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Obesity Comorbidity Diagnostic

Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factors: systematic review and meta-analysis

M. Ashwell[1,3], P. Gunn[2] and S. Gibson[2]

[1]Ashwell Associates, Ashwell, Herts, UK;
[2]Sig-Nurture Ltd, Guildford, Surrey, UK;
[3]Oxford Brookes University, Oxford, UK.

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Address for correspondence: Dr M Ashwell, Ashwell Associates, Ashwell Street, Ashwell, Herts SG7 5PZ, UK. E-mail: margaret@ashwell.uk.com

Summary

Our aim was to differentiate the screening potential of waist-to-height ratio (WHtR) and waist circumference (WC) for adult cardiometabolic risk in people of different nationalities and to compare both with body mass index (BMI). We undertook a systematic review and meta-analysis of studies that used receiver operating characteristics (ROC) curves for assessing the discriminatory power of anthropometric indices in distinguishing adults with hypertension, type-2 diabetes, dyslipidaemia, metabolic syndrome and general cardiovascular outcomes (CVD). Thirty one papers met the inclusion criteria. Using data on all outcomes, averaged within study group, WHtR had significantly greater discriminatory power compared with BMI. Compared with BMI, WC improved discrimination of adverse outcomes by 3% ($P < 0.05$) and WHtR improved discrimination by 4–5% over BMI ($P < 0.01$). Most importantly, statistical analysis of the within-study difference in AUC showed WHtR to be significantly better than WC for diabetes, hypertension, CVD and all outcomes ($P < 0.005$) in men and women.

For the first time, robust statistical evidence from studies involving more than 300 000 adults in several ethnic groups, shows the superiority of WHtR over WC and BMI for detecting cardiometabolic risk factors in both sexes. Waist-to-height ratio should therefore be considered as a screening tool.

Keywords: Body mass index (BMI), receiver operating characteristics (ROC), waist circumference (WC), waist-to-height ratio (WHtR).

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Introduction

Body mass index (BMI) has been used as a proxy for obesity for many years, but, in recent years, indices of abdominal obesity (first waist–hip ratio [WHpR] and then waist circumference [WC]) have increasingly been associated with higher cardiometabolic risk in both cross-sectional and prospective studies. The use of waist-to-height ratio (WHtR) for detecting abdominal obesity, and health risks associated with it, was first proposed in the mid-1990s (1–3). Interest in the effectiveness of this measure is rising in both adults and children in many different ethnic groups and countries (4–10).

A meta-analysis published in 2008 (11) focused on hypertension (HT) and included data from 19 cross-sectional studies in the Asia–Pacific region. It concluded that 'No anthropometric variable was systematically better than others at the discrimination of hypertension'.

A further meta-analysis, looking at more risk factors but only including 10 papers published up to the end of 2006 (12), concluded that statistical evidence supported the superiority of measures of centralized obesity, especially WHtR, over BMI for detecting cardiovascular (cardiovascular disease [CVD]) risk in men and women.

A systematic review (9) included the evidence from 78 studies published from 1950 to mid-2009 and drew on evidence from prospective and cross-sectional studies, in adults and in children, which reported relationships between WHtR and either BMI, WC, or both, and outcomes of cardiometabolic risk. Although this *narrative* analysis was done on many more studies than its forerunners, it could only suggest that WHtR and WC were significant predictors of cardiometabolic outcomes more often than BMI because meta-analysis of all studies was not included.

The volume of papers reporting relevant data has increased substantially. We therefore took this opportunity to perform a full robust meta-analysis on the published data until 2010 to see which indicator of abdominal obesity should be recommended for screening purposes.

Methods

Literature search strategy

A systematic review was conducted which considered papers in the Medline and EMBASE databases up until 31 August 2010. Search terms used a combination of keywords: body mass index or BMI, waist or wst circumference or WC, waist-to-height ratio or waist height or waist ht or WHtR or waist to stature ratio or wst stature or WSR or stature and girth. There were no language restrictions as long as an abstract in English was available. We identified additional studies through hand-searches of bibliographies from primary studies and review articles.

Study selection

Two reviewers (SG and MA) independently assessed the suitability of these retrieved articles for use in the meta-analysis using information supplied in the title and abstract in the first sift. The following inclusion/exclusion criteria were used.

Study inclusion criteria

- Primary studies, either prospective or cross-sectional design.
- Human subjects, male, female or mixed, adults, any ethnic group.
- WHtR, and either BMI or WC, measured at least once.
- Studies with a cardiometabolic risk factor or disease end point and presenting the relationship between the anthropometric indices and this end point (for diagnostics used to define end points, please see Table 1).
- Studies reporting receiver operating characteristics (ROC) analyses.

Study exclusion criteria

- Literature reviews, intervention studies, abstracts from conference proceedings.
- Studies in children and adolescents.

Once papers had been identified on the basis of information in the title and abstract, full papers were obtained for all relevant studies, either from journal archives or directly from the authors. These papers were then scrutinized by the two reviewers (SG and MA) independently to identify those with sufficient information for data extraction for the meta-analysis.

Meta-analysis of data from receiver operating characteristics curves

Meta-analysis was used to assess the overall power and precision of each of the three anthropometric indices in predicting the five disease outcomes or risk factors (diabetes, HT, dyslipidaemia, metabolic syndrome [MS] and CVD [including coronary heart disease (CHD) incidence/mortality and high CHD risk]). Data on area under the ROC curve (AUC) for each study (means, 95% confidence interval [CI], sample size) were extracted and entered into a database for analysis by software package Comprehensive Meta-analysis v2 (CMA: Biostat Inc., NJ, USA). Where papers gave values adjusted for covariates, these were used in preference to unadjusted values. Results for men and women were treated separately. Where studies reported results in two ethnic groups, these were treated separately (i.e. study group was used as the unit of analysis). Where studies reported individual health outcomes as well as composite risk scores, the analysis was restricted to the former. Data given for different age groups were combined to give an all-age mean. Random effects models were used, as most appropriate for studies from different populations, or where criteria for outcomes may differ between studies (13). Random effects analysis allows that the true effect size may vary from study to study. The schematic plots (forest plots) illustrate the AUC and confidence limits for each study and the weighted mean AUC over all studies, by index and by outcome. Differences in mean effect size (pooled AUC) between BMI and WC and between BMI and WHtR were assessed for significance using the Q statistic (heterogeneity). For outcomes in which WHtR was significantly different from BMI, we also investigated whether WHtR gave improved prediction over WC by

Table 1 Details of included studies

References	Authors	Year study conducted	Country	Ethnicity	Design	Subjects – men	Subjects – women	Age range (year) or mean ± SD	Risk factors with definitions
(15)	Aekplakorn, 2006	2000	Thailand	Thai	Cross-sectional	2,093	3,212	≥35	D (1), HT (1), Dyslip (1), MS (1)
(14)	Aekplakorn, 2007	1985	Thailand	Thai	Prospective (17 years follow-up)	2,536	0	35–59	CVD (1)
(16)	Can, 2009	2003	Turkey	Turkish	Cross-sectional	571	1,121	≥18	D (1), HT (2), Dyslip (1), MS (2), CVD (2)
(17)	Cristo Rodriguez Perez, 2010	2000–5	Canary Islands	Spanish	Cross-sectional	2,913	3,816	43.1 ± 12.8 (m); 43.0 ± 12.9 (w)	D (NR), HT (NR), Dyslip (NR), MS (NR), CVD (NR)
(18)	Gracey, 2007	2003 and 2004	Australia	Aboriginal	Cross-sectional	144	186	18–88	D (2), HT (2), Dyslip (8)
(19)	He, 2009	2002	China (National)	Chinese	Cross-sectional	23,980	26,925	18–79	D (3)
(20)	Ho, 2003	1995 and 1996	Hong Kong	Chinese	Cross-sectional	1,412	1,483	25–74	D (2), HT (3), Dyslip (2), CVD (3)
(21)	Hsieh and Muto	1996–1999	Tokyo	Japanese	Cross-sectional	6,141	2,137	49.5 ± 8.9 51.9 ± 9.0	MS (3)
(22)	Haun, 2009	2000	Brazil	Brazilian	Cross-sectional	391	577	30–74	CVD (2)
(40)	Koch, 2008	1997–1999	Chile	Chilean	Prospective (8 years)	6,714	6,340	42 ± 15 (m and w)	D (1), HT (1), Dyslip (2), MS (5)
(23)	Lee, 2008	2005–7	Korea	Korean	Cross-sectional	577	995	>30	D (4), HT (4), Dyslip (6)
(24)	Li, Ford, 2010	1988–1994	USA National	Non-Hispanic White; non-Hispanic Black; and Mexican Americans	Cross-sectional	2,994	3,283	>20	D (2)
(25)	Li, 2009	1999–2001	Australian Aborigines and Torres Strait islanders	Indigenous Australian	Cross-sectional	881	471	>15	D (5), HT (1), Dyslip (3)
(26)	Lin, 2002	1998–2000	Taiwan	Taiwanese	Cross-sectional	26,359	29,204	37.3 ± 10.9 (m) 37.0 ± 11.1(w)	D (6), HT (1), Dyslip (1), MS (1)
(27)	Mansour, 2007	2005	Iraq	Iraqi	Cross-sectional	6,693	6,293	45.6 ± 15.7 (m and w)	D (2), HT (2)
(28)	Mellati, 2009	2002–2003	Zanjan, Iran	Iranian	Cross-sectional	1,310	1,458	21–75	D (6), HT (6), Dyslip (7)
(29)	Mirmiran, 2004	Pre-2000?	Tehran, Iran	Iranian	Cross-sectional	4,449	6,073	18–74	D (6), HT (2), Dyslip (1), MS (1)
(30)	Mombelli, 2009	2008	Italy	Italian	Cross-sectional	552	552	58 ± 13 (m) 64 ± 11 (w)	MS (4)
(41)	Page, 2009	1986	USA Nurses study	American mixed	Prospective (16 years)	0	45,563	40–65	CVD (1)
(31)	Paniagua, 2008	2006–2007	Thailand	Thai	Cross-sectional	451	940	≥35	D (4), HT (4), Dyslip (6)
(32)	Park, 2009	2005	Korea National	Korean	Cross-sectional	2,327	3,102	>20	D (1), HT (5), Dyslip (1)
(33)	Pua, 2005	2003	Singapore	Chinese, Malay, Indian	Cross-sectional	0	566	18–68	D (6), HT (1), Dyslip (4), MS (1)
(34)	Sakurai, 2006	1996	Japan	Japanese	Cross-sectional	2,935	1,622	35–59	HT (2)
(42)	Sargeant, 2002	1993–1996	Jamaica	African ancestry	Prospective (4 years)	290	438	25–74	D (2)
(5)	Schneider, 2007	2003	Germany	Mainly Caucasian	Cross-sectional	2,016	3,361	20–79	D (7), Dyslip (5), MS (3)
(43)	Shafiee, 2009	Not stated	Iran	Iranian	Prospective (3.5 years)	0	2,801	>20	D (3)
(35)	Taylor, 2010	Not stated	New Zealand	(47% Maori, 53% White	Cross-sectional	452	1,087	17–82	D (8), MS (4)
(36)	Tseng, 2010	2001	Taiwan	Taiwanese	Cross-sectional	2,280	2,403	25–75	D (1), HT (3), Dyslip (6)
(37)	Wang, 2009	2007	Beijing, China	Chinese Han	Cross-sectional	3,704	6,392	18–85	MS (5)
(38)	Welborn, 2007	1989	Australia	Australian	Prospective (11 years)	4,508	4,698	20–69	CVD (1)
(39)	Zhou, 2009	2006	China	Chinese	Cross-sectional	13,558	15,521	30–100	HT (2)

Full diagnostics available from the authors.

running a separate meta-analysis of the within-study difference between these two indices (*Z*-test) assuming a correlation of 0.95 between WC and WHtR (14).

Results

Study selection

Figure 1 shows the flow chart of study selection. The search produced 693 references, of which 304 were excluded for the reasons shown. From the 389 relevant papers, 77 abstracts were identified as potentially suitable because they contained ROC analysis of the relevant anthropometric indices and the relevant cardiometabolic outcomes. Full text was therefore scanned to ascertain whether sufficient data were available to input into the meta-analysis. Forty-nine of the 77 papers were excluded because they did not have the relevant data. In some instances, authors were contacted directly to supply missing information (e.g. obtaining CIs for the mean AUC values). Three other papers were identified as being relevant from cross referencing. Finally, 31 papers were deemed to be suitable for data extraction for the meta-analysis. Of these, 30 included women and 28 included men.

Included papers

Table 1 shows details of these 31 papers. Of these, 26 reported cross-sectional studies (5,15–39), and five reported prospective studies (14,40–43), the longest with a follow-up of 17 years (14).

Studies were conducted between 1985 and 2008, in 18 different countries. Six countries were from Asia, two from the Middle East, two from Australasia, four from Europe,

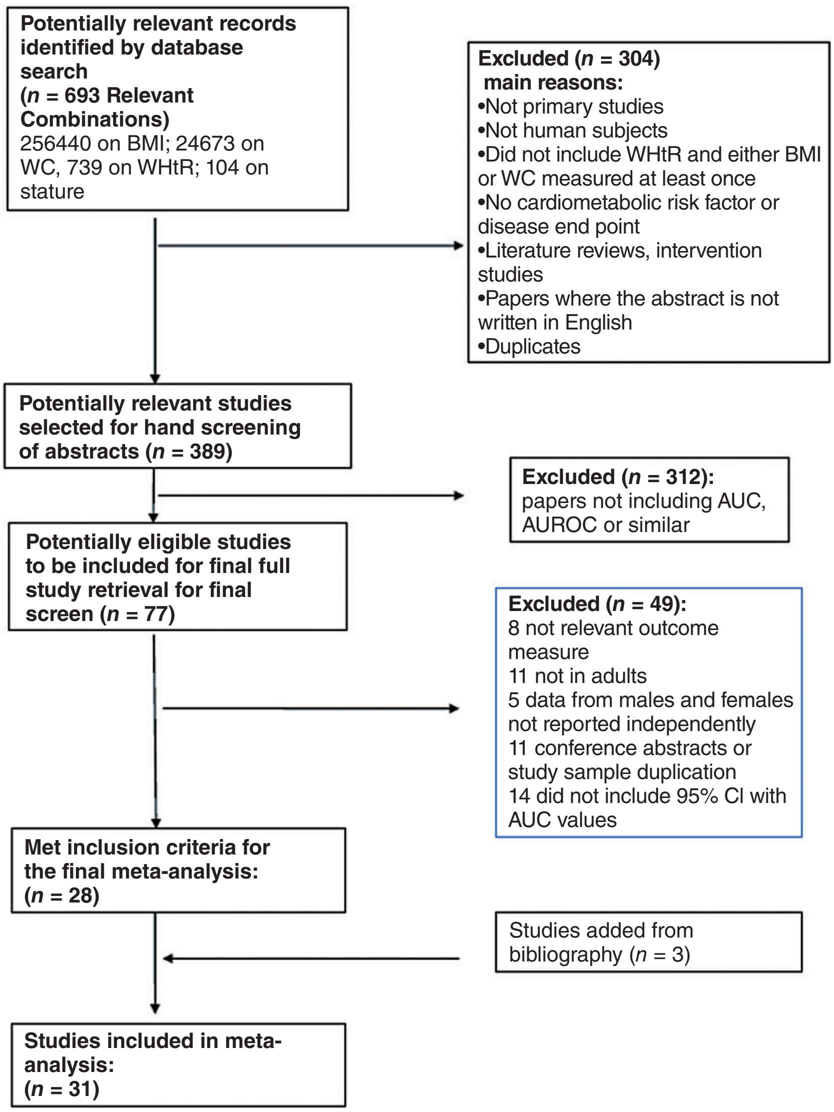

Figure 1 Flow chart of study selection. AUC, area under the curve; AUROC, area under the receiver operating characteristics curve; BMI, body mass index; CI, confidence interval; WC, waist circumference; WHtR, waist-to-height ratio.

two from South America and one from the Caribbean. Fifteen studies included subjects of Asian ethnicity. The study population size ranged from less than 200 to over 45,000 participants with a total of 123,231 men and 182,620 women. The age limits for inclusion into each of the individual studies ranged from 18 to 100 years.

Outcomes were grouped into five broad categories: diabetes (D), HT, dyslipidaemia, MS and CVD outcomes (includes CHD and CVD outcomes and calculations of high coronary risk score). Papers used different diagnostic criteria for these outcomes, which are summarized in Table 1. A summary category 'all outcomes' was also created, with a mean AUC calculated as the mean of all measured outcomes within study group, ($n = 33$).

Meta-analysis

Table 2 shows the mean area under the curve (AUC) and lower and upper 95% CIs for two sexes, for three anthropometric indices, for five specific health outcomes and for a combined outcomes variable. Statistical significance (*P* values) of pooled AUCs for the two indices of abdominal obesity (WC and WHtR) compared with BMI (a proxy for total obesity) is also shown for all the health outcomes.

The implications of these results are reported in relation to the specific health outcome:

Diabetes

Twenty studies for men (5,15–20,23–29,31,32,35,36, 40,42) and 22 for women (as men plus (33) and (43)) included diabetes as an outcome. As the studies by Li and McDermott (25) and Taylor *et al*. (35) each gave data on two ethnic groups, this made a total of 22 study groups for men and 24 for women.

As Table 2 shows, WHtR had the highest, and BMI had the lowest, pooled AUC for both men and women, while the AUC for WC was intermediate. Diabetes risk among women was correctly discriminated by BMI 70% of the time (i.e. mean AUC was 0.70 with 95% CIs at 0.67 and 0.73). In contrast, diabetes was correctly discriminated 74% of the time for WC (mean AUC = 0.74 [0.72, 0.76]) and 75% for WHtR (mean AUC = 0.75 [0.73, 0.77]). Among men, mean AUC for BMI was 0.66 (0.64, 0.69); for WC it was 0.70 (0.68, 0.72); and for WHtR it was 0.71 (0.69, 0.73).

Figures 2 and 3 show the Forest plots of AUC scores for diabetes risk in men and women, respectively. Random effects pooled area under the ROC curves (AUC) is shown for BMI, WC and WHtR (a, b and c). Horizontal lines represent the 95% CI; diamonds represent the overall estimates.

Statistical comparison of the AUC scores for indices of abdominal obesity with BMI indicated that both WHtR

Table 2 AUC values with 95% confidence intervals for anthropometric indices against health outcomes in men and women

	Mean AUC	Lower 95%	Upper 95%	*P* value for comparison with BMI
Diabetes				
Men ($n = 22$ groups)				
BMI	0.663	0.639	0.686	
WC	0.699	0.680	0.718	0.020
WHtR	0.711	0.694	0.728	0.001
Women ($n = 24$ groups)				
BMI	0.699	0.668	0.730	
WC	0.742	0.720	0.765	0.026
WHtR	0.752	0.728	0.775	0.007
HT				
Men ($n = 18$ groups)				
BMI	0.654	0.627	0.682	
WC	0.677	0.652	0.701	0.24
WHtR	0.690	0.668	0.713	0.047
Women ($n = 19$ groups)				
BMI	0.693	0.659	0.726	
WC	0.718	0.690	0.746	0.25
WHtR	0.732	0.707	0.757	0.06
Dyslipidaemia/high TG				
Men ($n = 16$ groups)				
BMI	0.675	0.655	0.696	
WC	0.680	0.651	0.709	0.81
WHtR	0.685	0.661	0.709	0.55
Women ($n = 17$ groups)				
BMI	0.653	0.630	0.677	
WC	0.683	0.658	0.707	0.09
WHtR	0.689	0.663	0.716	0.047
MS				
Men ($n = 12$ groups)				
BMI	0.721	0.697	0.746	
WC	0.747	0.703	0.792	0.32
WHtR	0.750	0.697	0.803	0.33
Women ($n = 13$ groups)				
BMI	0.724	0.699	0.750	
WC	0.754	0.720	0.787	0.176
WHtR	0.762	0.735	0.790	0.047
CVD				
Men ($n = 6$ groups)				
BMI	0.616	0.572	0.661	
WC	0.669	0.620	0.717	0.12
WHtR	0.707	0.658	0.756	0.007
Women ($n = 6$ groups)				
BMI	0.633	0.552	0.713	
WC	0.683	0.604	0.761	0.38
WHtR	0.704	0.619	0.789	0.23
All outcomes (mean of measured outcomes for each study)				
Men ($n = 31$ groups)				
BMI	0.667	0.650	0.684	
WC	0.694	0.678	0.709	0.026
WHtR	0.704	0.689	0.718	0.002
Women ($n = 33$ groups)				
BMI	0.681	0.658	0.704	
WC	0.714	0.698	0.731	0.022
WHtR	0.725	0.709	0.741	0.002

Statistical test (Q statistic) for heterogeneity in effect sizes between indices (WC vs. BMI; WHtR vs. BMI).
For more powerful test of the hypothesis that the difference between WC and WHtR equals zero, see Table 3.
AUC, area under the curve; BMI, body mass index; CVD, cardiovascular disease; HT, hypertension; MS, metabolic syndrome; TG, triglyceride; WC, waist circumference; WHtR, waist-to-height ratio.

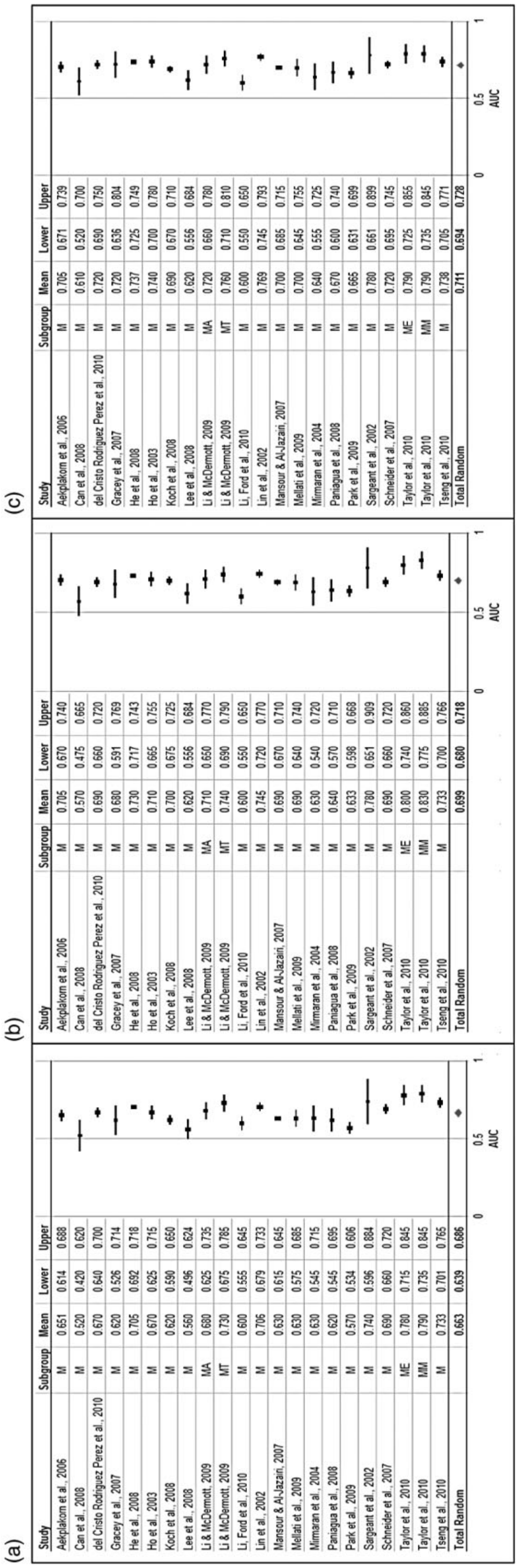

Figure 2 Discrimination of diabetes among men and women: pooled AUCs for BMI, waist circumference and waist-to-height ratio. (a) Discrimination of diabetes among men: pooled AUC for BMI. (b) Discrimination of diabetes among men: pooled AUC for waist circumference. (c) Discrimination of diabetes among men: pooled AUC for waist-to-height ratio. AUC, area under the curve; BMI, body mass index; M, male; MA, male Aborigine; ME, male Europeans; MM, male Maori; MT, male Torres Strait islanders.

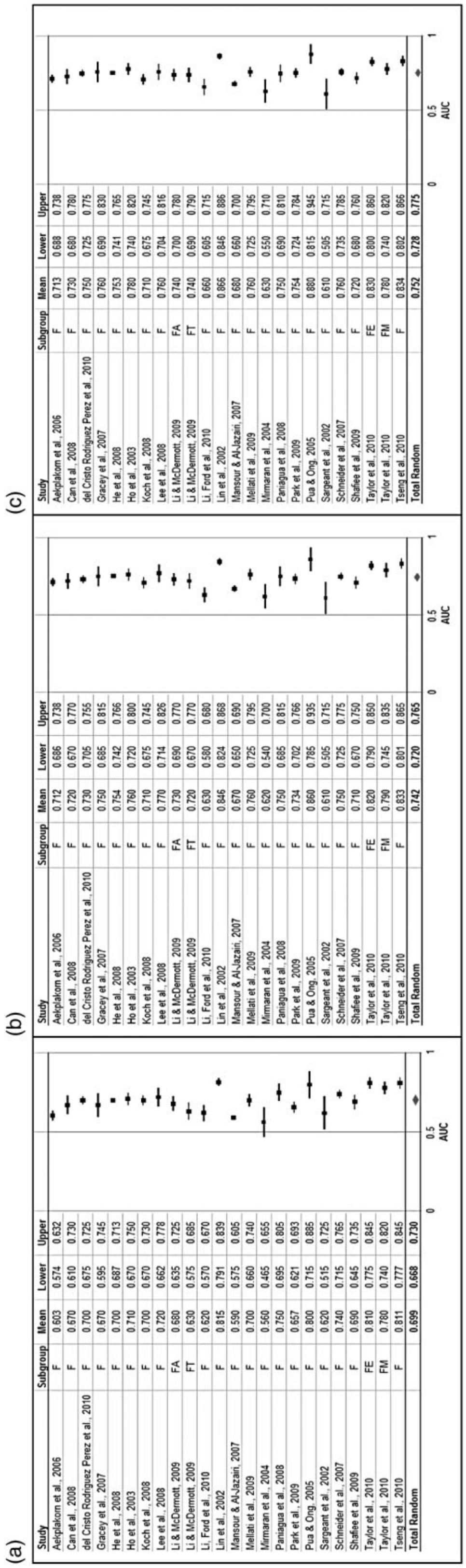

Figure 3 (a) Discrimination of diabetes among women: pooled AUC for BMI. (b) Discrimination of diabetes among women: pooled AUC for waist circumference. (c) Discrimination of diabetes among women: pooled AUC for waist-to-height ratio. AUC, area under the curve; BMI, body mass index; F, female; FA, female Aborigine; FE, female Europeans; FM, female Maori; FT, female Torres Strait islanders.

($P = 0.001$ and $P < 0.001$ in men and women, respectively) and WC ($P < 0.05$ for WC for both men and women) were significantly better at discriminating diabetes risk compared with BMI.

Hypertension

Eighteen study groups included HT as an outcome for men (15–18,20,23,25–29,31,32,34,36,39,40) and 19 for women (as men plus (33)).

Discrimination was 3–4% better with WHtR than BMI. Mean AUCs were 0.65 (0.63, 0.68) for BMI and 0.69 (0.67, 0.71) for WHtR ($P = 0.047$) among men and 0.73 (0.71, 0.76) and 0.69 (0.66, 0.73) among women ($P = 0.06$). Mean AUCs for WC were intermediate. Statistical significance of the indices of abdominal obesity against BMI at $P < 0.05$ was achieved by WHtR in men but not by WC for men or women.

Dyslipidaemia

Sixteen studies in men (5,15–18,20,23,25,26,28,29,31, 32,36,40) and 17 in women (as men plus (33)) included dyslipidaemia or high triglyceride levels as an outcome.

Among men there was no significant difference in AUCs between indices (0.68–0.69). In women, BMI (mean AUC = 0.65) was a significantly poorer indicator than WHtR (AUC = 0.69; $P = 0.047$).

Metabolic syndrome

Among men in 12 study groups (5,15–17,21,26,29, 30,35,37,40), the difference in AUCs between indices was not statistically significant. Among women (13 study groups including (33)), BMI was significantly poorer than WHtR (0.72 vs. 0.76; $P = 0.047$).

Cardiovascular disease outcomes

Only seven studies reported outcomes or risk related to CVD. In three studies, this was myocardial infarction (fatal or non-fatal) (14,20,41), in one it was cardiovascular mortality (38), and three calculated high coronary risk (usually Framingham score) (16,17,22). One study was just on men (14) and one just on women (41) giving six study populations for each sex.

All were consistent in showing WHtR > WC > BMI in AUC values, although not all differences were statistically significant. WHtR was 9% better than BMI at predicting CVD risk in men ($P = 0.007$). Values for WC were not significantly better than BMI in men or women. The results were similar following exclusion of the studies using the risk score (16,17,22).

All outcomes

Using data on all outcomes, averaged within study group, WHtR had significantly greater discriminatory power compared with BMI. Compared with BMI, WC improved discrimination of adverse outcomes by 3% ($P < 0.05$), but WHtR improved discrimination by 4–5% ($P < 0.01$).

Consistency of results

For all five specific health outcomes, WHtR had better discriminatory power compared with BMI. WC gave values that were nearly as good as WHtR, but more often fell short of statistical significance.

This ranking order was consistent among both sexes, although there was no statistical difference between indices in men for dyslipidaemia and MS, and for women in HT.

Discrimination, as measured by AUCs, tended to be 3–4% higher for women than for men for diabetes and HT outcomes. However, there were no significant differences in AUC between studies in Asian and non-Asian populations.

Is waist-to-height ratio significantly better than waist circuference in predicting outcomes?

Because each individual was measured on each index, a more powerful way to address the hypothesis that WHtR is superior to WC is by calculating the *difference* in AUC between these two indices for each study and then to test this against the null hypothesis that the difference is zero.

Table 3 shows that WHtR gave significantly better discrimination than WC for all outcomes apart from MS in men ($P = 0.6$). WHtR gave superior discrimination over WC for CVD outcomes ($P < 0.0001$ for men; $P = 0.002$ for women), for diabetes and HT ($P < 0.0001$), for dyslipidaemia ($P = 0.036$ for men; $P = 0.001$ for women) and for all outcomes combined ($P < 0.0001$). The absolute difference in AUC for WHtR over WC was 1–2%.

Discussion

This robust meta-analysis, including data on more than 300,000 individuals from diverse populations across the world, confirms previous claims from smaller and less robust analyses that measures of abdominal obesity, especially WHtR, provide a superior tool for discriminating obesity-related cardiometabolic risk compared with BMI. The studies within the meta-analysis used several different diagnostics for defining cardiometabolic risk (see Table 1) but this did not influence our conclusions. Our 'within studies' comparison, which showed that WHtR was significantly superior to WC, is the first, to our knowledge, to report this result. The differences were consistent across

Table 3 Difference in AUC between WHtR and WC in men and women *within studies* for diabetes, dyslipidaemia, hypertension, CVD and all outcomes

	Number of studies	Improvement in AUC (WHtR > WC) (95% CI) Mean	Lower 95%	Upper 95%	*P* value
Men					
Diabetes	22	0.016	0.009	0.022	*P* < 0.0001
Hypertension	18	0.014	0.008	0.019	*P* < 0.0001
Dyslipidaemia	16	0.005	0.000	0.010	*P* = 0.036
Metabolic syndrome	12	0.003	–0.010	0.016	*P* = 0.662
CVD	6	0.039	0.029	0.050	*P* < 0.0001
All outcomes	32	0.012	0.006	0.017	*P* < 0.0001
Women					
Diabetes	24	0.011	0.007	0.015	*P* < 0.0001
Hypertension	19	0.014	0.007	0.022	*P* < 0.0001
Dyslipidaemia	17	0.008	0.003	0.013	*P* = 0.001
Metabolic syndrome	13	0.009	0.000	0.017	*P* = 0.04
CVD	6	0.020	0.008	0.033	*P* = 0.002
All outcomes	33	0.010	0.007	0.013	*P* < 0.0001

Results show a separate meta-analysis of the difference between these two indices assuming a correlation of 0.95 (Aekplakorn *et al.*, 2007 (14)). Effects were pooled using random effects model. *P* values show Z-test of null (two-tailed).
AUC, area under the curve; CI, confidence interval; CVD, cardiovascular disease; WC, waist circumference; WHtR, waist-to-height ratio.

different health outcomes and statistically significant in several comparisons, even though our test for statistical difference between pooled mean AUC values was conservative. The 'rank' order for AUC was always WHtR > WC > BMI.

Meta-analysis is a powerful tool to assess the totality of evidence now available and can overcome the problem of basing conclusions on individual papers. For instance, inconsistent results can be found with the different outcomes (e.g. (15,27)), and the indices often perform differently in different sexes, age groups and ethnic groups (e.g. see (25) for inconsistent performance and (35) for consistent performance). Our meta-analysis has demonstrated statistically that WHtR is superior to WC as well as being superior to BMI in the discrimination of cardiometabolic risk.

Justification for comparing three anthropometric indices

Many anthropometric indices have been used to predict cardiometabolic risk, but our systematic review process focused on BMI, WC and WHtR and did not include waist-to-thigh ratio (e.g. (24)), waist-to-hip ratio (WHpR) (e.g. (25)), conicity index or sagittal diameter, which feature in several papers. The first two have performed no better than WC in previous meta-analyses (12). The latter two, even though they have been reported as the best predictor in certain populations (22) (44), were excluded from our analysis because so few studies used them and because they would be less suitable for routine public health screening purposes.

It should also be noted that some authors use different terminology and abbreviations (e.g. waist–stature ratio) for what is essentially WHtR. Elsewhere, we have urged consistency in the use of waist-to-height ratio, abbreviated to WHtR, which is the most popular terminology (45).

Justification for restricting meta-analysis to studies with receiver operating characteristics analyses

The only other meta-analyses of anthropometric indices and cardiometabolic risk, to our knowledge, have focused on studies that included ROC analysis. One concluded that 'no anthropometric index was systematically better than others at the discrimination of hypertension' (11) and the other concluded that 'statistical evidence supports the superiority of measures of central obesity, especially waist-to-height ratio over BMI, for detecting cardiovascular risk factors in both men and women' (12).

Our intention was to use a similar strategy, i.e. focusing on those studies that had included ROC analysis to compare the discriminatory power not only of CVD risk factors but also CVD if possible. ROC analysis has emerged as a popular method for assessing the effectiveness of diagnostic tests measured on a continuous scale, independent of the cut-off point used. It has been widely used in medical imaging and radiology (46). The ROC curve is a plot of q = (sensitivity) vs. P = (1-specificity) for all possible threshold values. A value of 1 would suggest perfect (100% discrimination) while 0.5 (the diagonal) indicates discrimination that is no better than chance. In practice, most anthropometric measures only expect to assess cardiovascular risk factors with 60–70% accuracy and are thus best regarded as first-stage, or population-based, screening measures.

Bias and confounding of the systematic review and meta-analysis

Results of all meta-analyses need to be interpreted with caution concerning their potential bias, confounding and generalizability. Publication bias may exist because publishers and authors often favour publishing positive findings over negative ones. However, a specific check on bias (funnel plot) revealed no association between effect size and sample size; such an association is often used as an indicator of publication bias. Confounding is most likely to arise from variability in the definitions of different diagnostic criteria in the different studies, especially for a composite diagnosis such as MS. These measurement error effects would, however, tend to reduce the likelihood of a significant result.

Large studies omitted from meta-analysis

This decision to focus on studies including ROC analysis meant that many papers, which compared relative risk (RR) of different anthropometric indices with health outcomes, but did not include a full ROC analysis, have not been included in our meta-analysis. Notable among the papers that lacked ROC analysis have been some major prospective studies (47–51), some details of which are discussed below.

In the European Prospective Investigation into Cancer and Nutrition study, reporting on nearly 15,000 deaths out of more than 350,000 subjects in nine countries, RR of death from all causes in the highest as compared with the lowest quintile of the WHtR in the multivariable-adjusted model (including BMI) was 2.22 (95% CI, 1.94–2.55) among men and 2.03 (95% CI, 1.76–2.34) among women, whereas for WC it was 2.05 (95% CI, 1.80–2.33) for men and 1.78 (95% CI, 1.56–2.04) for women (47,48).

A prospective (11 years) study of body size and risk for stroke among more than 45,000 women below age 60 showed that, in contrast to BMI, several different measures of abdominal obesity (WHtR > WC > WHpR) are strong predictors of stroke in women (49).

The multivariable-adjusted hazard ratios (95% CIs) for total stroke in Zhang's study of risk of stroke in more than 67,000 Chinese women comparing the highest vs. lowest quintiles of these measurements were 1.71 (1.49–1.97), 1.77 (1.53–2.05) and 1.91 (1.61–2.27) for BMI, WC and WHtR (51).

Gelber's analysis of data from the 14 years follow-up of more than 16,000 men in the Physicians Health Study and the 5.5 years follow-up of more than 32,000 women in the Women's Health Study led the authors to conclude that 'The WHtR demonstrated statistically the best model fit and strongest associations with CVD (50)'.

Overall, these large prospective studies showed the same ranking order for predictive ability of the anthropometric indices, i.e. WHtR > WC > BMI. Their authors all support the use of WHtR in their recommendations. We would encourage other researchers, if possible, to conduct ROC analysis in order to help comparability with other studies.

Recent studies published after the systematic review

Our systematic review included papers published until the end of August 2010. This field is now attracting enormous interest and most studies now measure BMI and WC, with many of them also including calculation of WHtR as this requires no further measurement. Discriminatory power is often measured using ROC analysis and by comparing AUCs and so many recent papers would meet our inclusion criteria. We have read these papers and from the authors' data and conclusions, we are confident that they would support the overall conclusions of our meta-analysis.

Comparison with previous meta-analyses

The Obesity in Asia Collaboration meta-analysis of raw data collated specifically in a large database (11) focused on HT and included data from more than 173,000 individuals in 19 cross-sectional studies in the Asia–Pacific region. It concluded that 'No anthropometric variable was systematically better than others at the discrimination of hypertension'. However, based on their pooled AUC values, WHtR had the highest discriminatory capability of the four anthropometric indices in the studies (WHtR > WC > WHpR > BMI), but this was not statistically significant.

Lee's meta-analysis of 10 published studies (12) included data on 88,000 individuals. They consistently found that the AUC values were ranked in this order: WHtR (highest), WC = WHpR and BMI (lowest) with statistical significance being shown between WHtR and BMI for diabetes and for HT in men.

With our increased number of published studies (33) in the meta-analysis and increased subject numbers (n = 305,851), we observed the same consistent ranking order. We found WHtR and WC to be statistically superior to BMI for identifying diabetes in both sexes. Statistical significance was achieved for WHtR, but not WC, in HT in men and women, in CVD in men, and in dyslipidaemia and MS in women. Furthermore our matched pair analysis (Table 3) showed, for the first time, that WHtR was a better discriminator than WC for diabetes, dyslipidaemia, HT and CVD in both sexes.

Waist-to-height ratio and waist circumference compared across a wide range of heights

Many have argued that WC alone is unsatisfactory because people with the same WC but different heights are unlikely to have the same cardiometabolic risk (52). However, it has not often been possible to prove that WHtR is better than WC in populations where there is not a wide range in height. The innovative component of our meta-analysis is not only that it includes a large number of subjects but also studies across different populations, including 15 of Asian ethnicity whose height tends to be shorter than other races (53). This is possibly why we are the first to show conclusively that WHtR is a better screening tool than WC. The effect size was similar in Asian and non-Asian groups so we do not consider the ethnic mix a limitation on the generalizability of our findings. The difference in AUC we have shown between WHtR and WC in Table 3 is modest but we believe it to be clinically significant. Other authors (54) have argued for clinical superiority of different CVD risk scores on the basis of AUC differences of similar size.

Biological plausibility for why waist-to-height ratio could be superior to waist circumference

Many authors have considered mechanisms to explain why measures of abdominal obesity are superior to BMI in predicting cardiometabolic risk. These invariably relate to the high metabolic and inflammatory activity of the visceral fat depots within the abdominal cavity (55) in comparison to subcutaneous depots in other parts of the body such as the gluteo-femoral region (56). This can give a plausible explanation for the superiority of measures of abdominal obesity, which reflect visceral obesity, over BMI in predicting metabolic risk, but why should WC divided by height be superior to WC alone? In general, height has usually been shown to have inverse associations with cardiometabolic morbidity and mortality (57) and this is probably because height, as well as having a major genetic component, can also reflect general early life exposures (58). A recent report from Chile (59) proposes that adverse environmental exposures in critical growth periods in early life 'programme' short stature and predisposition to abdominal adiposity, insulin resistance and other cardiometabolic risk factors in adult life, thus providing a biologically plausible way to explain the superiority of WHtR over WC and BMI. Further, the independent effect of height on cardiometabolic risk might not be the total explanation for the superiority of WHtR. Schneider *et al.* (60) found that short subjects in the DETECT study have higher levels of risk factors than tall subjects if grouped by WC, but not if grouped by WHtR, and they speculate that these differences cannot be attributed to height alone.

Practical considerations of screening tools: waist-to-height ratio is superior to waist circumference

In 2006, Franzosi (61) posed the question 'Should we continue to use BMI as a cardiovascular risk factor?' On the basis of the evidence in our meta-analysis and that of Lee *et al.* (12), we believe that it is definitely time to reconsider other simple screening tools for cardiometabolic risk.

The most effective screening measures must be practical as well as effective. BMI requires measures of weight and height, while WHtR requires measures of WC as well as height. Self-assessment of height is known to be more accurate than that of weight (62) and the measure of WC requires a simple tape measure rather than weighing apparatus. Although WC can be measured at different sites, it has been demonstrated that this does not alter its risk prediction (63). Importantly, WHtR offers advantages of a simple boundary value which could be used for men and women, and maybe children, of all ethnic groups (4). Analysis of suggested cut-off values from 34 analyses in 16 different papers showed that the mean of proposed boundary values for WHtR, weighted for study size, in men and women, respectively, was 0.52 and 0.53 for diabetes, 0.53 and 0.50 for CVD, 0.50 and 0.50 for HT outcomes, 0.49 and 0.49 for lipid outcomes, and 0.50 and 0.49 for MS outcomes. The mean proposed boundary value (the first cut-off level indicating risk) for WHtR was 0.5. Within these study populations, there were subjects with Caucasian, Asian, Afro-Caribbean and Central American ethnic backgrounds (9). We did not calculate a mean value for WHtR in the studies used in this meta-analysis from similar ethic backgrounds, but those authors who suggested a value invariably supported the value of WHtR 0.5. This value not only converts into the simple message of 'Keep your waist circumference to less than half your height', but also provides the first boundary value for increased risk on a public health tool – a chart of WC against height (64–66).

Conclusion

This systematic review and meta-analysis is the first to show that WHtR was a better predictor than WC for diabetes, dyslipidaemia, HT and CVD risk in both sexes in populations of various nationalities and ethnic groups.

By including data on more than 300,000 individuals from diverse populations across the world, it supports previous suggestions that measures of abdominal obesity provide superior tools for discriminating obesity-related cardiometabolic risk compared with BMI. Moreover, WHtR has better discriminatory power than WC.

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Conflict of Interest Statement

The authors declare no conflict of interest. MA devised and copyrighted the Ashwell® Shape Chart which is distributed to health professionals on a non-profit making basis.

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