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REVIEW

Body mass index, waist circumference and waist:hip ratio as predictors of cardiovascular risk—a review of the literature

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Overweight and obesity have become a major public health problem in both developing and developed countries as they are causally related to a wide spectrum of chronic diseases including type II diabetes, cardiovascular diseases and cancer. However, uncertainty regarding the most appropriate means by which to define excess body weight remains. Traditionally, body mass index (BMI) has been the most widely used method by which to determine the prevalence of overweight in, and across, populations as well as an individual's level of risk. However, in recent years, measures of central obesity, principally waist circumference and the waist:hip ratio and to a lesser extent the waist:height ratio, which more accurately describe the distribution of body fat compared with BMI, have been suggested to be more closely associated with subsequent morbidity and mortality. There is also uncertainty about how these measures perform across diverse ethnic groups; earlier, most of the evidence regarding the relationships between excess weight and risk has been derived chiefly from Caucasian populations, and hence, it remains unclear whether the relationships are consistent in non-Caucasian populations. The purpose of this review, therefore, is to provide an overview of the current evidence-base focusing predominantly on three main questions: (1) Which, if any, of the commonly used anthropometric measures to define excess weight is more strongly associated with cardiovascular risk? (2) Which of the anthropometric measures is a better discriminator of risk? and (3) Are there any notable differences in the strength and nature of these associations across diverse ethnic groups?
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Introduction

It is widely accepted that being overweight, traditionally defined as having a body mass index (BMI; obtained by dividing the individual's weight in kilograms by height in metres squared) $>25\,kg/m^2$, is a major risk factor for a wide range of chronic diseases and injuries including cardiovascular disease (CVD), type II diabetes, and certain site-specific cancers including colorectal and breast cancer (Connolly *et al*., 2002; Chouraki *et al* 2008). A recent report from the Prospective Studies Collaboration, which was based on >66 000 deaths, estimated that optimal survival is achieved at a BMI of 22.5–25 kg/m^2 with reductions in life expectancy of 3 and 10 years in individuals with moderate (BMI 30–35 kg/m^2) and extreme obesity (BMI 40–50 kg/m^2), respectively, the latter being equivalent to the years lost by lifetime smoking (Prospective Studies Collaboration, 2009).

Although BMI has traditionally been the chosen method by which to measure body size in epidemiological studies, alternative measures, such as waist circumference (WC) (Wei *et al*., 1997; Welborn and Dhaliwal, 2007), waist:hip ratio (WHR) (Jansses *et al*., 2004; Bigaard *et al*., 2005) and the waist:height ratio (WHtR) (Ho *et al*., 2003; Ashwell and Hsieh, 2005), which reflect central adiposity, have been suggested to be superior to BMI in predicting CVD risk. In part, this stems from the observation that ectopic body fat (i.e. which is stored in the abdomen) is related to a range of metabolic abnormalities, including decreased

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glucose tolerance, reduced insulin sensitivity and adverse lipid profiles, that are in turn risk factors for type II diabetes and CVD. Central adiposity has been highlighted as a growing problem, particularly among Asian populations where individuals may exhibit a 'normal' BMI but have a disproportionately large WC. Currently, the WHO recognizes that WC between 94.0–101.9 cm in men and 80.0–87.9 cm in women, and WHR >0.8 and 0.9 in women and men, respectively, correspond with the BMI overweight range of 25–29.9 kg/m^2 (WHO, 2000a,b). But, as these estimates are derived from predominantly Caucasian populations, it has raised issues about the applicability of these cut-point values in non-Caucasian populations (WHO, 2000b). There is no consensus over which of these measures is the most strongly associated with CVD risk, either within or between different ethnic groups. Providing answers to these fundamental questions is a key requirement for the effective management of weight and for defining prevention strategies for the weight-related morbidity within and between populations.

Hence, the purpose of this report was to provide an overview of the current literature focusing on three main questions: (1) Which, if any, of the commonly used anthropometric measures to define excess weight is more strongly associated with CVD risk? (2) Which of the anthropometric measures is a better discriminator of CVD risk? (3) Are there any notable differences in the strength and nature of these associations across diverse ethnic groups?

Association between measures of global and central obesity with hypertension, diabetes and dyslipidaemia

Over the past two decades, several hundred papers have been published that have reported on some aspect of the association between different measures of current body size and one or other cardiovascular risk factors. Several authors have attempted to systematically evaluate the strength and nature of these associations and it is these overviews that form the basis of this current review. Vazquez and colleagues conducted a meta-analysis of cohort studies that examined the association between different anthropometric measures of obesity and risk of incident type II diabetes (Vazquez *et al*., 2007). In all 32 of the included studies, the progression from a non-diabetic state (i.e. normal glucose tolerance or impaired glucose tolerance) to overt type II diabetes was explored. The pooled relative risk estimates (95% confidence interval) for incident diabetes associated with a one standard deviation increment in BMI, WC and WHR were 1.87 (95% CI: 1.67–2.10), 1.87 (95% CI: 1.58–2.20) and 1.88 (95% CI: 1.61–2.19), respectively, showing that these indicators have similar associations with incident diabetes (Table 1). Modest regional differences were reported for WHR (but not with BMI or WC) such that the effect was stronger in Caucasian compared with Asian populations: Europe (1.9, 95% CI: 1.7–2.2) and United States (1.7, 95% CI: 1.4–2.2) versus Asia (1.4, 95% CI: 1.1–1.7).

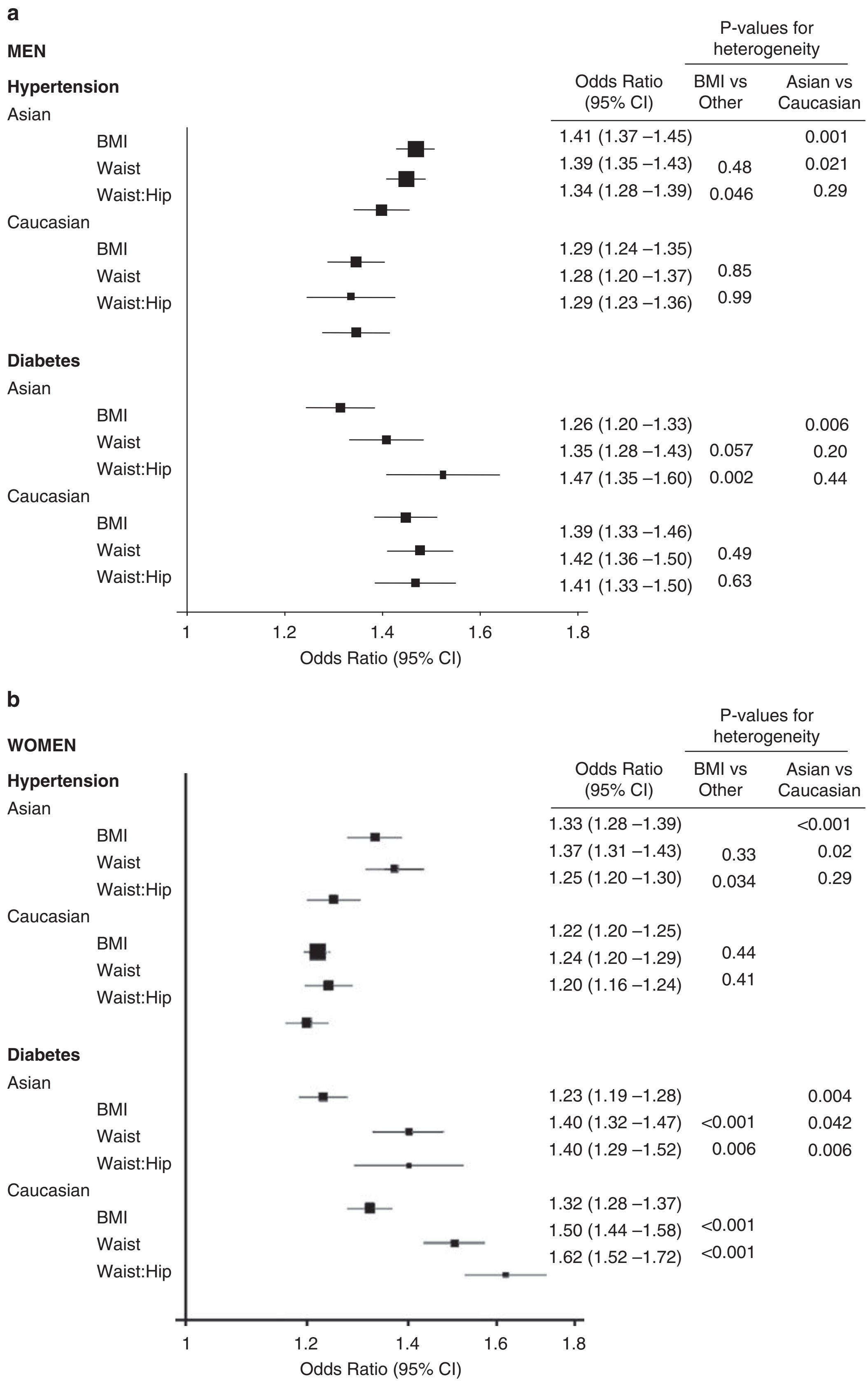
These data are slightly at odds with findings from the Obesity in Asia Collaboration (OAC), an individual participant data meta-analysis involving >263 000 individuals (73% Asian) from 21 cross-sectional studies in the Asia-Pacific region (Huxley *et al*., 2008). Findings from this study indicated that with the exception of Caucasian men, measures of central obesity were actually more strongly associated with prevalent diabetes than BMI (Huxley *et al*., 2008). For example, a 0.5 standard deviation increment in BMI was associated with a 20–30% prevalent odds ratio of diabetes, whereas for WC and WHR the same standard increment was associated with about 40% risk of diabetes (Figures 1a and b). The same, however, was not true for hypertension; for a standard increment, the odds of hypertension were comparable across the three anthropometric measures for both men and women, although of note was the stronger association in Caucasians compared with non-Caucasian populations. For example, a 0.5 s.d. increment in each of the three measures of current body size was associated with a 40% risk of prevalent hypertension in Caucasian men compared with only a 30% risk in non-Caucasian men (Figures 1a and b).

In a comparable meta-analysis from the Diabetes Epidemiology: Collaborative Analysis of Diagnostic Criteria in Asia Study (DECODA, 2008), which involved the collation of data from 16 cross-sectional studies, an examination of the strength of association between BMI, WC, WHR and WHtR with type II diabetes suggested little difference between the first of the three measures but a slightly stronger association with WHtR in both men and women:

Table 1 Pooled relative risk for BMI, WC and WHR with incident diabetes stratified by age, gender and geographical region

Measurement	*No. of studies*	*Pooled relative risk*							
		Overall	*Age group*		*Gender*		*Region*		
Total	*32*	*Overall*	*<50 years*	*⩾50 years*	*F*	*M*	*Asia*	*US*	*Europe*
Body mass index	32	1.87	1.7	2.0	2.4	2.0	2.4	1.7	2.0
Waist circumference	18	1.87	1.6	2.0	2.3	2.9	2.4	1.9	2.1
Waist : hip ratio	25	1.88	2.1	1.7	3.0	2.7	1.4	1.7	1.9

Abbreviations: F, female; M, male.
Adapted from Vazquez *et al*., (2007).


a
MEN
P-values for heterogeneity
Odds Ratio (95% CI)
BMI vs Other
Asian vs Caucasian
Hypertension
Asian
BMI
Waist
Waist:Hip
1.41 (1.37 –1.45)
0.001
1.39 (1.35 –1.43)
0.48
0.021
1.34 (1.28 –1.39)
0.046
0.29
Caucasian
BMI
Waist
Waist:Hip
1.29 (1.24 –1.35)
1.28 (1.20 –1.37)
0.85
1.29 (1.23 –1.36)
0.99
Diabetes
Asian
BMI
Waist
Waist:Hip
1.26 (1.20 –1.33)
0.006
1.35 (1.28 –1.43)
0.057
0.20
1.47 (1.35 –1.60)
0.002
0.44
Caucasian
BMI
Waist
Waist:Hip
1.39 (1.33 –1.46)
1.42 (1.36 –1.50)
0.49
1.41 (1.33 –1.50)
0.63
1
1.2
1.4
1.6
1.8
Odds Ratio (95% CI)
b
WOMEN
P-values for heterogeneity
Odds Ratio (95% CI)
BMI vs Other
Asian vs Caucasian
Hypertension
Asian
BMI
Waist
Waist:Hip
1.33 (1.28 –1.39)
<0.001
1.37 (1.31 –1.43)
0.33
0.02
1.25 (1.20 –1.30)
0.034
0.29
Caucasian
BMI
Waist
Waist:Hip
1.22 (1.20 –1.25)
1.24 (1.20 –1.29)
0.44
1.20 (1.16 –1.24)
0.41
Diabetes
Asian
BMI
Waist
Waist:Hip
1.23 (1.19 –1.28)
0.004
1.40 (1.32 –1.47)
<0.001
0.042
1.40 (1.29 –1.52)
0.006
0.006
Caucasian
BMI
Waist
Waist:Hip
1.32 (1.28 –1.37)
1.50 (1.44 –1.58)
<0.001
1.62 (1.52 –1.72)
<0.001
1
1.2
1.4
1.6
1.8
Odds Ratio (95% CI)

age-adjusted odds ratios for diabetes in men (women) for one standard deviation increment were 1.52 (1.59), 1.54 (1.70), 1.53 (1.50) and 1.62 (1.7), respectively. For hypertension, the findings from DECODA were comparable with those from the OAC such that there was little evidence that measures of central obesity were more strongly associated with hypertension: the prevalent odds ratios for hypertension were 1.68 (1.55), 1.66 (1.51), 1.45 (1.28) and 1.63 (1.5).

The relationship between measures of body anthropometry with dyslipidaemia, and its individual lipid components, has been less widely studied. The OAC has recently conducted the most comprehensive series of analyses to date of the relationships between total cholesterol, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol and triglycerides with measures of global and central obesity in Asian and non-Asian populations (Barzi *et al.*, in press). There were several key findings from this study; first, the magnitude of the associations between measures of body size and lipids were broadly similar between Asians and non-Asians. Second, no single measure of body size was superior at discriminating those individuals at increased risk of dyslipidaemia and, finally, WHR cut-points of 0.8 in women and 0.9 in men, in both sexes, were applicable across both regions for the optimal discrimination of individuals with any form of dyslipidaemia in line with previous findings from this collaboration that showed that these values are also optimal for the discrimination of individuals with diabetes and hypertension (Huxley *et al.*, 2008).

There are, however, several limitations of the data from both the OAC and DECODA groups. First, these analyses are cross-sectional, which precludes examination of the temporal nature of the association between measures of excess weight and cardiovascular risk factors, which is potentially of concern given that the development of diabetes or hypertension may influence body size. Second, these reviews have been limited to examining the association between measures of body size and surrogate measures of cardiovascular risk rather than between morbidity and mortality. This is largely as a consequence of there being far fewer data available on the relationship between different measures of adiposity and mortality outcomes, largely because it has not been until relatively recently that investigators have started to record measures of central obesity in their studies. Again, this is because of the greater difficulty, both in practical and cultural terms, in measuring waist and hip circumference (HC) as opposed to weight and height. Below, we have summarized the data from some large-scale overviews that have reported on the relationship between general and central obesity with cardiovascular outcomes.

Association between obesity indices and CVD risk

A review of the published evidence indicates that there is no clear agreement as to whether measures of central obesity are more strongly associated with cardiovascular morbidity and mortality compared with BMI, and there is a clear need for further long-term, large cohort studies to examine this issue further.

The Asia Pacific Cohort Studies Collaboration (Asia Pacific Cohort Studies Collaboration 2006) comprises data from >40 cohort studies within the Asia-Pacific region. Of these studies, 33 cohorts ($n = 310\,000$ individuals) had information on BMI and cardiovascular events but only six cohorts ($n = 45\,998$) had information on waist and HC. In this subgroup analysis, which was based on 601 coronary heart disease events and 346 strokes, a one standard deviation increase in BMI, WC, HC and WHR was associated with an increase in risk of CHD of 17% (95% CI: 7–27%), 27% (95% CI: 14–40%), 10% (95% CI: 1–20%) and 36% (95% CI: 21–52%), respectively. Subgroup analysis indicated that these associations were stronger in those aged <65 years, in men and in the non-Asian cohorts; however, caution should be applied when interpreting these analyses given the relatively small number of events within the subgroups and the overlapping confidence intervals around the point estimates. The authors further concluded that the associations tended to be consistently stronger for WC and WHR and weakest for HC by comparing the change in the likelihood ratio χ statistic (which is used as a measure of the improvement in the goodness of fit of the model) between the indices; but it should be noted that the differences in the likelihood ratio were modest (e.g. 276 for WHR versus 271 for WC) and hence the clinical relevance is questionable. By comparison, there was no clear association between any of the anthropometric indices with stroke outcomes; a one standard deviation increase in BMI, WC, HC and WHR was associated with a hazards ratio of 1.03 (95% CI: −9 to 16%), 1.05 (95% CI: −9 to 20%), 0% (95% CI: −11 to 13%) and 9% (95% CI: −8 to 28%), respectively. Furthermore, this study did not examine what happens to the relationship between BMI and CVD risk if adjustment is made for central obesity, which would address the issue of whether the effects of BMI on risk are independent of central obesity.

This question was explored by INTERHEART, a large case–control study involving >12 000 cases of myocardial infarction (MI) and 14 000 controls of varying ethnicity from

Figure 1 Age-adjusted odds ratios and 95% confidence intervals for prevalent type II diabetes and hypertension associated with 0.5 s.d. increment in each anthropometric measure: body mass index (BMI), waist circumference (WC) and waist:hip ratio (WHR). Results are shown separately by sex (**a**, for men; **b**, for women) and ethnic group (Asian, Caucasian). The strength of the association between WC and diabetes or hypertension and between WHR and diabetes or hypertension are compared against the strength of the association between BMI and diabetes or hypertension. For each variable, the strength of the association with diabetes or hypertension is compared between Asian and Caucasian individuals. *P*-values for the differences are shown. Figure 1(**a**, **b**) is reproduced through kind permission of Wiley–Blackwell (Huxley *et al.* 2008).

52 countries (Yusuf *et al.*, 2005). In this study, BMI was positively and linearly associated with MI such that individuals in the top quintile of the BMI distribution had an approximately 40% greater risk of MI compared with those in the lowest quintile: odds ratio 1.44, 95% CI: 1.32–1.57. After adjusting for WHR, the risk was significantly attenuated such that for the same comparison, the risk of MI was reduced to approximately 10%: odds ratio comparing highest with the lowest quintile of BMI 1.12 (95% CI: 1.03–1.22). As with BMI, WC and WHR were also strongly and linearly associated with risk of MI, but unlike BMI, the relationships were relatively unaffected after adjustment was made for BMI, indicating the independence of measures of central obesity in predicting risk of MI. In models adjusted for age, sex, region and smoking, the odds ratio for MI comparing the top with the lowest quintiles for WHR and WC were 1.75 and 1.33, respectively (both *P*-values <0.001), indicating a stronger association between WHR and risk of subsequent MI compared with WC.

The observation from INTERHEART that WHR is more strongly associated with cardiovascular risk compared with BMI or WC is at odds with findings from a recent study that involved a combined analysis of the Physician's Health Study ($n=16\,221$ men) and the Women's Health Study ($n=32\,700$) (Gelber *et al.*, 2008). In this study of >1900 CVD events (22% in women), which compared the cardiovascular risk associated with self-reported anthropometric indices (BMI, WC, WHR and WHtR), linear and positive associations were shown between each of these indices with CVD risk, the magnitude of which was broadly similar across the measures. There was some evidence that, especially in men, the WHtR was more strongly associated with CVD risk (and WHR the least strongly associated);however, after adjusting for BMI, the relationship was attenuated, but remained statistically significant. For example, the adjusted hazard ratio for CVD in men with WHtR $\geqslant 0.69$ was 2.36 (95% CI: 1.61–3.47) compared with those with $0.49 <$ WHtR $\leqslant 0.53$ and after adjustment for BMI the HR was reduced to 1.73 (95% CI: 1.05–2.83). A similar effect was also shown when BMI was added to WC, suggesting that some of the risk associated with central obesity is mediated in part by BMI. The authors concluded that although WHtR tended to be more strongly associated with CVD risk compared with BMI, the actual difference between the measures was small and unlikely to be clinically meaningful.

De Koning and colleagues conducted a meta-analysis of studies that had reported on the association between WC and/or WHR with cardiovascular outcomes (de Koning *et al.*, 2007). A total of 15 cohort studies with information on $>250\,000$ individuals and 4355 CVD events were eligible for inclusion. Eight of these cohorts had reported on the relationship between WHR and WC with CHD, four on WHR (only) with CVD (either stroke or CHD) and three on WC (only) and CVD outcomes. In a minimally adjusted model, a 10% increase in CVD risk equated to an approximately 5% increase in WC and a 0.02 unit increase in WHR in both men and women (an alternate way of viewing the data is that a 1 cm increase in WC and a 0.01 increase in WHR was associated with a 2 and 5% increased risk of incident CVD, respectively; Table 2). Further adjustment for smoking and lipids had no material effect on the results, indicating the independent nature of the relationship between measures of central obesity and CVD risk. However, this review had two notable limitations; first, it was unable to compare the strength of the association between measures of general and central obesity with CVD because it did not include studies that had also reported on the association between BMI and CVD. Second, although the authors stated in the review that they compared the strength of association of WC and WHR with CVD risk by pooling risk estimates comparing the highest versus the lowest quantiles of WC and WHR, this is not strictly statistically correct as it would have required that the analysis be restricted to those studies that had reported on *both* WC and WHR, which was not the case.

Table 2 Association between an increase in WC and WHR and cardiovascular disease risk in men and women (after minimal adjustment for age and cohort characteristics)

Increase in CVD risk (%)	*Waist circumference (cm)*			*Waist:hip ratio (U)*		
	M	*F*	*Combined*	*M*	*F*	*Combined*
10	4.71	5.08	5.04	0.02	0.02	0.02
20	9.02	9.72	9.65	0.03	0.04	0.03
30	12.98	13.99	13.88	0.05	0.05	0.05
40	16.64	17.95	17.80	0.06	0.07	0.06
50	20.06	21.63	21.64	0.08	0.08	0.08

Adapted from de Koning *et al.*, (2007).

Which anthropometric measure is the better discriminator of cardiovascular risk?

Given the broad similarities in the magnitude of the relationship between different measures of current body size with cardiovascular risk and its risk factors, it is perhaps not surprising that the discriminatory capability of each of these measures, as assessed by the area under the receiver operating characteristic curve, at identifying those individuals with the highest cardiovascular risk is also comparable. The OAC reported on the ability of BMI, WC and WHR to discriminate those individuals with prevalent diabetes or hypertension and showed that the area under the receiver operating characteristic curves ranged from 0.63 to 0.71 in men and from 0.66 to 0.80 in women with little statistically significant evidence of any consistent difference between the three measures across the sex and ethnic groups.

Lee *et al.* (2008) conducted a meta-analysis involving 10 studies (nine of which were cross-sectional) and over 88 000 individuals, to determine which of the four indices (BMI, WC, WHR and WHtR) is the best discriminator of major cardiovascular risk factors: hypertension, type II diabetes and

Table 3 Comparison of the discriminatory power (pooled AUC score) for three cardiovascular risk factors between measurements of obesity (BMI, WC, WHR, WHtR) stratified by gender (Lee *et al*., 2008)

CV risk factors	*Hypertension* (n = 8)		*Type II diabetes* (n = 9)		*Dyslipidaemia* (n = 7)	
Measurements	*Men*	*Women*	*Men*	*Women*	*Men*	*Women*
Body mass index	0.64	0.69	0.67	0.69	0.65	0.64
Waist circumference	0.67	0.71	0.70	0.74	0.64	0.66
Waist:hip ratio	0.67	0.71	0.72	0.75	0.64	0.66
Waist:height ratio	0.68	0.73	0.73	0.76	0.67	0.68

dyslipidaemia. In both men and women, measures of central obesity were superior to BMI as discriminators of cardiovascular risk factors, although the differences were small and unlikely to be of clinical relevance (Table 3). Further, the study showed that combining BMI with any measure of central obesity did not improve the discriminatory capability of the individual measures.

Ethnic differences in association between anthropometric measures and CVD risk

Recently, evidence has accumulated to suggest that the increasing prevalence of type II diabetes and CVD in Asian countries is occurring at levels of BMI much lower than the WHO BMI cut-point of 25.0 kg/m^2. One potential explanation that has been suggested to explain the diabetes epidemic across large parts of Asia is that ethnic differences may exist in the strength of the relationships between body size and metabolic and cardiovascular risk factors. For example, several studies have shown that, for a given BMI, adiposity can be substantially greater in Asian compared with Caucasian individuals. Moreover, there is evidence to suggest that within Asian populations there is significant variation in the association between adiposity and BMI. For example, Hong Kong Chinese, Indonesians, Singaporeans and urban Thai have been shown to have lower BMI's at a given percentage of body fat compared with Europeans, whereas individuals from Northern China (Beijing) and rural Thailand had similar values to Europeans (Deurenberg and Deurenberg-Yap, 2003). Further studies have reported ethnic differences in the slopes of the associations between BMI and CVD risk factors. For example, Bell and colleagues observed a stronger association between BMI and hypertension in Chinese compared with Caucasians, and in non-Hispanic Blacks compared with Caucasians and Mexican Americans (Bell *et al*., 2002). Similarly, the relationship between body build with fasting insulin concentration has been shown to be significantly steeper in South Asian compared with Caucasian children (Whincup *et al*., 2002).

Data from the OAC suggested that there was no evidence that the strength of the associations between BMI, WC or WHR and diabetes were stronger in Asians compared with Caucasians in both sexes (Figures 1a and b). Rather, the reverse was true, particularly in women, where the odds of prevalent diabetes associated with a 0.5 s.d. increment in each of the three indices of body weight with prevalent diabetes were consistently stronger in Caucasians. By comparison, for the same standard increment in anthropometric indices, the odds of hypertension were stronger (although not always statistically significantly so) in Asians compared with Caucasians for both men and women (Figures 1a and b). Findings from the APCSC substudy of six longitudinal cohorts showed that the strength of the associations between BMI, WC, WHR and HC with cardiovascular risk was similar in the Asian and non-Asian cohorts. However, as discussed earlier, these analyses are based on a relatively small number of events and require validation from future prospective studies.

Summary

This review attempted to summarize the evidence for three main questions. The first of these asked if there was evidence to indicate which of the commonly used measures to assess body size is more strongly associated with subsequent cardiovascular risk. In totality, the evidence was conflicting; for diabetes, there was some evidence to indicate that measures of central obesity were more strongly associated with risk compared with BMI, but this was not the case for hypertension and dyslipidaemia where the relationships with BMI, WC and WHR were similar. For cardiovascular outcomes, the evidence again was conflicting, with most studies (with the notable exception of INTERHEART), suggesting that the magnitude of the relationships between BMI and central obesity with cardiovascular mortality is broadly consistent. However, much of the evidence is based on cross-sectional studies and there is a clear need for further data from large-scale longitudinal studies. Perhaps not surprisingly, given the general consistency in associations between measures of body size and cardiovascular risk, there was limited evidence to support the superior discriminatory capability of any of the measures. Furthermore, the differences in discriminatory capability that were reported were too small to be of any clinical relevance. Finally, despite the often considerable differences in body size and fat distribution between different ethnic groups, there was little evidence to indicate that the magnitude of the associations between measures of body size and subsequent risk was appreciably different. However, again, the evidence is largely cross-sectional and requires confirmation from prospective studies.

Conflict of interest

The authors declare no conflict of interst.

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