Changing Guards: Time to move beyond Body Mass Index for population monitoring of excess adiposity

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Abstract

With the obesity epidemic, and the effects of aging populations, human phenotypes have changed over two generations, possibly more dramatically than in other species previously. As obesity is an important and growing hazard for population health, we recommend a systematic evaluation of the optimal measure(s) for population-level excess body fat. Ideal measure(s) for monitoring body composition and obesity should be simple, as accurate and sensitive as possible, and provide good categorisation of related health risks. Combinations of anthropometric markers or predictive equations may facilitate better use of anthropometric data than single measures to estimate body composition for populations. Here we provide new evidence that increasing proportions of aging populations are at high health-risk according to waist circumference, but not body mass index (BMI), so continued use of BMI as the principal population-level measure substantially underestimates the health-burden from excess adiposity.

Background to the problem

Obesity has been defined as a disease, with an International Classification of Diseases code, since the 1940s, but its prevalence and the complexity of its health consequences have changed radically since that time. The World Health Organization (WHO) defines obesity in two ways: first, "abnormal or excessive fat accumulation that may impair health", secondly, the most commonly used in epidemiology (assuming Europids), "a body mass index (BMI) greater than or equal to 30 kg/m^2". While weight and height can be measured cheaply and accurately, measuring body fat is more problematic as there is no 'gold-standard' reference method. Imaging, such as Magnetic Resonance Imaging, can measure adipose tissue volume accurately, but adipose tissue comprises only about 80% of total body fat, on average. That proportion varies substantially with obesity, with age and between sexes. Two-component methods, such as underwater weighing or deuterium dilution reliably estimate total body fat, but are too expensive and time-consuming for population-level use. Derivative methods such as Dual-energy X-ray absorptiometry, or bioelectrical impedance analysis (BIA), calibrated against one of the reference methods, are still too cumbersome for large-scale surveys. Anthropometric measures provide simpler, less expensive, assessment of body composition, and they may have similar accuracy to methods such as BIA although direct comparisons have not been published.

Which anthropometric measure(s) best identify high-risk adiposity has been much debated. While height and weight are easily measured, variations in the resulting BMI do not distinguish between differences in fat mass and muscle mass, factors which have opposite impacts on health and well-being, so BMI has poor discriminatory power. BMI explains about 67-75% of variance in Total Body Fat [1] (more so in women than in men) and its sensitivity to identify excess adiposity has been estimated at around 50%.[2] Its applicability in certain sub- populations can be misleading. For example, many athletes have large muscle-masses, resulting in a high BMI, but with low body fat. For the same BMI, Europids generally have less body fat than Asians, but more than Africans or Pacific Islanders. Furthermore, as people age, fat mass tends to increase while muscle mass decreases. Thus BMI may be artificially stable despite an increase in body fat, particularly among the elderly. The prevalence of sarcopenic obesity (co-existing obesity and sarcopenia, with multiple adverse health effects) is estimated to increase 5-fold between ages 60-69 and 80+ years.[3]

This paper does not set out to provide an in-depth review of the methods used to assess body composition, but assesses current and emerging options and also includes some new analyses of international survey data. Based on this new data, it draws attention to the limitations of BMI in the current context, and proposes alternatives.

Moving on

Various alternative or additional measures have been advocated to improve estimates of adiposity and/or to provide better prediction of ill-health and risk of chronic diseases. These include waist circumference (WC), waist-hip ratio (WHR), waist-height ratio, neck circumference, conicity index, and body adiposity index. Most of these involve computation of convenience-ratios, which do not correspond to biological interpretation. They are also hard to visualise, a particular obstacle to public understanding in applications for health promotion. Where the range of body fat is very large (as in most population surveys), WC correlates surprisingly strongly with total body fat, explaining 70.4-77.8% of variance, so it is a little better than BMI, at least in men.[1] It is also a slightly better predictor of metabolic risk and chronic diseases than BMI, partly by better identifying individuals at increased health risk through greater total body fat, and partly by also including those with central adiposity who are not identified by BMI.[4] WC alone has often proved a better correlate of the metabolically-hazardous abdominal visceral fat mass than WHR.[5]

Although WHO published a standard method using bony landmarks to measure WC in 1998,[6] its value has been devalued by wide use of less reliable methods. A systematic review of 120 studies identified 8 different protocols for measuring WC, only three using a site defined by fixed skeletal landmarks: (i) immediately above the iliac crest; (ii) immediately below the lowest rib; and (iii) midway between the lowest rib and the iliac crest.[7] These provide almost identical measures, and there is sufficient evidence that, with the appropriate training, WC can be measured reliably.[8, 9] Despite its limitations, WC still predicts health outcomes at least as well as BMI.[10, 11]

WC was primarily presented as an indicator for health promotion, with 'Action Levels' defined from regression curves against BMI and WHR among Europid adults.[4] These cut-points (Supplementary material, Table 1) have now been extensively validated by epidemiological research and were adopted by WHO and International Diabetes Federation in their recommendations for high-risk adiposity and associated health risks for Europid adults. Associations between risk factors and diseases are continuous, without discrete thresholds separating disease and no-disease, but cut-points are valuable for population health monitoring, to classify and quantify likely disease burdens, and to target health promotion. Although a large body of literature agrees that WC (and indices which include WC) predict metabolic outcomes a little more strongly than BMI, and most surveys now include WC, BMI has remained the primary measure for policy. Measurements of height, weight, and derived BMI in clinical practice had the highest inter-observer reliability (r>0.99) compared to other anthropometric measures for adiposity, though improvements have been observed for the other measures after training sessions.[9]

Changing needs in changing landscapes

As populations grow more obese and live longer, shapes have changed radically and improved population-level surveillance is critical to inform and adjust policies and priorities, to monitor secular changes with age and over time, and to assess the impact of interventions. In defining classification cut-offs, the ability to identify individuals at high risk (sensitivity) is important, without misclassifying too many at lower risk (specificity). However, using single outcomes (e.g. cardiovascular risk) to define specificity cut-offs, or in receiver operating characteristic (ROC) analysis, can be misleading. The commonest outcomes related to body composition considered in population surveys are type 2 diabetes, hypertension, heart disease and cancers. It has become customary to use area under the ROC curve statistics to balance specificity and sensitivity of cut-points, but it is most important to recognise that for adiposity, sensitivity and specificity are not equally important, because the intervention (weight management and prioritisation of prevention) has multiple benefits and minimal detriments.

As outlined above, there are clearly many reasons to challenge the WHO statement that “BMI provides the most useful population-level measure of overweight and obesity”. New analyses of international data mean that it is now time to move beyond BMI. These data suggest that, by using BMI alone, large and increasing segments of the burden of preventable ill-health related to adverse adiposity go unrecognised (Figure 1, grey shading**).**[12, 13] According to an Australian study in 2000, approximately 40% of the adults with a high-risk WC would not have been identified as high-risk because they had a non-obese BMI.[12] Similarly, the

Scottish Health Surveys and Health Surveys for England 2008-2010, found that 39% of adults with a high-risk WC were non-obese by BMI.[13] In both cases, approximately 18% of individuals in the general population who are at increased health risk through excess adiposity would not be identifiable using BMI. In American adults (NHANES 1999–2000), a high-risk WC was present in 8% of participants with a normal BMI, 43% of those with BMI 25-30 kg/m^2, and 96% of participants with BMI >30 kg/m^2.[14] This serious discordance between WC and BMI has grown more marked over recent years. WC has increased at a greater rate than BMI in those populations where it has been measured, and in some populations has continued to increase despite an apparent plateau in BMI (Supplementary material, Table 2).[15-19] Older people may even lose weight while continuing to increase WC.[20]

Actions and Solutions

All the data discussed above indicate that as modern populations live to greater ages, preventable ill-health associated with excess adiposity will continue to increase, but BMI alone will not serve health planners well (Figure 2). Public health researchers and politicians cannot be complacent about the obesity epidemic if rising BMI appears to level off.

The question we must ask is: who and what are we missing under current monitoring approaches? BMI (alone) is not an ideal indicator for the health burden associated with adverse body compositions given that the determinants of preventable health risks are in fact body fatness and muscle mass, operating on BMI in opposite directions and varying independently.[21] BMI and WC coupled together may predict health outcomes better, as is beginning to be recognized by clinical guidelines. Large numbers with low-to-moderate BMI despite a large WC will be misclassified into the normal-adiposity group. In an analysis of over 200,000 people in 17 countries, a higher WC was associated with a greater risk of cardiovascular disease even in those low (<24.5 kg/m^2) and middle third (24.5-<28.0 kg/m^2) of the BMI distribution. [22] There is some suggestion of a similar relationship with mortality in men.[23] Using prediction equations or categorical combinations of anthropometric markers would additionally reduce problems related to measurement errors. A recent systematic review found that combining crude indicators of body fat and gluteal muscle, waist and hip circumferences (but not as a fixed ratio) improved risk prediction models for cardiovascular disease and other outcomes.[24] Importantly, the authors acknowledged that their findings did not dispute the contribution of adiposity to cardiovascular risk, since excess adiposity influences blood pressure, diabetes and lipids, and that in settings where information of lipids is not available, substitution with anthropometric indicators for adiposity results in only modest lost of predictive ability.

It is now also possible to use published, and externally validated, equations based on standard measurements made in populations surveys (age, sex, height, weight, waist, hips) to capture variations in fat and muscle masses separately.[25] As with BMI or WC alone, individual categorisation should be avoided, but trends within populations, over time and with age, in body fat and skeletal muscle masses can provide much more specific information, potentially guiding future health promotion better than has been possible hitherto.

In conclusion, population health surveillance still focuses heavily on BMI alone, consequently missing almost a half of the population who are at increased health risk through excess adiposity. It is time to improve guidelines for population monitoring approaches by using other (combinations of) measures for body composition and to estimate both excess adiposity and low skeletal muscle mass, whose combined influences are lost with BMI. The optimal measure(s) should take into consideration measurement feasibility and accuracy, as well as strength, sensitivity and positive and negative predictive values for key health outcomes. Improved identification at a population level of those at increased health risk would lead to better prioritisation of policy and resources.

AUTHORS CONTRIBUTIONS

MEJL and PZZ have been involved since the beginning of the development of policy regarding the optimal measures of adiposity for different sexes, ages and ethnic groups. AP, MEJL and PZZ are international leaders in the fields of obesity and diabetes monitoring, prevention and management. SKT is an early career researcher who is building a strong track in obesity epidemiology and performed the analyses for Figure 1 (Australian data). EC and AV were involved in the development of the prediction equation for fat mass and skeletal muscle mass, and performed the analyses for Figures 1 and 2 (UK data). All authors contribution to the article’s discussion.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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FIGURES

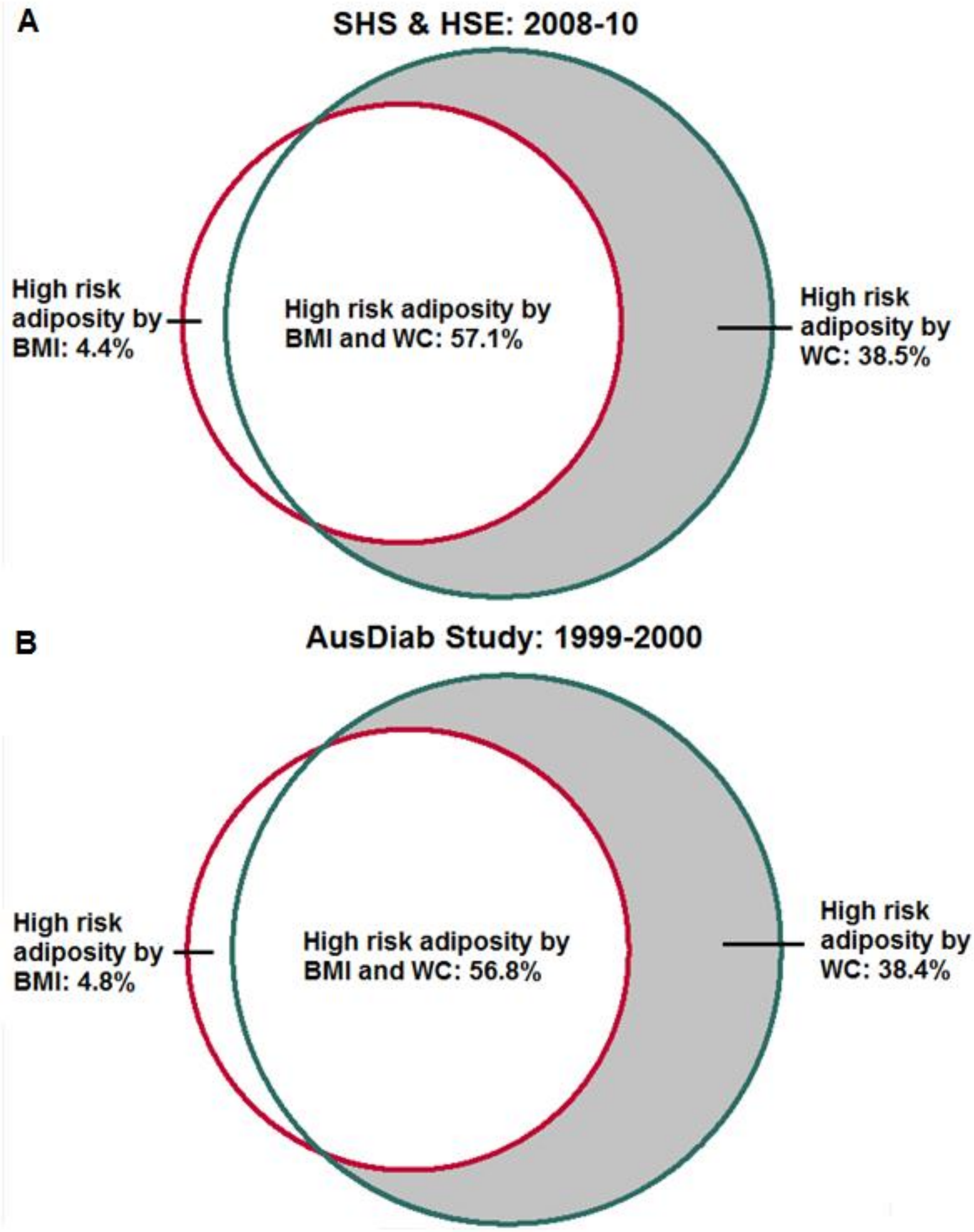

Figure 1. Identification of different individuals with high risk adiposity using body mass index (≥30 kg/m^2) or waist circumference (≥102 cm for men, ≥88 cm for women) in: (A) the combined Scottish Health Survey (SHS)/Health Survey for England (HSE) data from the UK; and (B) the Australian AusDiab study.[15, 16]

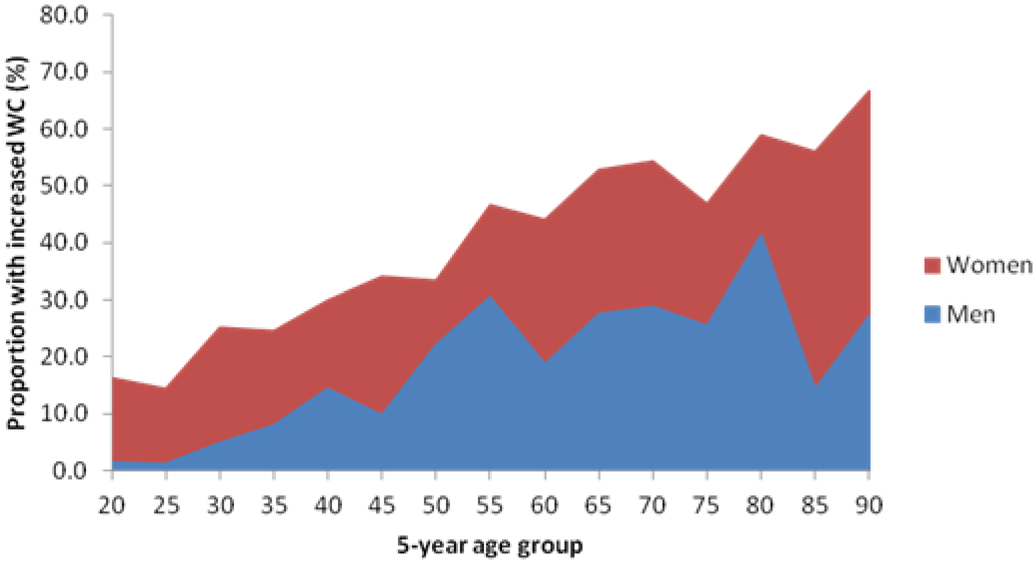

Figure 2. Prevalence by age of elevated WC (>80 cm for women, >94 cm for men) among individuals with BMI within the range 18.5–25 kg/m^2 in 2008-10 (data for Scotland and England combined)[29]

Supplementary material

Table 1. Waist Circumference Cut-offs for Health Promotion and Risk Classification (6, 9)

Classification	Risk of co-morbidities[a] Caucasian			Risk of co-morbidities Asian		
	BMI (kg/m^2)	Waist circumference (cm)		BMI (kg/m^2)	Waist circumference (cm)	
		Men 94-102 Women 80-88[b]	Men >102 Women >88[c]		Men < 90 Women < 80	Men ≥ 90 Women ≥ 80
Normal weight	18.5 – 24.9	–	– [d]	18.5 – 22.9	Average	Increased
Overweight	25.0 – 29.9	Increased	High	23.0 – 24.9	Increased	Moderate
Obese						
Class I	30.0 – 34.9	High	Very high	25.0 – 29.9	Moderate	Severe
Class II	35.0 – 39.9	Very high	Very high	≥ 30.0	Severe	Very severe
Class III	≥ 40.0	Extremely high	Extremely high			

[a] Disease risk for type 2 diabetes, hypertension, and cardiovascular disease
[b] Action level 1: for individuals to take personal steps to control weight/waist gain
[c] Action level 2: professional input is required to achieve sustained weight/waist loss
[d] Increased waist circumference can also be a marker for increased risk even in persons of normal weight

Table 2. Studies Examining Changes in BMI and Waist Circumference

Country	Year	Findings
United States [22]	1988 – 1994 to 2005 – 2006	Waist circumference has increased more than BMI (on average by 0.86 cm)
Scotland [20]	1998 – 2008	Proportionally greater increases in WC than in BMI.
Finland [19]	1987 – 2002	Increases in BMI had slowed in men and remained stable in women. Increases in abdominal obesity had continued in both sexes.
Hong Kong [18]	1996 – 2005	In men, the prevalence of general obesity (BMI ≥25 kg/m^2) remained stable but the prevalence of central obesity (waist circumference ≥90 cm) increased between 1996 and 2005. In the women, the prevalence of general obesity declined while the prevalence of central obesity (waist circumference ≥80 cm) remained stable.
Australia [21]	2000 – 2005 (period 1) and 2005 – 2012 (period 2)	The annualized weight gain in period 2 was 0.11kg/year less than in period 1, while the annualized waist circumference increase in period 2 was 0.07cm/year greater than in period 1.