Preventive Medicine 111 (2018) 378–383

Contents lists available at ScienceDirect

Preventive Medicine

journal homepage: www.elsevier.com/locate/ypmed

# Changes in waist circumference independent of weight: Implications for population level monitoring of obesity

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ARTICLE INFO

*Keywords:*
Population surveillance
Trends
Obesity
Waist circumference
Epidemiology

ABSTRACT

Population monitoring of obesity is most commonly conducted using body mass index (BMI). We test the hypothesis that because of increases in waist circumference (WC) independent of increases in weight, BMI alone detects an increasingly smaller proportion of the population with obesity.

*Methods:* Australian adults with measured height, weight, and WC were selected from three nationally representative cross-sectional surveys (1989, 1999–2000, 2011–12; n = 8313, 5903 & 3904). Participants were defined as having obesity using classifications for an obese BMI (≥ 30 kg·m$^{-2}$) and substantially-increased-risk WC (≥ 88 cm [women], ≥ 102 cm [men]). Age-standardised prevalence of obesity according to BMI and/or WC, and the proportion of these detected by BMI and by WC were compared across surveys.

*Findings:* Between 1989 and 2011–12, weight and WC increased by 5.4 kg and 10.7 cm (women), and by 7.0 kg and 7.3 cm (men). For women and men, 63% and 38% of increases in WC were independent of increases in weight. Over this period, the prevalence of obesity according to BMI and/or WC increased by 25.3 percentage-points for women (18.9% to 44.3%) and 21.1 percentage-points for men (17.1% to 38.2%). The proportion of these detected by BMI decreased for women by 20 percentage-points (77% to 57%) with no change for men. The proportion of these detected by WC increased for women and men by 10 percentage-points (87% to 97%) and 6 percentage-points (85% to 91%) respectively.

*Conclusion:* BMI alone is detecting a decreasing proportion of those considered obese by BMI and/or WC. Renewed discussion regarding how we monitor obesity at the population level is required.

## 1. Introduction

Accurate population monitoring of risk factors for key non-communicable diseases provides the foundation for their effective prevention and management (World Health Organization, 2013). As obesity is a leading contributor to the global burden of disease (Collaborators GBDRF, 2017), it is important to accurately and effectively monitor obesity prevalence at the population level. Internationally, body mass index (BMI, a measure of weight for height) and waist circumference (WC) are the two most common anthropometric classifications of obesity (World Health Organization, 2011). While it is established that there is imperfect overlap in categorisation of obesity according to BMI and WC, as individuals can be obese according to one indicator but not another (Lahti-Koski et al., 2007; Park et al., 2008; Lean et al., 1995), population obesity monitoring primarily relies on BMI alone (NCD Risk Factor Collaboration, 2016). This domination of BMI over other anthropometric markers of obesity has been attributed to recommendation by the World Health Organization (2011), and to a perceived

*Abbreviations:* AusDiab, Australian Diabetes, Obesity and lifestyle Study. A survey conducted in the year 1999–2000 representative of the Australian population; BMI, body mass index, an index of weight for height (kg·m$^{-2}$) used as an indicator of adiposity; NNPAS, National Nutrition Physical Activity Survey. A survey conducted in the year 2011–12 representative of the Australian population; RFPS, National Heart Foundation Risk Factor Prevalence Study. A survey conducted in the year 1989 representative of the urban Australian population; WC, waist circumference, the circumference around an individual's waist, used as an indicator of adiposity

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https://doi.org/10.1016/j.ypmed.2017.11.030
Received 14 August 2017; Received in revised form 27 October 2017; Accepted 27 November 2017
Available online 01 December 2017

redundancy in measuring both BMI and WC (NCD Risk Factor Collaboration, 2016), given their similar discriminative ability to predict cardio-metabolic risk factors and diseases (Huxley et al., 2010; Cheong et al., 2015; Seo et al., 2017).

However, there is some indication that the nature of obesity is changing to one of greater abdominal adiposity, indicated in part by greater increases in WC over time than would be expected based on increases in body weight (Stern et al., 2014; Janssen et al., 2012; Elobeid et al., 2007; Freedman and Ford, 2015; Albrecht et al., 2015; Walls et al., 2011a). We have previously demonstrated in the Mongolian context that as WC has increased independent of increases in body weight, BMI is detecting an increasingly smaller proportion of the population with obesity, as categorised by BMI or WC (Chimeddamba et al., 2017). However the implications in other countries have not been analysed. Given that current population monitoring initiatives rely on BMI, it is imperative that the extent to which BMI may be underestimating the level of population risk is quantified.

The first aim of this study was to firstly quantify the discordance in changes to WC and weight for urban Australian adults between 1989 and 2011–12. The second aim was to describe trends in classification of obesity according to BMI and WC, between 1989 and 2011–12.

We stratify all analyses by smoking status, body mass index category, highest educational attainment and age to both identify subgroups of interest and assess the potentially modifying effect of these factors.

## 2. Methods

### 2.1. Data source

Three nationally representative cross-sectional surveys were used: the 1989 National Heart Foundation Risk Factor Prevalence Study (RFPS); the 1999–2000 Australian Diabetes, Obesity and Lifestyle Study (AusDiab); and the 2011–12 National Nutrition and Physical Activity Survey (NNPAS), the details of which have been described previously (National Heart Foundation of Australia, 2001; Dunstan et al., 2002; Australian Bureau of Statistics, 2013). Briefly, the 1989 RFPS was a random selection of 9279 Australian adults (response rate 65%) aged 25–69 residing in State or Territory capital cities conducted between June and December of 1989 (National Heart Foundation of Australia, 2001). AusDiab was a multi-stage household based survey of all adult residents aged over 25 years from 11,479 private dwellings (response rate after sample loss: 70%) across Australia conducted over a 21 month period between 1999 and 2000, with biomedical information on 11,247 participants (Dunstan et al., 2002). The 2011–12 NNPAS was a multi-stage household-based survey of 9519 private dwellings (response rate after sample loss: 77%) across Australia from June 2011 to June 2011–12 with one randomly selected adult and (where applicable) one child (2–18 years) selected from each dwelling, totalling 12,153 participants (Australian Bureau of Statistics, 2013).

### 2.2. Outcome variables

Height and weight were obtained through similar methodology at all three time points. Trained interviewers measured participants' height (using a stadiometer, to the nearest 0.1 cm [2011 – 12] or 0.5 cm [1989, 1999–2000]), weight (using digital scales, to the nearest 0.1 kg) and WC (using a flexible steel measuring tape, to the nearest 0.1 cm [2011–12] or 0.5 cm [1989, 1999–2000]) after participants were instructed to remove shoes and bulky clothing. In AusDiab (1999–2000) and NNPAS (2011 – 12), where multiple measures were taken, the mean of the two closest measurements was used. There was variation in measurement of waist circumference across the three surveys. Measurements were taken at the narrowest point between the ribs and hips (1989), the mid-point between the iliac crest and lowest palpable rib (1999–2000), and the umbilicus (2011–12).

For the first aim, weight and WC were used as continuous variables.

For the second aim, WC was categorised as not-obese (< 88 cm for women, < 102 cm for men) and obese (≥ 88 cm for women, ≥ 102 cm for men) (World Health Organization, 2000), and BMI ($kg{\cdot}m^{-2}$) was calculated as weight (kg) × $height^{-2}$ (m) and categorised as not-obese (BMI < 30 $kg{\cdot}m^{-2}$) and obese (BMI ≥ 30 $kg{\cdot}m^{-2}$) (World Health Organization, 2000). We then examined classification of obesity according to the following BMI and WC combinations: obese according to BMI and/or WC (WC ≥ 88 cm (women), ≥ 102 cm (men) or BMI ≥ 30 $kg{\cdot}m^{-2}$); obese according to WC but not BMI (WC ≥ 88 cm (women), ≥ 102 cm (men) and BMI < 30 $kg{\cdot}m^{-2}$); obese according to BMI but not WC (WC < 88 cm (women), < 102 cm (men) and BMI ≥ 30 $kg{\cdot}m^{-2}$); obese according to BMI and WC (WC ≥ 88 cm (women), ≥ 102 cm (men) and BMI ≥ 30 $kg{\cdot}m^{-2}$); and not-obese (WC < 88 cm (women), < 102 cm (men) and BMI < 30 $kg{\cdot}m^{-2}$).

### 2.3. Potential effect modifiers

All analyses were conducted for women and men separately, and further stratified by smoking status, BMI category, highest educational attainment and age. BMI category was calculated from measured height and weight as specified above, and categorised as: normal weight (BMI ≥ 18.5 to < 25 $kg{\cdot}m^{-2}$); overweight (BMI ≥ 25 to < 30 $kg{\cdot}m^{-2}$); and obese (BMI ≥ 30 $kg{\cdot}m^{-2}$) (World Health Organization, 2011). Smoking status, education group and age group were self-reported in each survey, and categorised for ease of interpretation: age-group (25–34, 35–44, 55–64, 65–69), education group (dichotomised at completion of secondary school), and smoking status (never or ever smoker).

### 2.4. Exclusion Criteria

Of the 32,679 potential subjects across the three surveys (1989, 1999–2000, 2011–12), participants were ineligible for this analysis if they resided outside of capital cities (n = 0, 4336, 4365; to maximise comparability across the three surveys), were aged < 25 or > 69 years (n = 778, 787, 3107; to account for the inaccuracy of BMI at older ages (Prentice and Jebb, 2001)), or were pregnant at the time of the survey (n = 85, 57, NA). We further excluded participants who were missing information on height, weight or WC (n = 103, 70, 777) or other variables of interest (n = 0, 94, 0). Our final analytical populations comprised 8, 313 (1989), 5903 (1999–2000) and 3904 (2011–12) women and men.

### 2.5. Statistical analyses

Descriptive statistics were calculated for all study populations. All further analyses were age-standardised to the 2012 mid-year Australian population using the direct method (Bell, 1999), and survey weighted, where a person-level weight reflecting the Australian population distribution of age, sex and locale at the time of each survey was applied. Survey weights are calibrated by 'State by Part of State' (including urban areas), by sex and by age group, allowing us to make valid inferences about the urban Australian population from our analytic population classified by age and sex (Australian Bureau of Statistics, 2013).

To facilitate comparability with available data from the 2011–12 NNPAS, *group jackknife* variance estimation was used for all analyses (Bell, 1999). For the 1999–2000 AusDiab and the 1989 RFPS, where jackknife variance estimates were unavailable, they were created using cluster level information. For the RFPS we used postcode information to form pseudo-clusters, and these were used to create jackknife replicate.

We present key results in figures and tables, and include all results in appendices.

### 2.6. Quantifying changes in WC and changes in weight

Separate linear regressions, adjusting for age (continuous) were used to quantify average increases in WC and increases in weight over the 23-year period of 1989 to 2011–12. These analyses were also performed for the periods of 1989 to 1999–2000, and 1999–2000 to 2011–12 to describe average annual increases over these periods. For reference, we calculated mean height, weight, WC and BMI for all time points.

### 2.7. Quantifying changes in WC independent of changes in weight

To quantify average increases in WC independent of weight over the 23-year period of 1989 to 2011–12 we used a linear regression with WC as the dependent variable and time (years between the cross-sectional surveys) as the independent variable, adjusting for weight (continuous) and age (continuous). Information for all variables taken from both time points. Here the coefficient for survey year indicates the mean change in WC over time independent of changes in weight (Walls et al., 2011b). This analysis was additionally performed over the period of 1989 to 1999–2000, and 1999–2000 to 2011–12 to describe average annual increases over these periods. We conducted sensitivity analyses including height as a co-factor to analyse whether changes in WC independent of weight were attributable to changes in height.

We calculated the proportion of total change in WC which was independent of changes in weight by dividing the estimated change in WC independent of weight by the estimated change in WC.

We fitted a multiplicative interaction term between time and each potential effect modifier (smoking status, BMI category, education group, age group) to discern whether changes in WC independent of weight differed across covariate categories. For reference, we also calculated changes in WC independent of weight stratified by each potential effect modifier. We present all findings in appendices, and include subgroup results in key findings where a significant interaction was detected.

### 2.8. Describing trends in classification of obesity

To describe trends in classification of obesity according to BMI and/or WC, we calculated the proportion of individuals classified as obese using BMI and WC combinations as detailed above, and compared changes across the three surveys. We then examined changes in the prevalence of obesity according to BMI and/or WC between 1989 and 2011–12, and calculated the proportion of all those with obesity according to BMI and/or WC who would be detected as obese by BMI or by WC. The proportion of individuals detected as obese by BMI or by WC was calculated by dividing the proportion with obesity according to BMI (sum of obese by BMI but not WC, and obese BMI and WC) or according to WC (sum of obese by WC but not BMI, and obese BMI and WC) by the proportion with obesity according to BMI and/or WC.

Statistical significance for all analyses was tested at the 5% level while we followed current reporting practise in reporting all results as 95% confidence intervals. All analyses were conducted using Stata 14 software (StataCorp, 2015).

Ethics approval for the current study was obtained through the Monash University Human Research Ethics Committee; CF15/21 – 2015000018, and through Deakin University Human Research Ethics Committee; 2016-0141.

## 3. Results

Characteristics of the survey populations are presented in Table 1. The proportion of women and men were similar between surveys. For both sexes, mean age, and the proportion of never smokers was highest in 1999–2000, and the proportion that completed secondary school was highest in 2011–12.

**Table 1**
Summary statistics of analytic populations.

| | Sex | 1989 | 1999–2000 | 2011–12 |
|---|---|---|---|---|
| Final n[a] | | 8313 | 5903 | 3904 |
| % female (n) | | 51 (4199) | 54 (3176) | 51 (1979) |
| % higher education (n) | Women | 59 (2411) | 55 (1498) | 62 (1196) |
| | Men | 50 (2118) | 51 (1633) | 62 (1230) |
| % never smokers (n) | Women | 38 (1578) | 49 (1332) | 42 (811) |
| | Men | 60 (2503) | 63 (1987) | 54 (1068) |
| Age (mean (SD)) | Women | 45.5 (12.4) | 48.2 (11.4) | 45.3 (12.6) |
| | Men | 45.5 (12.3) | 47.6 (11.1) | 45.8 (12.6) |

[a] Number of individuals in the study population who met the inclusion criteria for analyses.

### 3.1. Mean change in waist circumference and mean change in weight

Over the 23-year period, weight and waist circumference increased by 5.4 kg (95% CI 4.3, 6.6; $R^2 = 0.05$) and 10.7 cm (95% CI 9.8, 11.6; $R^2 = 0.21$) for women, and by 7.0 kg (95% CI 5.9, 8.1; $R^2 = 0.06$) and 7.3 cm (95% CI 6.5, 8.1; $R^2 = 0.17$) for men, independent of age (Appendix Table 1). Between 1989 and 2011–12, both weight and WC increased for all subgroups of age, education and smoking status. Increases in WC were observed across all categories of BMI, however weight increased by < 1 kg for women and men in the normal weight (Fig. 1 and Appendix Table 1).

Annual increases in WC appeared to be similar over the eleven-year period of 1989 to 1999–2000 (0.5 cm for women [95% CI 0.4, 0.7], 0.4 cm for men [95% CI 0.3, 0.5]) and the twelve-year period of 1999–2000 to 2011–12 (0.4 cm for women [95% CI 0.3, 0.6], 0.2 cm for men [95% CI 0.1, 0.4]).

### 3.2. Mean change in waist circumference independent of weight

Between 1989 and 2011–12 for women and men respectively, WC increased by 6.7 cm (95% CI 6.3, 7.2; $R^2 = 0.79$) and 2.8 cm (95% CI 1.2, 4.3; $R^2 = 0.78$) more than would be expected from increases in weight (Table 2). Consequently, 63% and 38% of increases in WC were independent of increases in weight. Sensitivity analyses including height were not substantially different from the primary analysis; for women and men respectively WC increased by 6.6 cm (95% CI 6.2, 7.0; $R^2 = 0.82$) and 2.5 cm (95% CI 0.2, 4.9; $R^2 = 0.83$) independent of increases in weight and height, and 62% and 37% of increases in WC were independent of increases in weight and height. Annual increases in WC independent of weight appeared to be similar between 1989 and 1999-2000 (0.3 cm for women [95% CI 0.2, 0.4], 0.1 cm for men [95% CI 0.0, 0.3]) and 1999–2000–2011-12 (0.3 cm for women [95% CI 0.2, 0.4], 0.1 cm for men [95% CI 0.0, 0.2]).

We identified four significant interactions between effect modifiers and time. For women, smoking status was a significant effect modifier, whereby increases in WC independent of weight were 1.2 cm (95% CI 0.1, 2.4) greater for ever smokers compared to never smokers. For men, BMI category, smoking status and education group were significant effect modifiers, whereby increases in WC independent of weight were 1.1 cm (95% CI 0.2, 2.0) greater for never smokers compared to ever smokers, 1.2 cm (95% CI 0.3, 2.2) greater for men with a higher compared to a lower education, and increases for men in the normal weight category were 1.8 cm (95% CI 0.8, 2.7) and 1.6 cm (95% CI 0.3, 2.9) respectively greater than men in the overweight or obese category.

### 3.3. Classification of obesity according to body mass index and/or waist circumference

Among women (Fig. 2a and Appendix Table 2), the prevalence of obesity categorised by BMI and/or WC increased by 25.3 percentage-points between 1989 and 2011–12. Of the 18.9% of women categorised

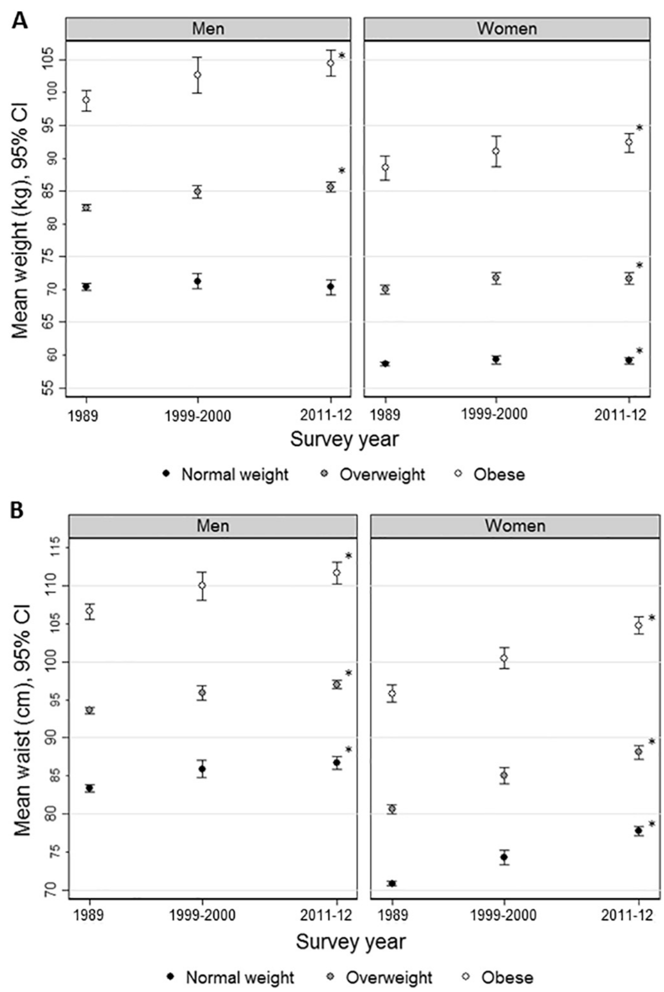


**Fig. 1.** Age-standardised mean weight (A) and waist circumference (B) for Australian women and men according to body mass index category†.
†Estimates were age-standardised to the 2012 mid-year Australian population using the direct method. Body mass index (BMI ($kg{\cdot}m^{-2}$)) was categorised in accordance with international recommendations: normal weight (BMI ≥ 18.5 $kg{\cdot}m^{-2}$ and < 25 $kg{\cdot}m^{-2}$), overweight (BMI ≥ 25 $kg{\cdot}m^{-2}$ and < 30 $kg{\cdot}m^{-2}$), obese (BMI ≥ 30 $kg{\cdot}m^{-2}$).
*Indicates significant increase between 1989 and 2011–12.

as obese according to BMI and/or WC in 1989, 77% were detected by BMI and 87% were detected by WC. Of the 31.0% of women categorised as obese according to BMI and/or WC in 1999–2000, 67% were detected by BMI and 95% were detected by WC. Of the 44.2% of women categorised as obese according to BMI and/or WC in 2011–12, 57% were detected by BMI and 97% were detected by WC.

Among men (Fig. 2b and Appendix Table 2) the prevalence of obesity categorised by BMI and/or WC increased by 21.1 percentage-points between 1989 and 2011–12. Of the 17.1% of men categorised as obese according to BMI and/or WC in 1989, 70% were detected by BMI and 85% were detected by WC. Of the 25.4% of men categorised as obese according to BMI and/or WC in 1999–2000, 68% were detected by BMI and 89% were detected by WC. Of the 38.2% of men categorised as obese according to BMI and/or WC in 2011–12, 71% were detected by BMI and 91% were detected by WC.

For both women and men, while the proportion with obesity according to BMI but not WC changed by approximately one percentage-point across surveys, substantial increases between 1989 and 2011–12 were observed for the proportion with obesity according to BMI and WC (increase of 12.1 percentage-points for women and 14.2 percentage-points for men), and with obesity according to WC but not BMI (increase of 14.5 percentage-points for women and 6.0 percentage-points

**Table 2**
Mean change in waist circumference independent of weight between 1989 and 2011–12.

| Subgroup | Sex | Mean change in WC adjusted for weight[a] | % independent of weight change[b] |
|---|---|---|---|
| | | Beta-coefficient (cm, 95% CI) | |
| | Women | 6.7 (6.3, 7.2) | 63% |
| | Men | 2.8 (1.2, 4.3) | 38% |
| BMI category | | | |
| Normal weight | Men | 3.7 (2.9, 4.4) | 100% |
| Overweight | Men | 2.0 (1.0, 3.1) | 58% |
| Obese | Men | 1.8 (0.2, 3.3) | 37% |
| Smoking status | | | |
| Ever smoker | Women | 7.5 (6.5, 8.4) | 60% |
| | Men | 2.2 (1.5, 2.9) | 33% |
| Never smoker | Women | 6.2 (5.5, 6.9) | 66% |
| | Men | 3.6 (1.0, 6.1) | 43% |
| Education group | | | |
| Lower education | Men | 1.8 (0.4, 3.2) | 26% |
| Higher education | Men | 3.3 (1.8, 4.9) | 44% |

WC, waist circumference.
[a] Adjusted for age and weight. Stratified results have been included only if the multiplicative interaction between the attribute and time was statistically significant.
[b] Calculated by dividing the mean change in WC independent of weight by the mean change in WC.

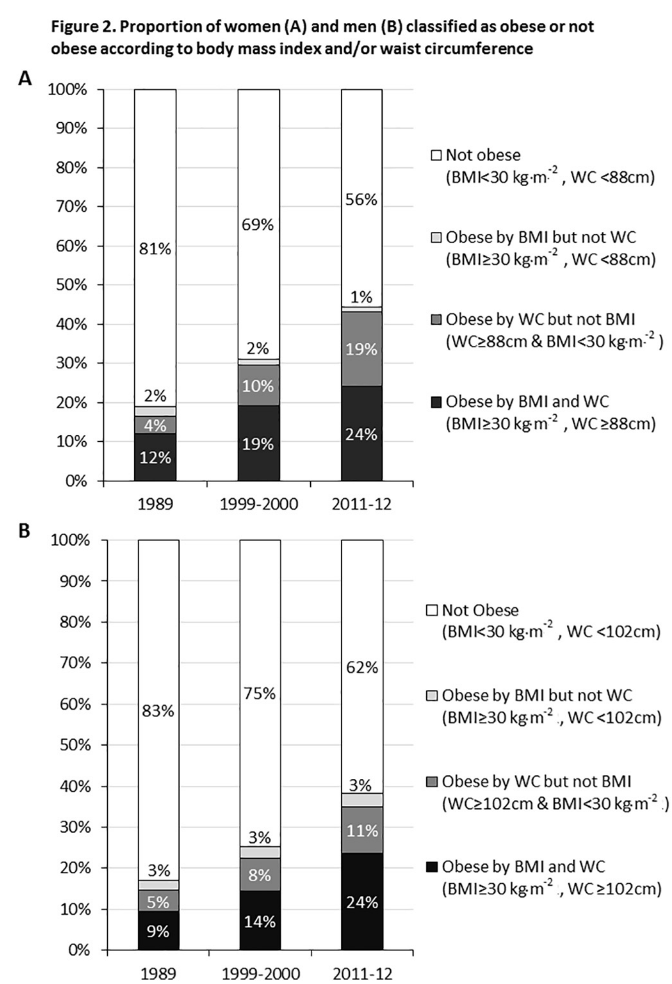


**Fig. 2.** Age-standardised proportion of women (A) and men (B) classified as obese or not obese according to body mass index and/or waist circumference.
BMI, body mass index ($kg{\cdot}m^{-2}$).
WC, waist circumference (cm).

for men) (Fig. 2a and b). This trend was similar across strata of smoking status, education group and age group for women and men (Appendix Table 2). The proportion of women with normal weight, and women and men with overweight who were classified as obese according to WC increased markedly between 1989 and 2011–12 (Appendix Table 2).

## 4. Discussion

Our results demonstrate that between 1989 and 2011–12, WC increased significantly more than would be expected based on increases in weight for urban Australian adults. If changes in weight and WC were in perfect accordance, we would observe a 0 cm change in WC independent of weight over time. In contrast, our results demonstrate that the phenotype of urban Australian adults significantly altered between 1989 and 2011–12, such that on average, compared to women and men in 1989, their counterparts in 2011–12 of the same age and weight had a 6.7 cm and 2.8 cm respectively greater WC. We observed these trends across all sub-categories of BMI, education, smoking status and age. There are important implications of these changes to WC independent of weight for population adiposity monitoring, particularly for women. Our results demonstrate that classifying obesity using BMI alone misses an increasing proportion of individuals categorised as obese according to their WC. Comparatively, when using WC to classify obesity, almost all those categorised as obese according to their BMI are detected.

Analyses stratified by BMI category indicate both how the phenotype of those we would typically consider normal weight and overweight has changed across the three surveys, as well as how the prevalence of obesity according to WC is distributed across the BMI spectrum. We found that the prevalence of obesity according to WC increased markedly between 1989 and 2011–12 for women classified as normal weight and women and men classified as overweight according to BMI. Consequently, by 2011–12, one in ten women with normal weight, one in two women with overweight and one in four men with overweight according to their BMI were obese according to their WC, but would not be detected as obese by population monitoring that relied on BMI alone.

Our findings of a 6.7 cm (0.3 cm per year) and 2.8 cm (0.1 cm per year) change in WC independent of weight between 1989 and 2011–12 for women and men respectively are consistent with previous estimates of changes in WC independent of weight for both higher and lower income countries (Lahti-Koski et al., 2007; Stern et al., 2014; Janssen et al., 2012; Elobeid et al., 2007; Freedman and Ford, 2015; Albrecht et al., 2015; Walls et al., 2011a). Estimates among women range from 0.7 cm per year in a study of Mexican women which modelled changes for a BMI of 35 $kg{\cdot}m^{-2}$ between 1999 and 2012 (Albrecht et al., 2015), to 0.05 cm per year in a study of US women between 1988 and 94 and 2005–06 (Walls et al., 2011a). Among men, estimates range from 0.3 cm per year in a study of Chinese men which modelled changes for a BMI of 25 $kg{\cdot}m^{-2}$ between 1993 and 2013 (Albrecht et al., 2015), to 0.1 cm per year in a study of US men between 1988 and 94 and 2005–06 (Walls et al., 2011a). Non-significant changes in WC independent of weight have also been reported for US women who are Non-Hispanic Black (Albrecht et al., 2015), and for some men studied in the US and UK (Freedman and Ford, 2015; Albrecht et al., 2015). Variation between studies is likely attributable to differences in time period, age-range, race/ethnic population composition and statistical methodology used. While a number of these studies examine changes in WC independent of BMI, rather than body weight, this is unlikely to be a significant source of variation between studies, as changes in BMI among adults predominantly occur due to changes in body weight. An important strength of our study is that as well as additionally examining important population subgroups, we marry findings for changes in WC independent of weight with the prevalence of obesity according to WC and/or BMI, thus allowing for the implications in discordant trends in WC and weight on population monitoring of obesity to be realised.

Our findings regarding the prevalence of obesity are in accordance with previous studies which compare the prevalence of obesity according to WC and according to BMI and find that the prevalence is consistently higher according to WC than BMI (Lahti-Koski et al., 2007; Park et al., 2008; Lean et al., 1995). Further, our findings are in accordance with a previous study which demonstrated that for a cohort of Australian adults, obesity incidence was 32% when defined using WC, compared to 15% when defined using BMI (Tanamas et al., 2014). Our results extend these findings to apply them to changes in the classification of obesity over time. Few studies have compared changes in the capacity of BMI and WC to capture obesity at the population level, and the extent to which they overlap in their categorisation (Tanamas et al., 2016a).

The current analyses cannot detect whether the observed increases in WC independent of weight are attributable to a shift from a gluteofemoral to abdominal distribution of adipose tissue, or whether people now have a relatively greater body volume for the same weight, due perhaps to a decrease in muscle and bone mass. Several factors have been found to potentially differentially influence WC and weight, including short sleep duration (Yi et al., 2013; Keith et al., 2006), sedentary behaviour (Keith et al., 2006), and endocrine disruptors such as smoking (Keith et al., 2006). Thus, the aetiology of this phenomenon should therefore be investigated in future work.

Strengths of this study include our use of age-standardised and survey-weighted representative data for urban Australian adults across a broad age range. Further, our stratification by BMI category, age group, smoking status and education group allows for inferences about subgroups of the population. That our findings were consistent across all subgroups of the population (albeit with varying magnitude between strata) indicates that these findings are less likely to have occurred due to chance. Another strength is our utilisation of both the earliest and most recently available nationally representative data for urban Australian adults which included measured WC, spanning a total of 23 years.

An important limitation of this study is our inability to control for race/ethnicity. Given the known association between race/ethnicity and body composition (Heymsfield et al., 2016), the changing composition of ethnic makeup of the Australian population (Price, 1999) may partially contribute to increases in WC independent of weight. However, as increases in WC independent of weight have been demonstrated across a broad range of populations and race/ethnicities (Albrecht et al., 2015), this is unlikely to account for all of the increase in WC independent of weight seen in the urban Australian adult population. Further, variation in the measurement of WC by the RFPS, AusDiab and NNPAS may partly account for our findings of increases in WC independent of increases in weight. However, comparison of WC measurement methodologies within the same individuals has demonstrated that the average variation is 0.8 cm for men, and 2.2 cm for women (Patry-Parisien et al., 2012). Hence, this variation is unlikely to account for all of the observed increases in WC independent of weight. Another limitation is the variation in survey methodology, sampling and response rates used by the three surveys, as well as the variation in characteristics of these study populations. While this means that some caution should be taken in comparing estimates from these three surveys, our stratified analyses allow for the comparison of similar population subgroups over time. The consistency with which our findings were exhibited across subgroups of the population increases our confidence that variation in survey methodology and population composition has not confounded our results. Finally, while we conduct multiple significance tests, in accordance with Skinner et al. (Skinner et al., 2016), we make no adjustment for this. We instead include a 95% CI for all tests to allow readers to draw their own conclusions as to the strength of this association, and note the marked consistency with which our findings are observed across all population subgroups.

In a context of increasing body weight and WC in Australia, we now demonstrate that between 1989 and 2011–12, WC increased more than would be expected based on increases in weight and there has been an increase in the prevalence of obesity according to WC but not BMI. Individuals identified as obese according to WC but not BMI have been shown to have similar clinical risk to those considered obese by both BMI and WC (Tanamas et al., 2016b). It is imperative that such individuals are detected in national monitoring initiatives, as current initiatives which rely on BMI are underestimating the level of population risk. We would therefore recommend that as well as BMI, an alternative or complementary indicator of obesity needs to be included in national monitoring initiatives and utilised to discern the level of obesity in the population. To inform this, further studies of how obesity according to BMI, WC and other measures correlate with measured body fat and incident disease risk, and how this is changing over time, are needed.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2017.11.030.

## Transparency document

The Transparency document associated with this article can be found, in online version.

## Acknowledgements

We wish to thank the National Heart Foundation's Risk Factor Prevalence Study Committee and the Australian Social Science Data Archive for access to the Risk Factor Prevalence Study, the AusDiab Steering Committee for access to the AusDiab study, and the Australian Bureau of Statistics for access to the National Nutrition and Physical Activity Survey.

## Financial support

This work was supported by an Australian Research Council (ARC) Linkage grant (LP120100418) and in part by the Victorian Government's Operational Infrastructure Support (OIS) Program. EG was supported by an Australian Government Research Training Program Scholarship, SKT was supported by a National Institutes of Health Visiting Fellow Award, CS was supported by an ARC Discovery Project Grant (DP120103277), VL was supported by the NHMRC Centre for Research Excellence in Healthy, Liveable & Equitable Communities (ID 1061404) PhD Scholarship, AP was supported by a National Health and Medical Research Council Career Development Fellowship (1045456) and is a researcher within the NHMRC Centre for Research Excellence in Obesity Policy and Food Systems (APP1041020), the Baker IDI Heart and Diabetes Institute and Deakin University.

All funders had no role in the design, analysis or writing of this article.

## Conflict of interest statement

The authors declare no conflicts of interest.

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