

## ORIGINAL ARTICLE

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

MEJ Lean<sup>1</sup>, C Katsarou<sup>1</sup>, P McLoone<sup>2</sup> and DS Morrison<sup>2</sup>**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 WC were objectively measured by trained observers.**RESULTS:** Subjects with data available on BMI/WC 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 WCs 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 in BMI (mean  $1.8 \text{ kg m}^{-2}$  (6.6%) in men and  $1.5 \text{ kg m}^{-2}$  (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 between 1998 and 2003. There were proportionally greater increases in WC than in BMI, especially in older women. This suggests a disproportionate increase in body fat, compared with muscle, particularly among older women.*International Journal of Obesity* (2013) 37, 800–808; doi:10.1038/ijo.2012.122; published online 4 September 2012**Keywords:** body fat; sarcopenia; ageing

## INTRODUCTION

Obesity, the 'disease process characterised by excessive body fat accumulation with multiple organ-specific consequences'<sup>1</sup> 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 ( $\geq 25 \text{ kg m}^{-2}$  = overweight,  $\geq 30 \text{ kg m}^{-2}$  = obese)<sup>2</sup> but waist circumference (WC) is a marginally better indicator of total body fat<sup>3</sup> and of health risks ( $>94 \text{ cm}$  men,  $>80 \text{ cm}$  women = increased risk;  $>102 \text{ cm}$  men,  $>88 \text{ cm}$  women = high risk for Caucasian adults).<sup>4,5</sup> Obesity at age 40 shortens life expectancy by about 7 years,<sup>6</sup> and its numerous health consequences have major negative impacts, potentially avoidable, on quality of life, health care and social support costs. Obese individuals spend 30% more than normal weight on medical care.<sup>7</sup> Total health-care costs of people with BMI 40 are about double those at BMI 20–21 ('ideal body weight').<sup>8,9</sup>

Obesity prevalence has increased dramatically globally and it is predicted to increase further.<sup>10</sup> Over 30% of US adults have BMI  $\geq 30$ .<sup>11</sup> European prevalences vary from 15 to 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  $35 \text{ kg m}^{-2}$  was exceeded by 6% of men and 11.2% of

women.<sup>12</sup> 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 60–70 years and decreased slightly in older ages.<sup>13</sup> In United States, BMI now continues to increase up to 80 years.<sup>14</sup> Obesity prevalence has also increased remarkably over time, especially among developed countries.<sup>11,15,16</sup> This increase is evident both in total populations and in different groups, younger adults showing significantly larger weight gains over time compared with older adults.<sup>17,18</sup>

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.<sup>19–21</sup> A recent English study confirmed this, and suggested that obesity prevalence is plateauing.<sup>22</sup> Longitudinal NHANES data showed how consequences of obesity can be seriously underestimated if based on BMI trends alone.<sup>23</sup> Despite its stronger associations with total body fat and with diabetes and cardiovascular disease risk, in most but not all studies little is known about time trends in WC.<sup>24–26</sup> The present study was designed to document and

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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.

## MATERIALS AND 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.<sup>27</sup> 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.<sup>28</sup> Overall, records were available for 12 939, 11 472 and 8215 subjects in 1998, 2003 and 2008 SHSs, 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 SHSs (1998, 2003 and 2008) were combined into a single database, organising respondents first by age groups, and second 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 (that is, ages 18–22) to 70 (ages 68–72) years. Thirteen synthetic birth-cohorts were constructed, each for 5 birth-years, identified by the middle year from 1928 (that is, born 1926–1930) to 1988 (born 1986–1990). For each birth-cohort, data on BMI and WC were available from the three surveys and at three 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 at 20 and 25 years,

respectively. Similarly, data for the eldest 1928–1933 birth-cohorts were only available at age 70 years and at 65 and 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. WC was measured with an inelastic tape, to the nearest 0.1 cm, mid-way between the lowest (10th) rib and the iliac crest. Mean of two measurements was used: if they differed by 3 cm or more, then a third measurement was recorded.

### Participants and study size

Data for the present analyses included adults aged 18–72 years, excluding pregnant women, with measured data available on weight, height and WC. 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 with *post-hoc* Bonferroni correction. Change in the prevalence of overweight and obesity over time was assessed using  $\chi^2$ -test. Differences in age and percentage of male and female participants between respondents and non-respondents were compared using  $\chi^2$ -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 (SPSS Inc., Chicago, IL, USA).

## 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 with 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

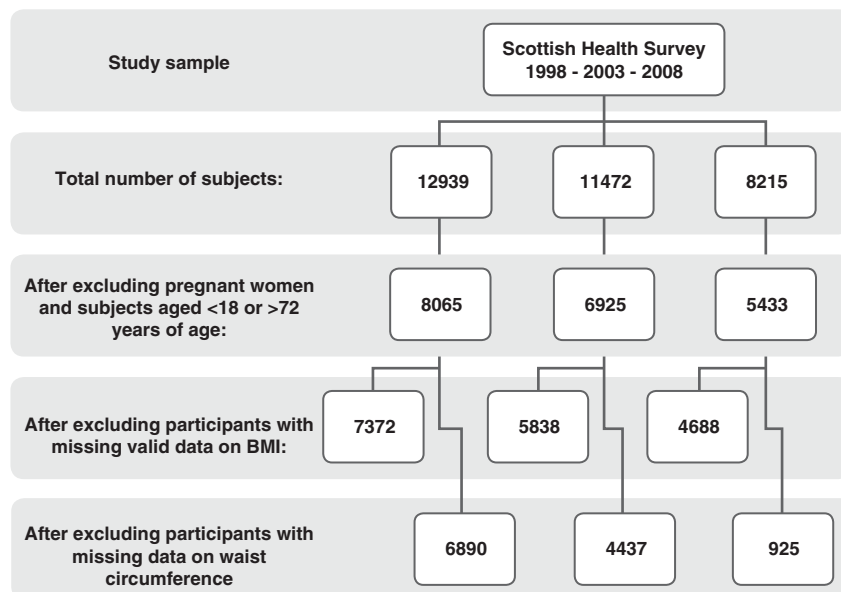


Figure 1. Study sample derivation.

measurements. In 1998 and 2003, men without WC measurements had marginally lower mean BMI ( $26.4$  vs  $26.9$   $\text{kg m}^{-2}$ ,  $P=0.016$  in 1998;  $27.2$  vs  $27.6$   $\text{kg m}^{-2}$ ,  $P=0.031$  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 to  $<30$ ,  $\geq 30$  and  $\geq 35$   $\text{kg m}^{-2}$ . The total with BMI 25– $30$   $\text{kg m}^{-2}$  rose successively among women at 32.6, 34.7 and 35.1% in the respective surveys of 1998, 2003 and 2008. Men had a higher prevalence of BMI 25– $30$   $\text{kg m}^{-2}$  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  $\geq 30$   $\text{kg m}^{-2}$  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  $\geq 30$   $\text{kg m}^{-2}$  in 1998 and 2003 ( $P=0.003$  and  $P=0.02$ , respectively), but in 2008, obesity prevalence was equal between the sexes. A BMI of  $\geq 35$   $\text{kg m}^{-2}$  was seen in 3.8, 6.1 and 6.2% of men and in 7.9%, 10.6% and 11.7% of women in 1998, 2003 and 2008, respectively: prevalence of BMI 30– $35$   $\text{kg m}^{-2}$  increased by 40% in men and 20% in women, while BMI  $>35$   $\text{kg m}^{-2}$  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 and 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  $\text{kg m}^{-2}$ , in women, from 0.5 to 2.0  $\text{kg m}^{-2}$ . 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 in 1998, significantly for men aged 45, 50 and 70 years and women aged 20, 40, 45 and 65, compared with those of the same age in 1998 (data not shown). BMI was higher in all age groups and both sexes in 2008 compared with 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 of 28  $\text{kg m}^{-2}$  at age 40 years, while those in the 1943 cohort only reached mean BMI 28  $\text{kg m}^{-2}$  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.

**Table 1.** Characteristics of respondents in each survey

	1998	2003	2008
<i>Respondents with valid BMI</i>			
Sample size (n)	7743	5838	4688
Men (%)	44.2	45.0	44.8
Age (s.d.), 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 (s.d.), 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 (s.d.), 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 (s.d.), $\text{kg m}^{-2}$	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)
<i>Respondents with valid waist circumference</i>			
Sample size (n)	6894	4437	925
Men (%)	44.6	45.1	45.5
Age (s.d.), 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 (s.d.), $\text{kg m}^{-2}$	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 (s.d.), 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)

Abbreviations: BMI, body mass index; WC, waist circumference. Numbers are mean values with standard deviations unless otherwise indicated.

**Table 2.** Distribution of BMI categories in men and women in 1998, 2003 and 2008

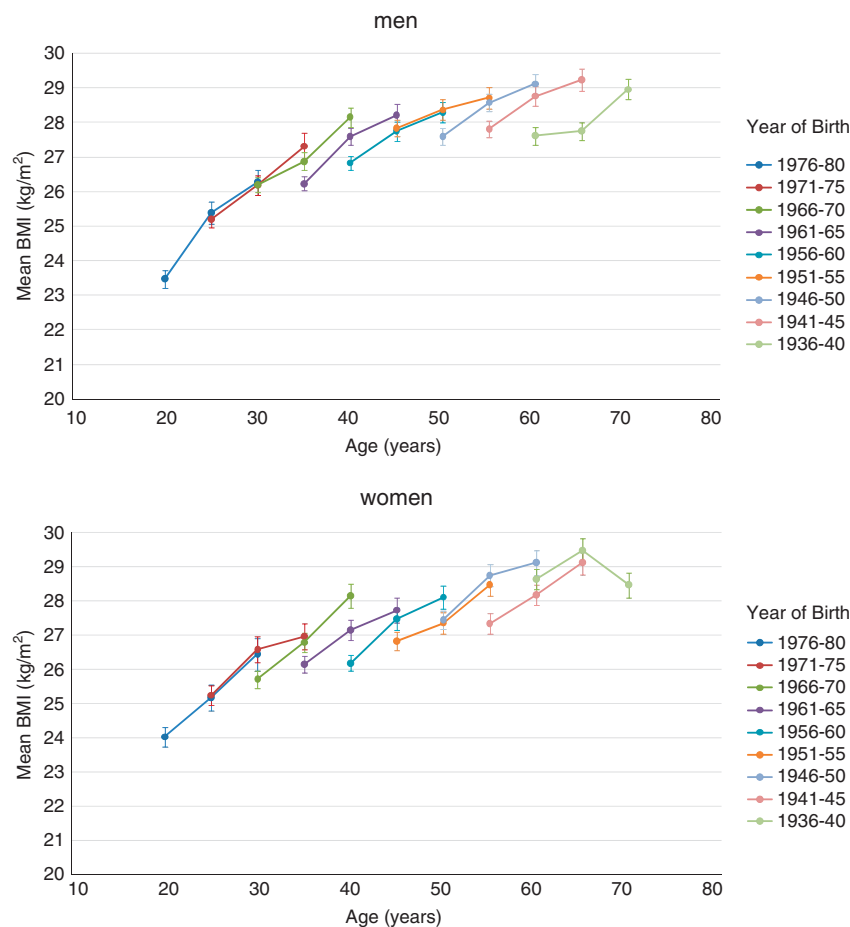
BMI ( $\text{kg m}^{-2}$ )		1998		2003		2008	
		%	(n)	%	(n)	%	(n)
Men	$<18.5$	1.1	(36)	1.2	(31)	1.0	(21)
	18.5 to $<25$	33.5	(1145)	28.6	(752)	24.7	(518)
	25 to $<30$	44.6	(1527)	45.8	(1203)	44.0	(924)
	30 to $<35$	17.1	(584)	18.3	(482)	24.0	(504)
	$\geq 35$	3.8	(129)	6.1	(161)	6.2	(131)
Women	$<18.5$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

Abbreviation: BMI, body mass index. Numbers are percentages and counts.

**Table 3.** Mean BMI by study year in men and women by age group

Sex	Age group	BMI ( $\text{kg m}^{-2}$ )									Difference in BMI		
		1998			2003			2008			2003–1998	2008–2003	2008–1998
		Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.	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*

Abbreviation: BMI, body mass index. Numbers are mean, s.d. and sample size (n). \* $P < 0.017$ .



**Figure 2.** Mean ( $\pm$  s.e.m.) BMI by age in each 5-year birth-cohort. Solid lines connect synthetic cohorts across the three SHSs.

**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 2–6 cm in men and 4–8 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 a more pronounced increase in mean WC, whereas older women also showed a marked rise. 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 WC

Age- and cohort-specific 10-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 with 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 one 10-year period 1998–2008, in an 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, for example, smoking,

occupation, physical activity and 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.

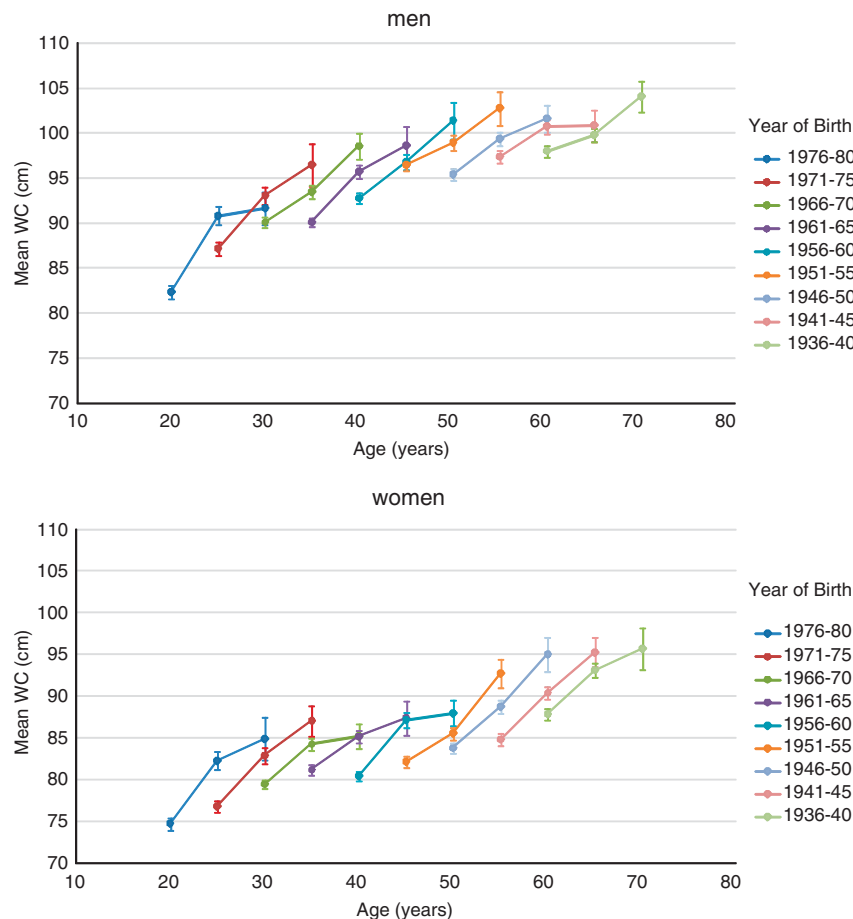
The increasing mean BMI in population surveys over the last 30–40 years could indicate three possibilities: (i) greater weight increases in those already obese (while the non-obese do not change), (ii) more rapid weight increases in younger people or (iii) continued weight gain into older age bands where previous 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,<sup>29</sup> although we found that the proportion with normal weight (BMI 18.5–25) has declined. The mean BMI of women aged 20 was already  $2 \text{ kg m}^{-2}$  greater in 2008 than in 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.

**Table 4.** Mean WC by study year in men and women by age group

Sex	Age group	WC (cm)									Difference in WC		
		1998			2003			2008			2003–1998	2008–2003	2008–1998
		Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.	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
Women	68–72	97.9	10.5	242	100.5	12.5	171	104.1	11.5	47	2.7	3.5	6.2*
	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*

Abbreviation: WC, waist circumference. Numbers are mean, s.d. and sample size (n). \* $P < 0.017$ .





**Figure 3.** Mean ( $\pm$  s.e.m.) WC by age in each 5-year birth-cohort. Solid lines connect synthetic cohorts across the three SHSs.

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.<sup>29</sup> We observed sharp increases in prevalences of BMI  $\geq 35$  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.<sup>20,22</sup> Moreover, Howel<sup>22</sup> found that the increase in overweight and obesity prevalence between periods was greater in older men than it was in younger men. 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 WC. Although WC is closely correlated with BMI, it is a somewhat better predictor of total body fat,<sup>3</sup> and of health risks<sup>24,25</sup> and disability in the elderly.<sup>30</sup> 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.<sup>3</sup> However, other cross-sectional population studies have shown larger increases in WC, in relation to BMI,<sup>17,24,31</sup> 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 (that is, 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.<sup>32-34</sup> 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 in 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.<sup>13,14</sup> A BMI increase with age, levelling off at a younger age in men than in women, has been observed previously.<sup>20</sup> 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

**Table 5.** Percentage change in mean BMI and mean WC between 1998 and 2008

	Men			Women		
	BMI	WC	Ratio BMI:WC	BMI	WC	Ratio BMI:WC
<i>Age group</i>						
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
<i>Birth-cohort</i>						
1976–1980	11.9	11.3	1.1	10.0	13.6	0.7
1971–1975	8.4	10.7	0.8	6.8	13.3	0.5
1966–1970	7.5	9.4	0.8	9.4	7.2	1.3
1961–1965	7.6	9.4	0.8	6.0	7.6	0.8
1956–1960	5.4	9.3	0.6	7.3	9.4	0.8
1951–1955	3.2	6.5	0.5	6.1	12.9	0.5
1946–1950	5.5	6.5	0.8	6.1	13.3	0.5
1941–1945	5.1	3.6	1.4	6.5	12.3	0.5
1936–1940	4.9	6.2	0.8	−0.6	8.9	−0.1

Abbreviations: BMI, body mass index; WC, waist circumference. Numbers are percentages and ratio between change in BMI and change in WC.

more prolonged weight gain, while BMI appears to change less among older women (Table 3).

#### Period effects

An increasing BMI over time has been well documented. In Germany, over 5 years between 1989/90 and 1994/95, mean BMI increased  $0.3\text{--}0.4\text{ kg m}^{-2}$ , and waist by 1 cm, with some suggestion of a greater increase among older women.<sup>35</sup> The Swedish MONICA study reported increases in BMI at every age of men and women over 18 years, greater among the youngest groups.<sup>36</sup> In the present study, age-specific BMI was significantly greater at 2008 than at 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.<sup>37</sup> 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.<sup>20</sup> Changes in WC have had less attention. In the United States, NHANES analyses documented rising WCs between surveys of 1988–1994 and 1999–2000, that is, 8–9 years, of about 3.5 cm in men.<sup>38</sup> Eloheide *et al.*<sup>39</sup> 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 WCs with both rising over time.

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,<sup>22</sup> 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 35–60 years, later birth-cohorts had higher BMIs and WCs. The effect was more clearly and consistently seen in men than in women. Below 35 years and above 55 years, there was no consistent relationship between birth-cohort and BMI in women but a consistent trend towards 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.<sup>20</sup>

#### 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.<sup>17,19–22,40,41</sup> 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,<sup>19,20</sup> particularly among men.<sup>20</sup> Obesity prevalence was consistently greater at all ages in more recent English cohorts<sup>22</sup> and in the United States,<sup>17,40,41</sup> although two of these studies used self-reported data<sup>40,41</sup> and birth-cohort and period effects were not distinguished in one.<sup>40</sup> 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 and exercise patterns—or metabolic differences determined by fetal or early-life factors. Declining smoking, in more recent birth-cohorts,<sup>42</sup> could account for greater BMI, but other studies have concluded that smoking cessation does not account for rising BMI or obesity prevalence,<sup>43</sup> and WC is greater among smokers.<sup>44</sup> Changes in educational and socio-economic status might possibly contribute at least for women, who show closer associations between socio-economic status and BMI,<sup>45</sup> but there is no evidence for such changes, and the present obesogenic environment affects all educational segments rather uniformly,<sup>46</sup> such that proportional differences in BMI among socio-economic groups might reduce.<sup>47</sup>

It seems reasonable to hypothesise 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.<sup>48</sup> 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.<sup>49</sup> Smoking cessation and a non-smoking state, which has become more frequent in Scotland is associated with lower, not higher, WC,<sup>44</sup> 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.<sup>23,37,38</sup>

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, diabetes and overall mortality.<sup>13,50,51</sup> 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<sup>23,30</sup> 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.<sup>23,51,52</sup> 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<sup>-2</sup>). 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 (Supplementary Appendix Tables 1 and 2 and Figures 1 and 2). Un-weighted data were used, since weighting variables to adjust for selection probability and non-response were available only for 2003 and 2008 data sets. 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.

### CONFLICT OF INTEREST

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