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Obesity

Twelve-Year Weight Change, Waist Circumference Change and Incident Obesity: The Australian Diabetes, Obesity and Lifestyle Study

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Objective: This study aimed to describe the changes in weight and waist circumference (WC), examine the incidence of obesity as defined by body mass index (BMI) and WC, and describe the changes in the prevalence of obesity over 12 years.
Methods: In 1999/2000, 11,247 adults aged ≥25 years were recruited from 42 randomly selected areas across Australia. In total, 44.6% of eligible participants completed follow-up in 2011/12. Height, weight, and WC were measured at both surveys.
Results: People who were 25–34 years of age at baseline gained an average of 6.7 kg weight and 6.6 cm WC, whereas those aged ≥75 years lost an average of 4.5 kg and gained an average of 0.8 cm. Women had a greater increase in WC than men, but did not differ in terms of weight gain. The 12-year incidence of obesity was 15.0% when defined by BMI and 31.8% when defined by WC. According to BMI and WC combined, the percentage of the cohort that was normal weight decreased from 33 to 21% and the percentage that was obese increased from 32 to 49% between baseline and 2012.
Conclusions: In addition to BMI, assessment of WC should be incorporated more frequently when assessing population trends of obesity and the burden of disease associated with excess adiposity.

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Introduction

Obesity is estimated to be the third largest contributor to the overall burden of disease in Australia (1). It has been shown to increase the risk of a range of health conditions including diabetes, cardiovascular disease, musculoskeletal disease, disability, sleep apnoea, and mortality (2-4). The Australian Health Survey in 2011/12 found that overweight and obesity is still on the rise in adults, with a prevalence of 62.8% in 2011/12 compared to 61.2% in 2007/08 (5). However, little is known about the rates of weight change in the Australian adult population, or how they vary across the population. Such information can indicate how the prevalence of obesity and associated health burden will develop into the future.

Assessment of obesity in the population has commonly relied on the measures of body mass index (BMI). Waist circumference (WC) provides a complementary measure of excess bodyweight. Less attention, however, has been paid to how the WC of the population has tracked over time. In US adults, the population increases in WC have been greater than one would expect from the observed increases in BMI (6). Similar findings have been reported in Swedish, Finnish, German, and Scottish studies (7-10). This likely represents an increase in the proportion of obesity that is abdominal. Abdominal adiposity is strongly associated with obesity-related complications. It has been found to be associated with accelerated atherosclerosis independent of BMI in men with no prior atherosclerotic disease (11). It has been suggested to be more strongly associated

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with metabolic and cardiovascular problems compared to total adiposity (12,13), even in people within the normal range of BMI (14). Consequently, current estimates of population trends in BMI may underestimate the burden of disease by not taking into account those who are obese according to WC.

The Australian Diabetes, Obesity, and Lifestyle (AusDiab) study provides an opportunity for contemporary analysis of recent weight and WC change for Australian adults. Using this cohort, we aimed to: (i) describe the changes in the prevalence of overweight and obesity, and absolute and percent changes in weight and WC over a period of 12 years between 1999/2000 and 2011/12; and (ii) examine the incidence of obesity in an Australian adult population as determined by BMI and WC over a period of 12 years between 1999/2000 and 2011/12.

Methods

The Australian Diabetes, Obesity, and Lifestyle (AusDiab) study methods and response rates have been described elsewhere (15). In brief, a stratified cluster sample of 11,247 adults aged ≥25 years was drawn from 42 randomly selected census collector districts across Australia in 1999/2000. More than 85% of this population-based sample was from an Australian, New Zealand, or British background. Information was collected using a household interview, followed by a biomedical examination (15). Among those who completed a biomedical examination, 4,614 participants (44.6%) completed follow-up in 2011/12. Ten participants were missing anthropometric measures and were therefore excluded from the analysis. Compared to those who completed follow-up, those who did not were older, had a higher BMI and larger WC at baseline, were less likely to live in a major city, more likely to live in a socioeconomically disadvantaged area, and less likely to have a high level of education (Appendix, Supporting Information).

Height was measured to the nearest 0.5 cm without shoes using a stadiometer. Weight was measured without shoes and excess clothing to the nearest 0.1 kg using a digital weighing scale. BMI (kg/m^2) was calculated and categorized as: (i) normal BMI: 18.5–24.9 kg/m^2; (ii) overweight BMI: 25–29.9 kg/m^2; and (iii) obese BMI: ≥30 kg/m^2. In all, 34 participants were classified as underweight (BMI, <18.5 kg/m^2). Owing to the small number (<1%), underweight participants were combined with the normal BMI group. WC was measured at the point midway between the iliac crest and the costal margin and the mean of two measures was calculated. WC was categorized as: (i) low risk: <94 cm for men, <80 cm for women; (ii) moderate risk: 94–101.9 cm for men, 80–87.9 cm for women; and (iii) high risk: waist ≥102 cm for men, ≥88 cm for women (16).

Area-level socioeconomic position was measured using an aggregate measure of individual level data known as the Index of Relative Socioeconomic Disadvantage (IRSD). The IRSD is a component of the Socioeconomic Indexes for Areas (SEIFA) which characterizes the general socioeconomic position of census collection districts in Australia (17). It was developed by the Australian Bureau of Statistics to create a summary measure from a group of 20 variables (related to education, income, employment, family composition, housing benefits, car ownership, ethnicity, English language proficiency, and residential overcrowding) that display dimensions of social disadvantage (17). For these analyses, IRSD scores were based on the 2001 census, and the data were divided into population quintiles with the lowest quintile (1st) representing the most socioeconomically disadvantaged and the highest quintile (5th) representing the most socioeconomically advantaged.

The Accessibility/Remoteness Index of Australia (ARIA) was developed in 1999 as a method to define a remoteness or accessibility value for every location in Australia. It is calculated based on the road distance measurements from more than 12,000 populated localities to the nearest Service Centres in five size categories (major cities, inner regional, outer regional, remote, and very remote) based on the population size.

Educational attainment was obtained through interviewer administered questionnaire and categorized as: (i) low: secondary school qualification or lower; (ii) middle: attained trade or technician's certificate, associate or undergraduate diploma, or nursing or teaching qualification; (iii) high: attained a bachelor degree or postgraduate diploma.

Statistical analysis

All statistical analyses were based on the 4,457 participants who returned to follow-up in 2011/12 and had complete data available. Analyses were stratified by age, sex, baseline BMI, baseline WC, ARIA, IRSD, and level of education. Obesity was defined in three ways: (i) based on BMI ≥30 kg/m^2; (ii) based on WC (≥102 cm for men and ≥88 cm for women); and (iii) based on BMI or WC combined (BMI ≥30 kg/m^2 or waist ≥102 cm for men and ≥88 cm for women). Incident cases of obesity were defined as participants who were not obese at baseline but were obese at follow-up in 2011/12. Age- and sex-adjusted proportion of incident obesity for each stratum was estimated using logistic regression.

Change in weight was calculated as weight in 2011/12 minus weight at baseline. Similarly, change in WC was calculated as WC in 2011/12 minus WC at baseline. Percent change in weight was calculated as change in weight divided by weight at baseline, and similarly for WC. Age- and sex-adjusted mean 12-year change in weight or WC and mean percent change in weight or WC over 12 years were estimated for each stratum using linear regression.

Change in the prevalence of normal weight, overweight, and obese between baseline and follow-up in 2011/12 was described by 10-year age groups and stratified by sex. Bodyweight categories were defined by BMI and WC combined as summarized in Table 1.

Results

The mean baseline age of those who attended follow-up was 49 years. In total, 45.1% were men and around 40% of attendees were in the normal weight category both according to BMI and WC (Table 2).

TABLE 1 Bodyweight categories according to both BMI and WC

	BMI category		WC category
Normal	Normal	*and*	Low risk
Overweight	Overweight	*and*	Low or moderate risk
	Normal or overweight	*and*	Moderate risk
Obese	Obese	*or*	High risk

BMI categories: normal, 18.5–24.9 kg/m^2; overweight, 25–29.9 kg/m^2; obese: ≥30 kg/m^2
WC categories: low risk:, <94 cm for men, <80 for women; moderate risk: 94–101.9 for men, 80–87.9 for women; high risk: ≥102 for men, ≥88 for women.

TABLE 2 Characteristics of the study population at baseline

	Men	Women	Total
N	2,009	2,448	4,457
Age (years)	49.5 ± 11.4	48.5 ± 11.2	49.0 ± 11.3
Weight (kg)	82.6 (75.0–92.0)	67.4 (60.0–77.3)	75.1 (64.8–85.8)
BMI (kg/m^2)	26.6 (24.3–29.1)	25.2 (22.5–29.0)	26.0 (23.4–29.1)
WC (cm)	95.8 (89.3–103.4)	82.3 (74.3–91.1)	89.2 (79.5–98.5)
BMI categories[a]			
Normal	619 (30.8)	1,175 (48.0)	1,794 (40.3)
Overweight	1,001 (49.8)	778 (31.8)	1,779 (39.9)
Obese	389 (19.4)	495 (20.2)	884 (19.8)
WC categories[b]			
Low risk	844 (42.0)	1,061 (43.3)	1,905 (42.7)
Moderate risk	587 (29.2)	605 (24.7)	1,192 (26.7)
High risk	578 (28.8)	782 (31.9)	1,360 (30.5)
ARIA			
Major cities	925 (45.9)	1,108 (45.3)	2,031 (45.6)
Inner regional	534 (26.6)	645 (26.4)	1,179 (26.5)
Outer regional	501 (24.9)	624 (25.5)	1,125 (25.2)
Remote/Very remote	51 (2.5)	71 (2.9)	122 (2.7)
Quintiles of IRSD			
1st (most disadvantaged)	255 (12.7)	304 (12.4)	559 (12.5)
2nd	369 (18.4)	465 (19.0)	834 (18.7)
3rd	303 (15.1)	384 (15.7)	687 (15.4)
4th	447 (22.3)	523 (21.4)	970 (21.8)
5th (least disadvantaged)	635 (31.6)	772 (31.5)	1,407 (31.6)
Education[c]			
Low	505 (25.1)	972 (39.7)	1,477 (33.1)
Middle	985 (49.0)	976 (39.9)	1,961 (44.0)
High	519 (25.8)	500 (20.4)	1,019 (22.9)

Data are *n* (%), mean ± SD, or median (interquartile range).
[a]BMI categories: normal, 18.5–24.9 kg/m^2; overweight, 25–29.9 kg/m^2; obese: ≥30 kg/m^2.
[b]WC categories: low risk:, <94 cm for men, <80 for women; moderate risk: 94–101.9 for men, 80–87.9 for women; high risk: ≥102 for men, ≥88 for women.
[c]Education: (i) low: secondary school qualification or lower; (ii) middle: attained trade or technician's certificate, associate or undergraduate diploma, or nursing or teaching qualification; (iii) high: attained a bachelor degree or post-graduate diploma.
Abbreviations: ARIA, Accessibility/Remoteness Index of Australia; IRSD, Index of Relative Socioeconomic Disadvantage.

When using BMI or WC to define obesity, the prevalence of obesity at baseline was 32.0% (Table 3). The mean change in weight over 12 years was 2.7 kg and the mean change in WC was 5.3 cm. Change in weight and change in WC both decreased with age. However, although people aged 65 years and over typically lost, rather than gained, weight over 12 years, they still gained WC. Change in weight was similar for men and women though change in waist was higher in women. Change in waist was similar across each baseline BMI category, whereas change in weight was highest for those who were normal weight at baseline and lowest for those who were obese. In general, weight gain was greater for those with a lower socioeconomic position (live in more remote and more socioeconomically disadvantaged areas, and have a lower level of education). A similar pattern was observed with change in WC although some inconsistencies were observed according to the individual measures of socioeconomic position. Percent change in weight and waist generally showed a similar pattern to absolute change in weight and waist, with the exception of percentage change in weight by sex where women had a higher percent increase in weight than men (Table 3).

The incidence of obesity over 12 years was 15.0% when defined by BMI, 31.8% when defined by WC, and 32.1% when defined by BMI or WC (Table 4). Incidence of obesity by BMI decreased with age and higher educational attainment, and was higher for those who live further away from regional cities and for those who reside in more disadvantaged areas. There was no difference in incidence by sex. When defining incident obesity by WC, some different patterns were observed. Incidence of obesity by WC increased with age up to the age of 54–65 years when incidence declined. Incidence was higher for women than for men and for those with a lower educational attainment. Incidence was generally higher for those from a lower socioeconomic position (Table 4). The pattern for incidence of obesity was similar when obesity was defined by WC only and by WC and BMI combined.

Owing to the substantial proportion of individuals who had a high risk WC but were not obese according to BMI, we examined the implication of the 12-year changes on prevalence of weight status based on a combination of WC and BMI (Figures 1 and 2). At baseline, 33% of the total population was normal weight according to both their BMI and WC. By 2012, <22% were normal weight. Over 12 years, the percentage of the population that was obese according to their BMI or WC increased from 32 to 49% (data not shown).

Discussion

In this 12-year follow-up of a national population-based cohort of Australian adults, incidence of obesity was 15% when measured by BMI and almost one-third when measured by WC. Consequently, less than a quarter of the cohort remained in the normal bodyweight category according to both their BMI and their WC by 2012. The pattern of incidence of obesity across subgroups in the population varied depending on the method used to define obesity. Incidence of obesity was higher in women than in men when defined by WC, but did not differ by sex when defined by BMI. The pattern of change in weight and WC over 12 years also differed, such that people aged 65 years and over tended to lose weight but gain WC. Higher incidence of obesity was observed with increasing level of remoteness (defined by ARIA) and increasing area-level socioeconomic disadvantage (defined by IRSD) when obesity was defined by BMI, but not when obesity was defined by WC.

The average annual weight gain in this cohort over a 12-year period was 0.20 kg for men and 0.24 kg for women, and the average annual increase in WC was 0.36 and 0.52 cm for men and women, respectively. In two select populations of Australian adults, the average weight was previously reported to increase by 0.4–0.9 kg per year (18-20). The discrepancy with our findings may be attributable to several factors. Neither of the previous studies were contemporary Australian general populations, with one examining a cohort of women with young children, a population known to be at particular

TABLE 3 Change in weight and WC over 12 years

	Obese[a] at baseline (%)	Change in weight (kg) mean (95% CI)	Change in weight (%) mean (95% CI)	Change in waist (cm) mean (95% CI)	Change in waist (%) mean (95% CI)
All	32.0	2.7 (2.4, 2.9)	3.7 (3.5, 4.0)	5.3 (5.1, 5.6)	6.4 (6.1, 6.6)
Age (years)					
25–34	20.1	6.7 (6.1, 7.4)	9.4 (8.6, 10.2)	6.6 (5.9, 7.3)	8.1 (7.3, 8.9)
35–44	24.5	4.7 (4.3, 5.1)	6.5 (6.0, 7.0)	6.4 (6.0, 6.8)	7.7 (7.2, 8.2)
45–54	33.0	2.7 (2.3, 3.0)	3.7 (3.2, 4.1)	5.7 (5.3, 6.1)	6.7 (6.2, 7.1)
55–64	40.5	0.4 (−0.1, 0.8)	0.7 (0.1, 1.2)	4.1 (3.6, 4.6)	4.8 (4.2, 5.3)
65–74	43.5	−2.0 (−2.7, −1.3)	−2.4 (−3.3, −1.5)	2.8 (2.1, 3.6)	3.4 (2.5, 4.3)
≥75	43.9	−4.5 (−6.3, −2.7)	−6.0 (−8.3, −3.7)	0.8 (−1.2, 2.7)	1.1 (−1.2, 3.3)
	$P < 0.001$				
Sex					
Men	30.6	2.4 (2.1, 2.7)	2.9 (2.6, 3.3)	4.3 (4.0, 4.7)	4.6 (4.2, 5.0)
Women	33.2	2.9 (2.6, 3.1)	4.4 (4.0, 4.7)	6.2 (5.9, 6.5)	7.8 (7.4, 8.1)
	$P = 0.07$				
BMI at baseline[b]					
Normal	1.8	2.9 (2.6, 3.2)	4.7 (4.3, 5.1)	5.2 (4.9, 5.6)	6.9 (6.5, 7.3)
Overweight	28.7	2.6 (2.3, 2.9)	3.4 (3.0, 3.8)	5.5 (5.1, 5.8)	6.3 (5.9, 6.7)
Obese	100.0	2.2 (1.8, 2.7)	2.4 (1.8, 3.0)	5.4 (4.9, 5.9)	5.3 (4.8, 5.9)
	$P < 0.001$				
WC at baseline[c]					
Low risk	0.3	2.9 (2.6, 3.2)	4.6 (4.2, 5.0)	6.1 (5.8, 6.4)	8.0 (7.6, 8.4)
Moderate risk	5.2	2.6 (2.2, 3.0)	3.4 (2.9, 3.9)	5.1 (4.7, 5.6)	5.9 (5.4, 6.3)
High risk	100.0	2.4 (2.0, 2.8)	2.7 (2.3, 3.2)	4.5 (4.1, 4.9)	4.5 (4.0, 4.9)
	$P < 0.001$				
ARIA					
Major cities	29.1	2.5 (2.2, 2.8)	3.6 (3.2, 4.0)	5.7 (5.4, 6.1)	6.9 (6.5, 7.3)
Inner regional	32.5	2.5 (2.1, 2.9)	3.5 (3.0, 4.0)	5.2 (4.8, 5.7)	6.2 (5.7, 6.7)
Outer regional	36.4	3.0 (2.6, 3.4)	4.2 (3.6, 4.7)	4.6 (4.1, 5.0)	5.4 (4.9, 6.0)
Remote/Vvery remote	36.1	3.0 (1.8, 4.2)	4.0 (2.5, 5.6)	6.8 (5.5, 8.2)	7.8 (6.2, 9.3)
	$P < 0.001$				
IRSD					
1st Quintile	39.2	3.0 (2.4, 3.6)	4.1 (3.4, 4.9)	5.6 (5.0, 6.2)	6.4 (5.7, 7.2)
2nd Quintile	36.6	2.9 (2.5, 3.4)	4.0 (3.4, 4.6)	5.1 (4.6, 5.6)	6.0 (5.4, 6.6)
3rd Quintile	35.2	2.3 (1.8, 2.8)	3.3 (2.6, 3.9)	5.0 (4.4, 5.6)	5.9 (5.3, 6.6)
4th Quintile	31.2	2.9 (2.5, 3.3)	4.2 (3.6,4.7)	4.9 (4.4, 5.4)	5.8 (5.3, 6.4)
5th Quintile	25.4	2.3 (2.0, 2.7)	3.3 (2.9, 3.8)	5.8 (5.5, 6.2)	7.1 (6.6, 7.6)
	$P < 0.001$				
Education					
Low	36.0	2.9 (2.5, 3.2)	4.0 (3.5, 4.4)	5.5 (5.1, 5.9)	6.5 (6.0, 6.9)
Middle	32.4	2.9 (2.6, 3.2)	4.0 (3.6, 4.4)	5.6 (5.3, 6.0)	6.7 (6.3, 7.0)
High	25.5	1.9 (1.5, 2.4)	2.8 (2.3, 3.4)	4.5 (4.1, 5.0)	5.6 (5.1, 6.1)
	$P < 0.001$				

[a]Obesity defined by: BMI ≥30 kg/m^2 or WC ≥102 for men and ≥88 for women.
[b]BMI categories: normal, 18.5–24.9 kg/m^2; overweight, 25–29.9 kg/m^2; obese: ≥30 kg/m^2.
[c]WC categories: low risk:, <94cm for men, <80 for women; moderate risk: 94–101.9 for men, 80–87.9 for women; high risk: ≥102 for men, ≥88 for women.
Analyses according to age group were sex adjusted and analyses according to sex were age adjusted. All other analyses were age and sex adjusted.
Abbreviations: ARIA, Accessibility/Remoteness Index of Australia; CI, confidence interval; IRSD, Index of Relative Socioeconomic Disadvantage. *P*-value was calculated using χ^2-test.

risk of weight gain (19), and the other examining participants of the Melbourne Collaborative Cohort Study (MCCS) (18), a cohort study beginning in the early 1990s which purposely over-sampled southern European migrants. Furthermore, the age profile of the AusDiab population differed from MCCS, with a baseline age range of 25–85 and 40–69 years, respectively. This may impact the overall amount of

TABLE 4 Incidence of obesity over 12 years

	Incidence of obesity by BMI (95% CI)	Incidence of obesity by WC (95% CI)	Incidence of obesity by BMI or WC (95% CI)
All	15.0 (13.8, 16.2)	31.8 (30.2, 33.5)	32.1 (30.5, 33.8)
Age (years)			
25–34	19.8 (15.8, 23.8)	27.2 (22.7, 31.8)	29.5 (24.8, 34.3)
35–44	15.6 (13.3, 17.9)	30.3 (27.3, 33.2)	30.1 (27.1, 33.1)
45–54	15.2 (13.2, 17.3)	33.5 (30.6, 36.3)	33.8 (30.8, 36.7)
55–64	13.4 (10.9, 16.0)	34.6 (30.6, 38.5)	34.5 (30.5, 38.5)
65–74	11.2 (7.6, 14.8)	33.0 (26.7, 39.3)	32.5 (26.2, 38.8)
≥75	6.1 (−0.6, 12.8)	23.6 (9.3, 37.8)	22.1 (7.7, 36.5)
Sex			
Men	14.9 (13.2, 16.6)	27.7 (25.4, 30.0)	28.1 (25.8, 30.5)
Women	15.1 (13.5, 16.7)	35.4 (33.1, 37.7)	35.1 (33.1, 37.8)
BMI at baseline[a]			
Normal	1.5 (1.0, 2.0)	15.2 (13.6, 16.8)	15.3 (13.7, 16.9)
Overweight	31.2 (28.9, 33.4)	54.5 (51.8, 57.2)	57.4 (54.7, 60.1)
Obese	N/A	79.0 (69.6, 88.3)	N/A
WC at baseline[b]			
Low risk	3.9 (3.0, 4.7)	14.6 (13.0, 16.1)	15.3 (13.7, 16.9)
Moderate risk	22.3 (19.9, 24.8)	59.9 (57.1, 62.7)	60.9 (58.1, 63.8)
High risk	45.6 (41.4, 49.8)	N/A	N/A
ARIA			
Major cities	14.0 (12.3, 15.7)	31.7 (29.3, 34.0)	32.0 (29.6, 34.4)
Inner regional	15.9 (13.6, 18.2)	33.7 (30.5, 37.0)	34.6 (31.3, 37.9)
Outer regional	15.6 (13.2, 18.0)	29.7 (26.3, 33.0)	29.3 (26.0, 32.6)
Remote/very remote	18.2 (10.4, 25.9)	35.9 (25.5, 46.4)	34.4 (23.9, 44.8)
IRSD			
1st Quintile	19.0 (15.2, 22.7)	31.9 (27.0, 36.8)	32.6 (27.6, 37.6)
2nd Quintile	17.3 (14.4, 20.2)	33.6 (29.7, 37.6)	33.2 (29.2, 37.2)
3rd Quintile	13.8 (10.8, 16.7)	33.2 (28.9, 37.5)	32.5 (28.1, 36.8)
4th Quintile	15.9 (13.3, 18.4)	32.1 (28.6, 35.6)	32.9 (29.3, 36.5)
5th Quintile	12.3 (10.4, 14.1)	30.2 (27.4, 32.9)	30.7 (28.0, 33.5)
Education			
Low	16.5 (14.3, 18.7)	35.2 (32.1, 38.2)	35.6 (32.5, 38.7)
Middle	15.8 (14.0, 17.6)	32.6 (30.1, 35.1)	33.1 (30.5, 35.6)
High	11.8 (9.7, 13.9)	26.2 (23.1, 29.3)	26.0 (22.8, 29.1)

Incidence presented as percentage over a 12-year period
[a]BMI categories: normal, 18.5–24.9 kg/m^2; overweight, 25–29.9 kg/m^2; obese: ≥30 kg/m^2.
[b]WC categories: low risk:, <94 cm for men, <80 for women; moderate risk: 94–101.9 for men, 80–87.9 for women; high risk: ≥102 for men, ≥88 for women.
Analyses according to age group were sex adjusted and analyses according to sex were age adjusted. All other analyses were age and sex adjusted.
Abbreviations: ARIA, Accessibility/Remoteness Index of Australia; CI, confidence interval; IRSD, Index of Relative Socioeconomic Disadvantage; N/A, not applicable.

weight gain observed as older people tend to lose weight rather than gain weight. To the best of our knowledge, there has been no previous examination of the average annual increase in WC in Australia.

Similar patterns for weight gain by age, sex, and baseline BMI have been reported by other studies (18,21). In AusDiab, ARIA, IRSD, and education level were used as surrogate markers of socio-economic positioning. Although we found no clear dose–response relationship with any of these markers, weight gain tended to be greater for those with a lower socioeconomic position. Change in WC over time according to socio-demographic factors has not been previously examined in Australia though a similar trend in WC by age and level of education has been reported in the United States (22).

The incidence of obesity in this study was double when defined by WC compared to when defined by BMI. This may be explained by differences in the patterns of weight and WC change. Older people tended to lose weight while still gaining WC. This suggests that in this age group, there was loss in muscle mass (23) (driving weight

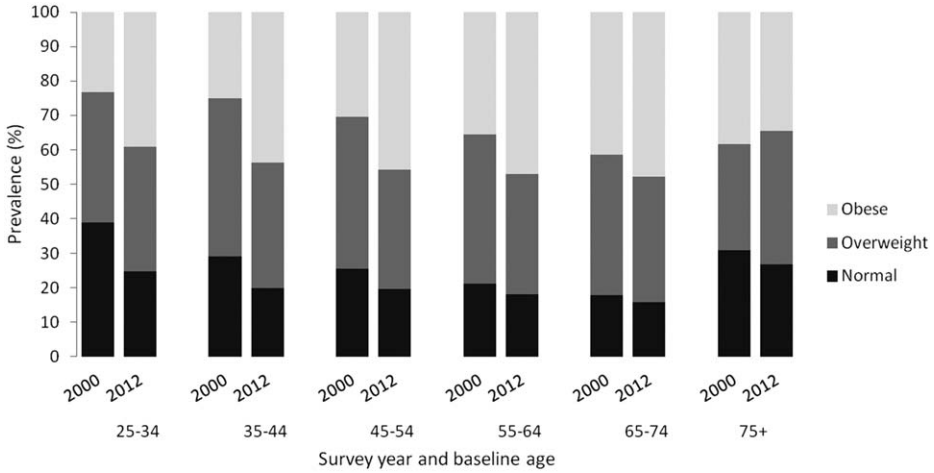

Figure 1 Prevalence of normal weight, overweight, and obese at baseline and 2011/12 categorized by BMI and WC according to baseline age in men.

loss), accompanied by an increase in fat mass (driving WC increase). Furthermore, women gained more WC than men although no difference in absolute weight gain was observed. This may be linked to a change in fat distribution that commonly occurs after menopause in women (24), which may not necessarily be accompanied by an increase in bodyweight. We found that the magnitude of the incidence of obesity was largely similar when obesity was defined by a combination of BMI and WC and when it was defined by WC only. This is not surprising as the majority of participants with a BMI in the obese range also had a high risk WC although a significant proportion with a high risk WC had BMI in the normal and overweight range (Appendix, Supporting Information). This discordance between WC and BMI has been poorly described by others in the literature (25-27). One Australian study found that 6.5% of men and 22% of women aged 18–65 years with acceptable BMI (<25 kg/m^2) had excessive WC ($\geq$94 cm for men and $\geq$80 cm for women) (25). Data from the China Health and Nutrition Survey reported 7.6 and 13.5% of individuals with BMI <23 kg/m^2 had central obesity (WC $\geq$90 cm for men and $\geq$80 cm for women) in 1993 and 2009, respectively (27).

There is some evidence to suggest that BMI and WC have been tracking differently over the past few decades. WC in a few populations has been described as continuing to increase despite an apparent plateau in BMI trends. In US adults, population WC has increased between 1988–1994 and 2005–2006 above and beyond the increases observed in BMI (22). Similar findings were reported in Scottish adults between 1998 and 2008 (7). In Finnish adults, increases in BMI had slowed in men and remained stable in women, whereas increases in WC continued between 1987 and 2002 (8). Thus, if population monitoring of obesity was done using BMI alone, it would appear that the burden of obesity is improving

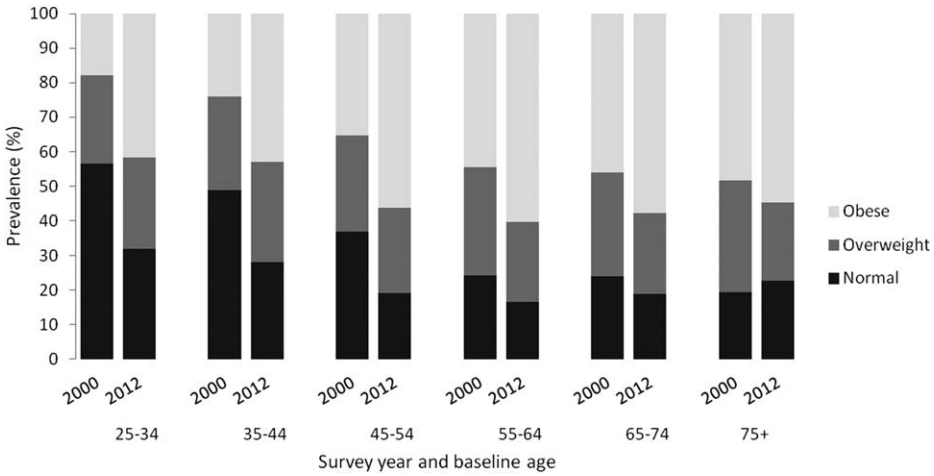

Figure 2 Prevalence of normal weight, overweight, and obese at baseline and 2011/12 categorized by BMI and WC according to baseline age in women.

despite a continuing upward trend in abdominal obesity (as indicated by WC). The findings that incidence of obesity was greatly increased when defined by WC compared to when defined by BMI may also have implications for estimates of the burden of obesity. WC cut-points were originally derived from a regression curve that identified WC values associated with BMI of $\geq$25 kg/m^2 and $\geq$30 kg/m^2 in 1995 (16). These cut-points were designed to be used as an alternative to BMI to identify those in need of weight management. Often, health reports focus on those with a BMI of $\geq$30 kg/m^2, which may represent only a subset of individuals who are obese. In AusDiab, as many as 40% of individuals at baseline with a BMI of $<$30 kg/m^2 had a high-risk WC. The Australian Health Survey in 2011/12 reported that 35.5% of adults aged 18 years and over were normal weight, 35.3% were overweight, and 27.5% were obese according to their BMI (5). Similar numbers with obesity according to BMI were observed in AusDiab in 2011/12 (27.3%). By comparison, according to BMI and WC combined, the proportion of the AusDiab population in 2011/12 who were normal, overweight, and obese was 21.1, 30.1, and 48.8%, respectively. It is uncertain whether the health risk profile differs for individuals with a non-obese BMI but a high-risk WC, those with an obese BMI but a non–high-risk WC, and those with both an obese BMI and a high-risk WC. One study found higher risk of incident hypertension in people with a high WC but a normal BMI (27), whereas another showed an increased risk of mortality with increasing WC within all BMI categories (28). To the best of our knowledge, no study has examined individuals with an obese BMI but low-risk WC, which may be owing to a low prevalence of people who fall within this category.

It is widely recognized that BMI as a measure of obesity has its limitations as it makes no differentiation between the contribution of fat and the muscle mass to overall bodyweight. WC, although harder to measure accurately, is accepted as a better indicator of adiposity, particularly central adiposity which is associated with a higher risk of metabolic diseases (29,30). Clinical guidelines released by the National Heart, Lung, and Blood Institute in the United States in 1998 recognized that WC should be measured in conjunction with BMI, particularly in those with a BMI of $<$35 kg/m^2, as there will be a number of people with BMI of $<$25 kg/m^2 who, despite their low BMI, will have disproportional abdominal fat which increases their cardiovascular risk (31). Similar recommendations were made in 2006, 2010, and 2013 by the Canadian Clinical Practice Guidelines, the Scottish Intercollegiate Guidelines Network, and the National Health and Medical Research Council in Australia, respectively (32-34). Thus, at least in clinical practice for the management of overweight and obesity, the value of measuring WC in addition to BMI appears to be well accepted. These recommendations should be extended for use in the assessments of trends of obesity in the population and the burden of disease associated with excess adiposity.

A potential limitation to our study is its generalizability owing to modest response rates. At baseline, 55.3% of eligible individuals participated in the physical examination. In 2011/12, 44.6% of eligible participants completed the follow-up. Respondents to the 2011/12 follow-up were younger and had lower baseline BMI and WC. Our findings suggest that these were the individuals who gained more weight and WC. This may have led to an overestimation of the average change in weight and WC of the population, and potentially influenced our total population estimates of the incidence of obesity. Nevertheless, the obesity prevalence estimate derived from the cohort in 2012 was very similar to that reported by the Australian Health Survey in 2012 (5). Our study population was also predominantly Anglo-Celtic, thus it is uncertain whether our findings would hold in other ethnic populations. The strengths of our study include a long follow-up period and a contemporary, population-based cohort, with objective measures for height, weight, and WC.

The AusDiab study provided an opportunity to assess the changes in weight and WC in a contemporary Australian adult cohort over a period of 12 years. Overall, we found an average annual weight gain of 0.20 kg for men and 0.24 kg for women. Although these increases may appear small, over time they accumulate to a significant amount of weight gain. We additionally found that the incidence of obesity was twice as high when determined by WC compared to BMI. Less than 22% of the cohort remained in the normal bodyweight category according to both BMI and WC by 2012. Often reports on trends and burden of obesity focus on BMI measures. Our findings indicate that this may lead to an underestimation of the problem and we suggest that the measures of WC should be incorporated more frequently as a complementary assessment of obesity. O

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References

1. AIHW. Overweight and Obesity. Canberra [cited 2013 July]; Available from: http://www.aihw.gov.au/overweight-and-obesity/.
2. Abdullah A, Peeters A, de Courten M, et al. The magnitude of association between overweight and obesity and the risk of diabetes: a meta-analysis of prospective cohort studies. *Diabetes Res Clin Pract* 2010;89:309-319.
3. Berrington de Gonzalez A, Hartge P, Cerhan JR, et al. Body-mass index and mortality among 1.46 million white adults. *N Engl J Med* 2010;363:2211-2219.
4. World Health Organization. Obesity. Preventing and Managing the Global Epidemic. Geneva, Switzerland: World Health Organization, 1998.
5. ABS. Australian health survey: updated results, 2011–2012. ABS cat. no. 4364.0.55.003. Canberra: Australian Bureau of Statistics, 2012.
6. Walls HL, Stevenson CE, Mannan HR, et al. Comparing trends in BMI and waist circumference. *Obesity* 2011;19:216–219.
7. Lean ME, Katsarou C, McLoone P, et al. Changes in BMI and waist circumference in Scottish adults: use of repeated cross-sectional surveys to explore multiple age groups and birth-cohorts. *Int J Obes* 2013;37:800-808.
8. Lahti-Koski M, Harald K, Mannisto S, et al. Fifteen-year changes in body mass index and waist circumference in Finnish adults. *Eur J Cardiovasc Prev Rehabil* 2007;14:398-404.
9. Berg C, Rosengren A, Aires N, et al. Trends in overweight and obesity from 1985 to 2002 in Goteborg, West Sweden. *Int J Obes* 2005;29:916-924.
10. Lissner L, Bjorkelund C, Heitmann BL, Lapidus L, Bjorntorp P, Bengtsson C. Secular increases in waist-hip ratio among Swedish women. *Int J Obes Relat Metab Disord* 1998;22:1116-1120.
11. Lakka TA, Lakka HM, Salonen R, Kaplan GA, Salonen JT. Abdominal obesity is associated with accelerated progression of carotid atherosclerosis in men. *Atherosclerosis.* 2001;154:497-504.
12. Zamboni M, Armellini F, Sheiban I, et al. Relation of body fat distribution in men and degree of coronary narrowings in coronary artery disease. *Am J Cardiol* 1992;70:1135-1138.
13. Folsom AR, Kaye SA, Sellers TA, et al. Body fat distribution and 5-year risk of death in older women. *J Am Med Assoc* 1993;269:483-487.
14. NIH-NHLBI. Clinical Guidelines on the Identification, Evaluation and Treatment of Overweight and Obesity in Adults. The evidence report. Bethesda, MD. 1998.

15. Dunstan DW, Zimmet PZ, Welborn TA, et al. The Australian diabetes, obesity and lifestyle study (AusDiab)—methods and response rates. *Diabetes Res Clin Pract* 2002;57:119-129.
16. Lean ME, Han TS, Morrison CE. Waist circumference as a measure for indicating need for weight management. *Br Med J* 1995;311:158-161.
17. Australian Bureau of Statistics. Information paper: census of population and housing. Socio-economic indexes for areas, Australia 2001 [cited 2013 June]; Available from: http://www.ausstats.abs.gov.au/ausstats/free.nsf/0/A5561C69BF600637CA256E20007B5DF1/$File/2039055001_2001.pdf.
18. Ball K, Crawford D, Ireland P, Hodge A. Patterns and demographic predictors of 5-year weight change in a multi-ethnic cohort of men and women in Australia. *Public Health Nutr* 2003;6:269-281.
19. Lombard C, Deeks A, Jolley D, Ball K, Teede H. A low intensity, community based lifestyle programme to prevent weight gain in women with young children: cluster randomised controlled trial. *Br Med J* 2010;341:c3215.
20. Brown WJ, Williams L, Ford JH, Ball K, Dobson AJ. Identifying the energy gap: magnitude and determinants of 5-year weight gain in midage women. *Obes Res* 2005;13:1431-1441.
21. Kuczmarski RJ. Prevalence of overweight and weight gain in the United States. *Am J Clin Nutr* 1992;55:495S-502S.
22. Abdullah A, Wolfe R, Stoelwinder JU, et al. The number of years lived with obesity and the risk of all-cause and cause-specific mortality. *Int J Epidemiol* 2011;40:985-996.
23. Thomas DR. Loss of skeletal muscle mass in aging: examining the relationship of starvation, sarcopenia and cachexia. *Clin Nutr* 2007;26:389-399.
24. Toth MJ, Tchernof A, Sites CK, Poehlman ET. Menopause-related changes in body fat distribution. *Ann N Y Acad Sci* 2000;904:502-506.
25. Booth ML, Hunter C, Gore CJ, Bauman A, Owen N. The relationship between body mass index and waist circumference: implications for estimates of the population prevalence of overweight. *Int J Obes Relat Metab Disord* 2000;24:1058-1061.
26. Nam S, Kuo YF, Markides KS, Al Snih S. Waist circumference (WC), body mass index (BMI), and disability among older adults in Latin American and the Caribbean (LAC). *Arch Gerontol Geriatr* 2012;55:e40-e47.
27. Du T, Sun X, Yin P, Huo R, Ni C, Yu X. Increasing trends in central obesity among Chinese adults with normal body mass index, 1993-2009. *BMC Public Health* 2013;13:327.
28. Jacobs EJ, Newton CC, Wang Y, et al. Waist circumference and all-cause mortality in a large US cohort. *Arch Intern Med* 2010;170:1293-1301.
29. Welborn TA, Dhaliwal SS, Bennett SA. Waist-hip ratio is the dominant risk factor predicting cardiovascular death in Australia. *Med J Aust* 2003;179:580-585.
30. Wang Y, Rimm EB, Stampfer MJ, Willett WC, Hu FB. Comparison of abdominal adiposity and overall obesity in predicting risk of type 2 diabetes among men. *Am J Clin Nutr* 2005;81:555-563.
31. NHLBI. Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults: The Evidence Report. National Institutes of Health, 1998.
32. Lau DC, Douketis JD, Morrison KM, Hramiak IM, Sharma AM, Ur E. 2006 Canadian clinical practice guidelines on the management and prevention of obesity in adults and children [summary]. *Can Med Assoc J* 2007;176:S1-S13.
33. Scottish Intercollegiate Guidelines Network. Management of obesity. A national clinical guideline. Edinburgh SIGN, 2010.
34. National Health and Medical Research Council. Clinical practice guidelines for the management of overweight and obesity in adults, adolescents and children in Australia. Melbourne: National Health and Medical Research Council, 2013.