0)*	*72.8*	*(15.8)*
	Height (sd); *cm*	166.9	(9.5)	167.2	(9.4)	167.6	(9.4)
	men	*174.4*	*(7.1)*	*174.6*	*(6.9)*	*175.0*	*(6.9)*
	women	*160.9*	*(6.3)*	*161.1*	*(6.4)*	*161.7*	*(6.5)*
	BMI (sd); kg/m^2	26.8	(4.9)	27.5	(5.3)	27.9	(5.4)
	men	*26.8*	*(4.3)*	*27.5*	*(4.6)*	*28.0*	*(4.7)*
	women	*26.7*	*(5.4)*	*27.5*	*(5.8)*	*27.9*	*(5.9)*
Respondents with valid waist circumference	Sample size (n)	6894		4437		925	
	Men (%)	44.6		45.1		45.5	
	Age (sd); *years*	45.9	(14.8)	47.8	(14.0)	48.1	(14.6)
	men	*45.8*	*(14.6)*	*48.0*	*(14.1)*	*49.2*	*(14.7)*
	women	*45.9*	*(15.0)*	*47.6*	*(13.8)*	*47.2*	*(14.5)*
	BMI (sd); kg/m^2	26.8	(4.8)	27.5	(5.1)	27.7	(5.2)
	men	*26.9*	*(4.2)*	*27.6*	*(4.5)*	*28.0*	*(4.5)*
	women	*26.7*	*(5.3)*	*27.5*	*(5.6)*	*27.5*	*(5.8)*
	WC (sd); *cm*	87.6	(13.4)	91.4	(13.7)	93.6	(14.2)
	men	*93.7*	*(11.6)*	*96.8*	*(12.2)*	*99.0*	*(12.5)*
	women	*82.7*	*(12.7)*	*87.0*	*(13.3)*	*89.1*	*(14.0)*

Table 2: Distribution of BMI categories in men and women in 1998, 2003 and 2008. Numbers are percentages and counts

		1998		2003		2008	
	BMI (kg/m^2)	%	(n)	%	(n)	%	(n)
Men	<18.5	1.1	(36)	1.2	(31)	1.0	(21)
	18.5–<25	33.5	(1145)	28.6	(752)	24.7	(518)
	25–<30	44.6	(1527)	45.8	(1203)	44.0	(924)
	30–<35	17.1	(584)	18.3	(482)	24.0	(504)
	≥35	3.8	(129)	6.1	(161)	6.2	(131)
Women	<18.5	1.9	(80)	1.4	(44)	1.4	(36)
	18.5–<25	42.1	(1820)	36.8	(1181)	33.2	(860)
	25–<30	32.6	(1411)	34.7	(1113)	35.1	(908)
	30–<35	15.5	(669)	16.6	(532)	18.6	(483)
	≥35	7.9	(342)	10.6	(339)	11.7	(303)

Table 3: Mean BMI by study year in men and women by age group. Numbers are mean, standard deviation (SD) and sample size (n)

		BMI (kg/m^2)									Difference in BMI		
		1998			2003			2008			2003-1998	2008-2003	2008-1998
Sex	Age group	mean	SD	n	mean	SD	n	mean	SD	n	mean	mean	mean
Men	18-22	23.5	3.45	178	24.2	4.31	137	24.06	4.04	113	0.7	-0.1	0.59
	23-27	25.2	3.89	261	25.4	4.11	157	26.18	4.29	128	0.2	0.8	0.98
	28-32	26.2	4.31	394	26.2	3.96	186	26.27	4.39	143	0.0	0.1	0.07
	33-37	26.2	3.97	393	26.9	4.28	272	27.31	4.91	156	0.6	0.4	1.08 *
	38-42	26.8	4.06	369	27.6	4.53	333	28.15	4.20	218	0.8	0.6	1.32 *
	43-47	27.8	4.49	346	27.7	4.56	264	28.21	4.83	225	-0.1	0.5	0.39
	48-52	27.6	4.45	335	28.4	4.78	265	28.29	4.42	218	0.8	-0.1	0.69
	53-57	27.8	4.14	305	28.6	4.45	298	28.71	4.71	235	0.8	0.1	0.90
	58-62	27.6	4.38	304	28.8	4.76	268	29.11	4.48	239	1.1 *	0.4	1.50 *
	63-67	27.4	4.28	286	27.8	3.95	244	29.23	4.70	221	0.3	1.5 *	1.80 *
	68-72	27.5	4.00	254	28.1	4.90	206	28.95	4.20	202	0.5	0.9	1.41 *
Women	18-22	24.0	4.51	251	24.7	5.40	168	25.91	6.10	149	0.7	1.2	1.87 *
	23-27	25.2	5.10	333	25.2	4.97	171	26.17	5.60	162	-0.1	1.0	0.93
	28-32	25.7	5.40	449	26.6	5.99	256	26.44	6.37	184	0.9	-0.1	0.73
	33-37	26.2	5.35	503	26.8	5.40	358	26.95	5.74	242	0.6	0.2	0.80
	38-42	26.2	4.98	479	27.1	5.66	378	28.14	5.87	283	1.0 *	1.0	1.96 *
	43-47	26.8	5.35	377	27.5	6.09	343	27.73	6.13	299	0.7	0.3	0.91
	48-52	27.4	5.41	428	27.3	5.59	346	28.10	5.90	285	-0.1	0.8	0.66
	53-57	27.3	5.60	363	28.7	6.00	347	28.47	5.20	252	1.4 *	-0.3	1.14 *
	58-62	28.6	5.56	366	28.2	5.35	322	29.11	5.92	266	-0.4	0.9	0.48
	63-67	28.4	5.37	367	29.5	5.94	306	29.11	5.58	260	1.1 *	-0.4	0.70
	68-72	27.4	4.91	408	28.5	5.08	215	28.46	5.27	208	1.1 *	0.0	1.07 *

*p<0.017

Table 4: Mean WC by study year in men and women by age group. Numbers are mean, standard deviation (SD) and sample size (n)

		WC (cm)									Difference in WC		
		1998			2003			2008			2003-1998	2008-2003	2008-1998
Sex	Age group	mean	SD	n	mean	SD	n	mean	SD	n	mean	mean	mean
Men	18-22	82.3	9.0	142	83.9	10.0	76	85.3	8.5	21	1.6	1.4	3.0
	23-27	87.1	10.4	214	90.8	10.3	102	92.7	8.8	21	3.7 *	1.9	5.6 *
	28-32	90.1	11.2	334	93.0	11.4	141	91.6	10.0	31	3.0 *	-1.4	1.5
	33-37	90.1	9.3	349	93.5	11.0	201	96.4	12.9	31	3.4 *	3.0	6.4 *
	38-42	92.7	10.4	325	95.7	11.2	242	98.5	8.6	34	2.9 *	2.9	5.8 *
	43-47	96.5	11.4	311	96.8	12.2	191	98.6	13.8	39	0.3	1.8	2.1
	48-52	95.4	11.2	306	98.9	12.2	214	101.4	13.4	45	3.5 *	2.5	6.0 *
	53-57	97.3	10.9	275	99.3	11.6	242	102.7	13.4	52	2.0	3.4	5.4 *
	58-62	98.0	11.2	295	100.7	11.9	218	101.6	11.2	56	2.7 *	0.9	3.6
	63-67	97.8	12.0	285	99.8	11.1	204	100.8	11.5	44	2.0	1.0	3.0
	68-72	97.9	10.5	242	100.5	12.5	171	104.1	11.5	47	2.7	3.5	6.2 *
Women	18-22	74.7	10.3	196	80.0	13.0	84	80.0	13.9	32	5.3 *	0.0	5.3 *
	23-27	76.8	11.2	272	82.2	12.1	123	84.5	13.3	29	5.5 *	2.3	7.7 *
	28-32	79.4	11.1	389	82.9	13.5	180	84.9	13.6	28	3.4 *	2.0	5.4 *
	33-37	81.2	13.4	429	84.2	12.6	261	87.0	12.7	49	3.1 *	2.8	5.8 *
	38-42	80.4	11.8	429	85.1	12.7	296	85.2	11.6	57	4.7 *	0.0	4.8 *
	43-47	82.1	12.4	339	87.1	14.1	255	87.3	15.2	55	5.0 *	0.2	5.2 *
	48-52	83.8	12.4	404	85.5	12.4	272	87.9	12.3	65	1.7	2.4	4.2 *
	53-57	84.8	12.5	323	88.7	12.9	285	92.7	11.7	46	3.9 *	4.0	7.9 *
	58-62	87.8	13.0	332	90.4	12.3	259	94.9	14.1	48	2.5 *	4.6	7.1 *
	63-67	87.8	12.2	337	93.1	14.2	257	95.2	13.2	58	5.2 *	2.2	7.4 *
	68-72	87.3	11.9	366	90.3	11.7	171	95.7	15.5	38	3.0 *	5.4 *	8.3 *

*p<0.017

Table 5: Percentage change in mean BMI and mean WC between 1998 and 2008. Numbers are percentages and ratio between change in BMI and change in WC

		Percentage change in mean BMI and mean WC between 1998 and 2008					
		men			women		
		BMI	WC	ratio BMI:WC	BMI	WC	ratio BMI:WC
Age Group	18-22	2.5	3.7	0.7	7.8	7.1	1.1
	23-27	3.9	6.4	0.6	3.7	10.1	0.4
	28-32	0.3	1.7	0.2	2.8	6.8	0.4
	33-37	4.1	7.1	0.6	3.0	7.2	0.4
	38-42	4.9	6.3	0.8	7.5	5.9	1.3
	43-47	1.4	2.2	0.6	3.4	6.3	0.5
	48-52	2.5	6.3	0.4	2.4	5.0	0.5
	53-57	3.3	5.5	0.6	4.2	9.3	0.4
	58-62	5.4	3.7	1.5	1.7	8.1	0.2
	63-67	6.6	3.1	2.1	2.5	8.4	0.3
	68-72	5.1	6.3	0.8	3.9	9.5	0.4
Birth-cohort	1976-80	11.9	11.3	1.1	10.0	13.6	0.7
	1971-75	8.4	10.7	0.8	6.8	13.3	0.5
	1966-70	7.5	9.4	0.8	9.4	7.2	1.3
	1961-65	7.6	9.4	0.8	6.0	7.6	0.8
	1956-60	5.4	9.3	0.6	7.3	9.4	0.8
	1951-55	3.2	6.5	0.5	6.1	12.9	0.5
	1946-50	5.5	6.5	0.8	6.1	13.3	0.5
	1941-45	5.1	3.6	1.4	6.5	12.3	0.5
	1936-40	4.9	6.2	0.8	-0.6	8.9	-0.1