OXFORD

REVIEW

Changing guards: time to move beyond body mass index for population monitoring of excess adiposity

S. K. Tanamas[1], M. E. J. Lean[2], E. Combet[2], A. Vlassopoulos[2], P. Z. Zimmet[1] and A. Peeters[1]

From the [1]Baker IDI Heart and Diabetes Institute, the Alfred Centre, Level 4, 99 Commercial Road, Melbourne, Victoria 3004, Australia and [2]Human Nutrition, School of Medicine, College of Medical Veterinary and Life Sciences, University of Glasgow, Royal Infirmary Campus, Alexandra Parade, Glasgow G31 2ER, UK

Address correspondence to S.K Tanamas, Baker IDI Heart and Diabetes Institute, 99 Commercial Rd, Melbourne Victoria 3004, Australia.
email: Stephanie.Tanamas@bakeridi.edu.au

Summary

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 categorization 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', second, the most commonly used in epidemiology (assuming Europids), 'a body mass index (BMI) greater than or equal to $30\,\mathrm{kg/m^2}$'. 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 in Europeans explains about 78–92% of variance in total body fat[1,2] (more so in women than in men) and its sensitivity to identify excess adiposity has been estimated at around 50%.[3] Its applicability in certain subpopulations 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.[4]

This article 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 visualize, 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 explains 60–87% of variance in total body fat.[1,2,5] 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.[6] A central accumulation of adiposity has been associated with glucose intolerance and hyperinsulinaemia, and subsequently an increased risk of type 2 diabetes. Metabolic differences between subjects with upper- and lower-body obesity were shown to be independent of differences in percentage of overall adiposity.[7] WC alone has often proved a better correlate of the metabolically hazardous abdominal visceral fat mass than BMI[1,2] and WHR,[8] and the addition of WC to BMI increases the variance of total and visceral fat mass explained by BMI by 2–4 and 11–16%, respectively.[1]

Although WHO published a standard method using bony landmarks to measure WC in 1998,[9] its significance 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.[10] These provide almost identical measures, and there is sufficient evidence that, with the appropriate training, WC can be measured reliably.[11,12] Despite its limitations, WC still predicts health outcomes at least as well as BMI.[13,14]

WC was primarily presented as an indicator for health promotion, with 'Action Levels' defined from regression curves against BMI and WHR among Europid adults.[6] These cut-points (Supplementary Table S1) 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, there are contrasting studies and the magnitude of difference has not been seen as large enough to warrant a change from a focus on BMI to WC. One of the main aims of this article is to draw other information into the mix, including proportion of the population captured by BMI-defined vs. WC-defined obesity as well as improvement in risk prediction, all of which starts to add up to a more convincing reason to consider WC going forward

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 recognize that for adiposity, sensitivity and specificity are not equally important, because the intervention (weight management and prioritization 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 unrecognized (Figure 1, grey shading).[15,16] 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.[15] 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.[16] In both cases, ~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/m², and 96% of participants with BMI >30 kg/m².[17] 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
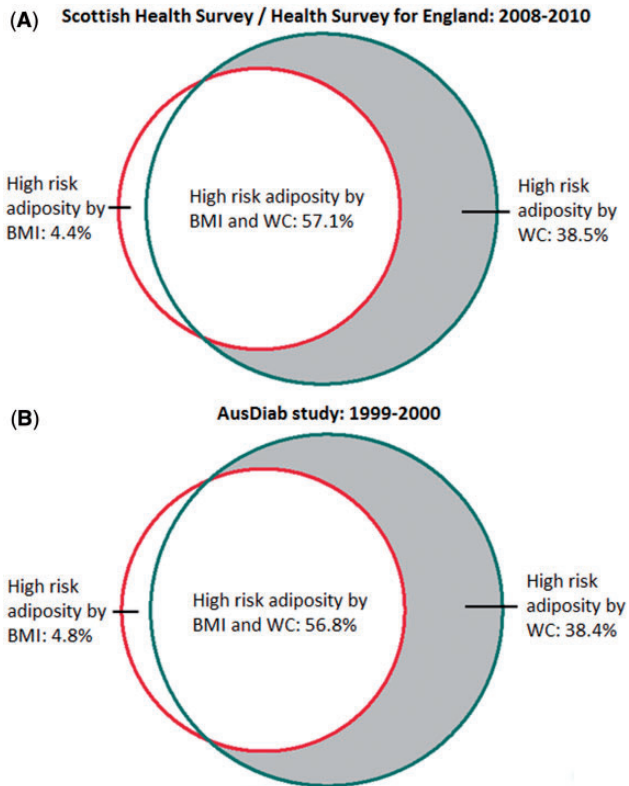
Figure 1. Identification of different individuals with high risk adiposity using body mass index (≥30 kg/m²) or waist circumference (≥102 cm for men, ≥88 cm for women) in: **(A)** the combined Scottish Health Survey/Health Survey for England data from the United Kingdom; and **(B)** the Australian AusDiab 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/m² in 2008–2010 (data for Scotland and England combined).[24]

(Supplementary Table S2).[18–22] This is particularly important in our aging population as the discordance between BMI and WC increases with age, with older people continuing to gain WC despite losing weight.[23] In light of this, we need to systematically examine the comparative risk prediction for health outcomes between BMI and WC at older ages.

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.[25] 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/m²) and middle third (24.5–<28.0 kg/m²) of the BMI distribution.[26] There is some suggestion of a similar relationship with mortality in men.[27] Using prediction equations or
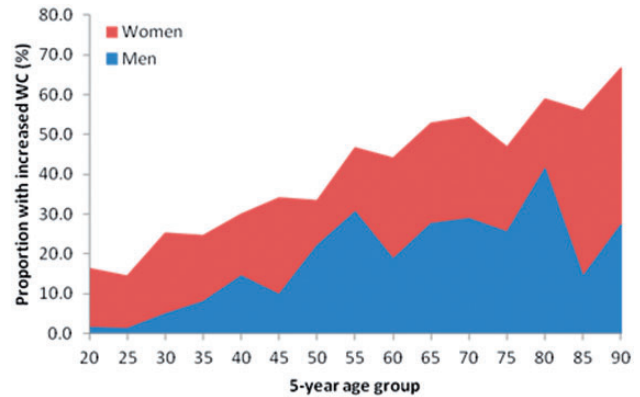
categorical combinations of anthropometric markers would additionally reduce problems related to measurement errors. A recent systematic review found that combining crude indicators of body fat and gluteal muscle, waist and hip circumferences (but not as a fixed ratio) improved risk prediction models for cardiovascular disease and other outcomes.[28] 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 loss 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 and hips) to capture variations in fat and muscle masses separately.[29] As with BMI or WC alone, individual categorization 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 prioritization of policy and resources.

Supplementary material

Supplementary material is available at *QJMED* online.

Funding

Conflict of interest: None declared.

References

1. Janssen I, Heymsfield SB, Allison DB, Kotler DP, Ross R. Body mass index and waist circumference independently contribute to the prediction of nonabdominal, abdominal subcutaneous, and visceral fat. *Am J Clin Nutr* 2002; **75**:683–8.

2. Lear SA, Humphries KH, Kohli S, Birmingham CL. The use of BMI and waist circumference as surrogates of body fat differs by ethnicity. *Obesity (Silver Spring)* 2007; **15**:2817–24.

3. Okorodudu DO, Jumean MF, Montori VM, *et al*. Diagnostic performance of body mass index to identify obesity as defined by body adiposity: a systematic review and meta-analysis. *Int J Obes (Lond)* 2010; **34**:791–9.

4. Baumgartner RN. Body composition in healthy aging. *Ann NY Acad Sci* 2000; **904**:437–48.

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

6. Lean ME, Han TS, Morrison CE. Waist circumference as a measure for indicating need for weight management. *BMJ* 1995; **311**:158–61.

7. Kissebah AH, Vydelingum N, Murray R, *et al*. Relation of body fat distribution to metabolic complications of obesity. *J Clin Endocrinol Metab* 1982; **54**:254–60.

8. Seidell JC, Oosterlee A, Deurenberg P, Hautvast JG, Ruijs JH. Abdominal fat depots measured with computed tomography: effects of degree of obesity, sex, and age. *Eur J Clin Nutr* 1988; **42**:805–15.

9. World Health Organization. *Obesity. Preventing and Managing the Global Epidemic*. Geneva, Switzerland: World Health Organization 1998.

10. Ross R, Berentzen T, Bradshaw AJ, *et al*. Does the relationship between waist circumference, morbidity and mortality depend on measurement protocol for waist circumference? *Obes Rev* 2008; **9**:312–25.

11. Klein S, Allison DB, Heymsfield SB, *et al*. Waist circumference and cardiometabolic risk: a consensus statement from shaping America's health: Association for Weight Management and Obesity Prevention; NAASO, the Obesity Society; the American Society for Nutrition; and the American Diabetes Association. *Diabetes Care* 2007; **30**:1647–52.

12. Sebo P, Beer-Borst S, Haller DM, Bovier PA. Reliability of doctors' anthropometric measurements to detect obesity. *Prev Med* 2008; **47**:389–93.

13. Huxley R, Mendis S, Zheleznyakov E, Reddy S, Chan J. Body mass index, waist circumference and waist:hip ratio as predictors of cardiovascular risk–a review of the literature. *Eur J Clin Nutr* 2010; **64**:16–22.

14. Vazquez G, Duval S, Jacobs DR Jr., Silventoinen K. Comparison of body mass index, waist circumference, and waist/hip ratio in predicting incident diabetes: a meta-analysis. *Epidemiol Rev* 2007; **29**:115–28.

15. Tanamas SK, Shaw JE, Backholer K, Magliano DJ, Peeters A. 12-year weight change, waist circumference change and incident obesity: the Australian Diabetes, Obesity and Lifestyle study. *Obesity* 2014; **22**:1538–45.

16. Vlassopoulos A, Combet E, Lean ME. Changing distributions of body size and adiposity with age. *Int J Obes (Lond)* 2013; **38**:857–64.

17. Ford ES, Mokdad AH, Giles WH. Trends in waist circumference among U.S. adults. *Obes Res* 2003; **11**:1223–31.

18. Ko GT, Tang JS, Chan JC. Worsening trend of central obesity despite stable or declining body mass index in Hong Kong Chinese between 1996 and 2005. *Eur J Clin Nutr* 2010; **64**:549–52.

19. Lahti-Koski M, Harald K, Mannisto S, Laatikainen T, Jousilahti P. Fifteen-year changes in body mass index and waist circumference in Finnish adults. *Eur J Cardiovasc Prev Rehabil* 2007; **14**:398–404.

20. Lean ME, Katsarou C, McLoone P, Morrison DS. 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 (Lond)* 2013; **37**:800–8.

21. Peeters A, Magliano DJ, Backholer K, Zimmet P, Shaw JE. Changes in the rates of weight and waist circumference gain in Australian adults over time: a longitudinal cohort study. *BMJ Open* 2014; **4**:e003667

22. Walls HL, Stevenson CE, Mannan HR, Abdullah A, Reid CM, McNeil JJ, *et al*. Comparing trends in BMI and waist circumference. *Obesity (Silver Spring)* 2011; **19**:216–9.

23. Tanamas SK, Shaw JE, Backholer K, Magliano DJ, Peeters A. Twelve-year weight change, waist circumference change and incident obesity: the Australian diabetes, obesity and lifestyle study. *Obesity (Silver Spring)* 2014; **22**:1538–45.

24. Vlassopoulos A, Combet E, Lean M. Changing distributiions of body size and adiposity with age. *Obes Rev* 2014; **15**:167–8.

25. Chung JY, Kang HT, Lee DC, Lee HR, Lee YJ. Body composition and its association with cardiometabolic risk factors in the elderly: a focus on sarcopenic obesity. *Arch Gerontol Geriatr* 2013; **56**:270–8.

26. Wormser D, Kaptoge S, Di Angelantonio E, *et al*. Separate and combined associations of body-mass index and abdominal adiposity with cardiovascular disease: collaborative analysis of 58 prospective studies. *Lancet* 2011; **377**:1085–95.

27. Pischon T, Boeing H, Hoffmann K, *et al*. General and abdominal adiposity and risk of death in Europe. *N Engl J Med* 2008; **359**:2105–20.

28. Cameron AJ, Magliano DJ, Soderberg S. A systematic review of the impact of including both waist and hip circumference in risk models for cardiovascular diseases, diabetes and mortality. *Obes Rev* 2013; **14**:86–94.

29. Al-Gindan YY, Hankey C, Govan L, Gallagher D, Heymsfield SB, Lean MEJ. Derivation and validation of simple equations to predict total muscle mass from simple anthropometric and demographic data. *Am J Clin Nutr* 2014; **100**(4):1041–51.