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A systematic review of waist-to-height ratio as a screening tool for the prediction of cardiovascular disease and diabetes: 0·5 could be a suitable global boundary value

Lucy M. Browning[1], Shiun Dong Hsieh[2] and Margaret Ashwell[1,3]*

[1]*Ashwell Associates Ltd, Ashwell Street, Ashwell, Hertfordshire SG7 5PZ, UK*
[2]*Health Management Centre, Toranomon Hospital, Toranomon, Minato-Ku, Tokyo, Japan*
[3]*Oxford Brookes University, Oxford OX3 0BP, UK*

This systematic review collated seventy-eight studies exploring waist-to-height ratio (WHtR) and waist circumference (WC) or BMI as predictors of diabetes and CVD, published in English between 1950 and 2008. Twenty-two prospective analyses showed that WHtR and WC were significant predictors of these cardiometabolic outcomes more often than BMI, with similar OR, sometimes being significant predictors after adjustment for BMI. Observations from cross-sectional analyses, forty-four in adults, thirteen in children, supported these predictions. Receiver operator characteristic (ROC) analysis revealed mean area under ROC (AUROC) values of 0·704, 0·693 and 0·671 for WHtR, WC and BMI, respectively. Mean boundary values for WHtR, covering all cardiometabolic outcomes, from studies in fourteen different countries and including Caucasian, Asian and Central American subjects, were 0·50 for men and 0·50 for women. WHtR and WC are therefore similar predictors of diabetes and CVD, both being stronger than, and independent of, BMI. To make firmer statistical comparison, a meta-analysis is required. The AUROC analyses indicate that WHtR may be a more useful global clinical screening tool than WC, with a weighted mean boundary value of 0·5, supporting the simple public health message 'keep your waist circumference to less than half your height'.

Waist-to-height ratio: Waist circumference: BMI: Central obesity: Abdominal obesity: Obesity

Introduction

A variety of anthropometric indices have been used as a proxy for total fat or abdominal fat to assess risk for diseases, particularly CVD and diabetes. The most widely recognised is the BMI. Although this measure is correlated with total body fat, it does not distinguish fat from muscle or between different body fat distributions[1]. In the mid 20th century it was first observed that individuals with a central fat distribution were at greater health risk than those with peripheral fat[2,3]. Vague observed that individuals with a 'central type' of fat distribution (android shape) were at greater health risk than those whose fat was deposited 'peripherally' (gynoid shape).

It has only been accepted in the last two decades that health risks (predominantly CVD and diabetes) can be determined as much by the relative distribution of the excess fat as by its total amount. The use of imaging techniques such as computed tomography (CT)[4] and MRI[1,5] indicated that the 'unhealthy apple shape' is associated with a preferential deposition of fat in the internal, visceral fat depots rather than the external, subcutaneous fat depots, this fat distribution being characteristic of the more 'healthy pear shape'[4].

An attempt to assess relative fat distribution was made with the ratio of waist circumference (WC) to hip circumference. This was shown to be a good predictor of health risk and was popular for many years[6]. However, although very useful for risk assessment, waist-to-hip ratio is not helpful in practical risk management because both waist and hip can decrease with weight reduction and so the ratio sometimes changes very little.

It was not until the end of the last century (1995) that WC by itself was proposed as an alternative proxy for central or abdominal obesity[7]. WC is strongly correlated with abdominal fat measures from advanced imaging techniques, and thought to represent fat stored in visceral depots.

Abbreviations: AUROC, area under receiver operator characteristics; DBP, diastolic blood pressure; HR, hazards ratio; ROC, receiver operator characteristics; RR, relative risk; SBP, systolic blood pressure; TC, total cholesterol; WC, waist circumference; WHtR, waist-to-height ratio.

* **Corresponding author:** Dr Margaret Ashwell OBE, email margaret@ashwell.uk.com

However, WC may over- and under-evaluate risk for tall and short individuals with similar WC.

At about the same time, several researchers independently proposed the waist-to-height ratio (WHtR) as another proxy for central obesity, correcting the WC for the height of the individual[8–12]. Similar to WC, WHtR has been strongly correlated with abdominal fat measured using imaging techniques[1,13].

If an anthropometric index is to be used in a public health context and be used for screening, it is invariably useful to invoke cut-off or boundary values. The correction of WC for height offers the advantage that it is possible that a single WHtR boundary value may be useful in different ethnic, age and sex groups[14], while WC requires population-specific boundary values[15].

The present paper systematically reviews the evidence supporting the use of WHtR, a proxy for abdominal fatness, as a predictor of CVD and diabetes, and their risk factors. In order to put the relationships into context, the review draws on evidence from prospective and cross-sectional studies, in adults and in children, which report relationships between WHtR and either BMI or WC, or both. Receiver operator characteristic (ROC) analyses are also summarised to indicate sensitivity and specificity of the potential predictors and to investigate possible boundary values for WHtR.

Methods

Search methods

A systematic literature search of electronic databases was conducted using Medline (from 1950 to week 3 of November 2008) and EMBASE (from 1980 until week 50 of 2008). Search terms were:

BMI OR body mass index OR body mass OR waist circumference OR wst circumference OR wst OR wst circum OR WC

AND

Waist-to-height OR waist to height OR waist height OR waist to ht OR waist-to-ht OR waist ht OR wst height OR wst ht OR WHtR OR waist circumference to height OR (stature AND girth).

Searches yielded 174 203 articles on BMI, 13 646 on WC and 286 on WHtR. Combining categories (to select papers including WHtR and either BMI or WC) and removing duplicates yielded 156 articles. All additional searches were completed up to 19 April 2009. This resulted in some 2009 publications being included. An additional twenty papers were found by hand-searching bibliographies of identified publications and key obesity journals for new or advance online publications and an additional search for waist–stature papers. Where there was difficulty locating the full-text versions of articles and in extracting suitable information, authors were asked to supply. Two reviewers (L. M. B. and M. A.) assessed the suitability of these 176 articles, independently, using the following inclusion and exclusion criteria.

Study inclusion criteria. Inclusion criteria were: (1) human subjects, male, female or mixed, any age, adults or children, any ethnic group; (2) primary studies, either prospective or cross-sectional design; (3) WHtR and either BMI or WC measured at least once; (4) studies must also have a mortality, a cardiometabolic disease endpoint or cardiometabolic risk outcome measure, and present the relationship between obesity and the disease endpoint or risk outcome.

Study exclusion criteria. Exclusion criteria were: (1) literature reviews, intervention studies (although include and use baseline data if they fit inclusion criteria); (2) papers not written in English.

Search results

Figure 1 shows the selection of articles for inclusion in the present review. Of the 176 ‘database’ identified articles, screening papers by title and abstract identified sixty-three as unsuitable. Reviewing the remaining papers from the full text identified a further thirty-seven as unsuitable. This gave a total of ninety-eight papers to be excluded from the review, for the following reasons: eight papers were written in a foreign language, forty-eight did not contain a suitable metabolic outcome measure, seven did not present results for WHtR and either BMI or WC, three were review articles, three were meta-analyses of previously published data, three were intervention studies, two were published letters and twenty did not contain suitable statistical analysis. Finally, we were unable to obtain full-text copies of four publications[16–19].

A total of seventy-eight papers met the inclusion criteria for the systematic review.

Results

The results have been divided by study design (prospective or cross-sectional) and subdivided by health outcome, diabetes and CVD including their respective traditional risk factors. Studies in children have been treated separately. Finally, separate to the analyses of all the data in the systematic review, we present the results of those studies found in the systematic review that included ROC analysis. Significance of study results is as reported in each article; in all cases this is $P < 0{\cdot}05$.

Prospective studies in adults

There were twenty-two separate publications that analysed prospective datasets in adults.

Diabetes outcomes. Table 1 includes the details of nine prospective studies with diabetes as the outcome measure[20–28]. However, two publications described populations derived from the same study group, with the more recent paper describing a smaller subpopulation[20,27].

Table 2 shows the predictive power of WHtR, WC and BMI for diabetes outcomes. Significant predictors were defined as significantly increased OR or hazards ratios (HR) of developing diabetes. WHtR and WC were significant predictors in prospective analyses within six of nine studies, which included men[22], men and women[24,25,27,28] and in men and women of different ethnic backgrounds[23].

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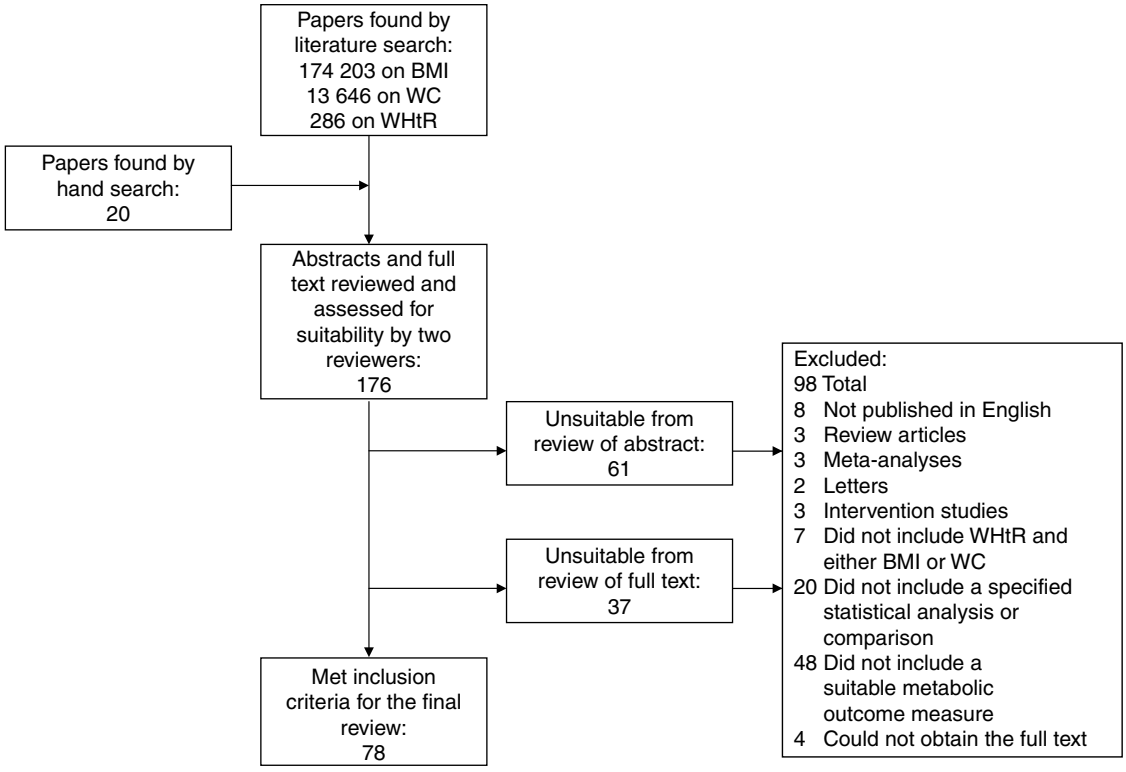

Fig. 1. Flow of the systematic review procedure. WC, waist circumference; WHtR, waist-to-height ratio.

BMI was a significant predictor in five of these same nine studies. Hadaegh *et al.* [22] showed no significant increase in risk across four BMI groups in risk of developing diabetes, after adjustment for additional factors, whilst for WC and WHtR groups there was a significant increased risk.

Other studies were significant in some, but not all of the analyses. Chei *et al.* [21] and Sargeant *et al.* [26] showed that WHtR, WC and BMI were significant predictors in women, but not men. Bray *et al.* [20] showed that WHtR, WC and BMI were significant in men, but not women. This contrasted with the result in the larger group from the same population[27], where WHtR, WC and BMI were significant predictors of diabetes in both men and women.

The values of OR and HR were similar for each of the three anthropometrical indices in most studies (values not presented in Table 2). However, in the Diabetes Prevention Program (DPP) population, the HR for WC in men was 1·42 (95 % CI 1·14, 1·77) for a 1 SD increase, while for WHtR in men the HR was 1·32 (95 % CI 1·08, 1·63) and for BMI was 1·30 (95 % CI 1·07, 1·57)[27]. Bray *et al.* reported similar trends in their subpopulation analysis of the DPP[20]. In contrast, each of the categories used by Hadaegh *et al.* gave higher relative risk (RR) for WHtR than WC or BMI[22].

CVD outcomes. Table 1 includes the details of prospective studies with any aspect of CVD as an outcome. In total, fourteen populations were studied, in fifteen separate analyses. One publication described two separate analyses in two distinct populations, the Women's Health Study and the Physicians' Health Study, which are tabulated separately[29]. Two publications described the same study population, with different outcomes and durations of follow-up, and are tabulated separately[30,31].

The studies have been subdivided by type of outcome, CVD events (fatal and non-fatal) and all-cause mortality[29,31–37], stroke[30,38] and hypertension and blood pressure[21,39–41]. One study was analysed for both diabetes and hypertension (included twice in Table 1)[21], while one study[35] was included after the addition of data published subsequently in response to a letter to the editor[42].

WHtR and WC were again significant predictors of outcomes in most (twelve of fifteen) of the studies, with BMI being a significant predictor in fewer (nine of fourteen) studies (Table 2). In cases where the anthropometric indices were not significant for the whole population, they were often significant in subpopulation analysis. In general, WC and WHtR tended to be significant more often than BMI. For example, Fuchs *et al.* found that WC and WHtR, but not BMI, were significant for hypertension in all study groups[39], and Wessel *et al.* found that WC and WHtR, but not BMI, were significant for all cardiovascular events, fatal and non-fatal[37].

The values of the statistical ratios (OR and HR) were similar for WHtR, WC and BMI in most studies (values not shown in Table 2). For example, Page *et al.* showed very similar OR after adjustment for multiple additional factors, 1·15 (95 % CI 1·10, 1·21) for WHtR, 1·17 (95 % CI 1·11, 1·25) for WC and 1·15 (95 % CI 1·07, 1·24) for BMI[34]. In two studies WHtR was a stronger predictor than WC. Aekplakorn *et al.* showed an OR per 1 SD increase in WHtR of 1·53 (95 % CI 1·21, 1·95) and for WC of 1·35 (95 % CI 1·06, 1·72)[32]. Pischon *et al.* showed for WHtR a RR for

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Table 1. Details of prospective studies in adults with diabetes or CVD as the outcome measure

	Study design			Population				
Study reference	Follow-up duration (years)	Outcome	Analysis type	Subjects (*n*)	Country	Age (years)	Sex	Inclusion criteria
Bray *et al.* (2008)[20]	3·2	Diabetes	HR per 1 SD increase	108	USA	≥25	M and F	Diabetes Prevention Program, control group BMI ≥ 24 kg/m^2, IGT, and IFG (5·3–6·9 mmol/l)
Chei *et al.* (2008)[21]	10·4	Diabetes	OR per 1 SD increase	3391	Japan	40–69	M (*n* 1102); F (*n* 2289)	Non-diabetic, non-hypertensive
Hadaegh *et al.* (2006)[22]	3·6	Diabetes	RR per categorical increase	1852	Iran	≥20	M	Tehran Lipid and Glucose Study Non-diabetic
Mansour & Al-Jazairi (2007)[24]	5	Diabetes	Comparison of means in diabetics *v.* non-diabetics	13 730	Iraq	≥18	M (*n* 7101); F (*n* 6629)	Non-diabetic
MacKay *et al.* (2009)[23]	5·2	Diabetes	OR per 1 SD increase	1073	USA	40–69	M (*n* 472); F (*n* 601)	Insulin Resistance Atherosclerosis Study Non-Hispanic White (*n* 430), African-American (*n* 282), Hispanic (*n* 361)
Nyamdorj *et al.* (2009)[25]	5, 6 and 11	Diabetes	HR per 1 SD increase	3945	Mauritius	25–74	M (*n* 1841); F (*n* 2104)	Non-diabetic, no hypertension, CVD or gout
Sargeant *et al.* (2002)[26]	4	Diabetes	OR per unit increase	728	Jamaica	25–74	M (*n* 290); F (438)	Non-diabetic
Anonymous (2006)[27]	3·2	Diabetes	HR per 1 SD increase	1070	USA	≥25	M (*n* 332); F (*n* 738)	Diabetes Prevention Program, control group BMI ≥ 24 kg/m^2, IGT, and IFG (5·3–6·9 mmol/l)
Tulloch-Reid *et al.* (2003)[28]	5·25	Diabetes	HR per 1 SD increase	1614	USA	≥18	M (*n* 624); F (*n* 990)	Pima Indian population Non-pregnant, non-diabetic
Aekplakorn *et al.* (2007)[32]	17	CVD (fatal and non-fatal MI)	HR per 1 SD increase	2536	Thailand	35–59	M	
Cox *et al.* (1998)[33]	7	CVD morbidity and mortality	OR per quintile	2854	UK	35–75	M (*n* 1284); F (*n* 1570)	Health and Lifestyle Survey No known diabetes, cancer or CVD
Gelber *et al.* (2008)[29]	9	CVD events	RR per categorical increase	16 332	USA	40–84	M	Physicians' Health Study
Gelber *et al.* (2008)[29]	6	CVD events	RR per categorical increase	32 700	USA	>45	F	Women's Health Study
Page *et al.* (2009)[34]	16	CVD (fatal or non-fatal MI)	HR per unit increase	45 563	USA	40–65	F	Nurses' Health Study No cancer, heart disease or stroke
Pischon *et al.* (2008)[35] with additional data in comment Gaglione *et al.* (2009)[42]	9·7	Death (all causes)	RR per quintile	359 387	Nine European countries	25–70	M (34·6 %); F (65·4 %)	European Prospective Investigation into Cancer and Nutrition No history of cancer, heart disease or stroke
Welborn & Dhaliwal (2007)[36]	11	Death (all-cause and CVD)	HR per 1 SD increase	9309	Australia	20–69	M (*n* 4508); F (*n* 4698)	
Wessel *et al.* (2004)[37]	3·9	CVD events (fatal and non-fatal)	OR per unit increase HR per unit increase	906	USA	Adult	F	Women's Ischemia Syndrome Evaluation Study Recruited with chest discomfort or suspected MI
Zhang *et al.* (2004)[31]	2·5	CVD (fatal or non-fatal MI)	RR per tertile increase	67 334	China	40–70	F	Shanghai Women's Health Study No history of stroke, CVD or cancer
Lu *et al.* (2006)[38]	11	All stroke	OR per quintile	33 578	Sweden	30–50	F	Swedish Women's Lifestyle and Health Cohort Study
Zhang *et al.* (2009)[30]	7·3	Total stroke	HR per quintile	74 942	China	40–70	F	Shanghai Women's Health Study
Chei *et al.* (2008)[21]	10·4	Hypertension	OR per 1 SD increase	2972	Japan	40–69	M (*n* 974); F (*n* 1998)	No hypertension
Fuchs *et al.* (2005)[39]	5·6	Hypertension	HR per unit increase	592	Brazil	18–80	M (*n* 255); F (*n* 337)	No hypertension
Nyamdorj *et al.* (2008)[40]	5, 6 and 11	Hypertension	HR per 1 SD increase	3634	Mauritius	25–74	M (*n* 1658); F (*n* 1976)	Non-diabetic, no hypertension, CVD or gout
Panagiotakos *et al.* (2009)[41]	5	Hypertension	HR per unit increase	3042	Mauritius	>18	M (*n* 1514); F (*n* 1528)	No CVD

HR, hazards ratio; M, male; F, female; IGT, impaired glucose tolerance; IFG, impaired fasting glycaemia; RR, relative risk; MI, myocardial infarction.

Table 2. Summary of the results of all prospective studies in adults, by outcome

	WHtR			WC			BMI		
Outcome	Summary score*	Significant in all analyses	Significant in some or none of the analyses	Summary score*	Significant in all analyses	Significant in some or none of the analyses	Summary score*	Significant in all analyses	Significant in some or none of the analyses
Diabetes	6/9	In men[22], men and women[24,25,27,28] and men and women of different ethnic backgrounds[23]	In men, but not women[20], in women, but not men[21], in whole population and men when analysed separately, but not women separately[26]	6/9	In men[22], men and women[24,25,27,28], and men and women of different ethnic backgrounds[23]	In men, but not women[20], in women, but not men[21], in whole population and men when analysed separately, but not women separately[26]	5/9	In men and women[24,25,27,28] and in men and women of different ethnic backgrounds[23]	In men, but not women[20], in women, but not men[21], before, but not after adjustment for IFG/IGT[22] and in whole population and men when analysed separately, but not women separately[26]
CVD events (fatal and non-fatal)	7/9	In men[29,32,36], women[29,31,34,36] and men and women[35]	In non-hypertensive men, but not whole population[33], for all adverse events but not for obstructive CAD, major adverse events or all-cause mortality[37]	7/9	In men[29,32,36], women[29,31,34,36] and men and women[35]	In non-hypertensive men, but not whole population or women[33], for all adverse events but not for obstructive CAD, major adverse events or all cause mortality[37]	6/8	In men[29,32,36] and women[29,31,34,36]	Not in whole population or non-hypertensive men and women[33], for obstructive CAD, all adverse events, major adverse events or all-cause mortality[37]
All stroke	2/2	In women[38] and in women before and after adjustment for BMI[30]		2/2	In women[38] and in women before and after adjustment for BMI[30]		1/2	In women[30]	Before, but not after adjustment for history of hypertension and diabetes[38]
Hypertension, SBP and DBP	3/4	In men and women[39,41] and men and women of different ethnic backgrounds[40]	In urban men and rural women, but not rural men and urban women[21]	3/4	In men and women[39,41] and men and women of different ethnic backgrounds[40]	In urban men and urban and rural women, but not rural men[21]	2/4	In men and women[41] and men and women of different ethnic backgrounds[40]	Not in whole study population[39], in urban men and rural women, but not rural men and urban women[21]

WHtR, waist-to-height ratio; WC, waist circumference; IFG, impaired fasting glycaemia; IGT, impaired glucose tolerance; CAD, coronary artery disease; SBP, systolic blood pressure; DBP, diastolic blood pressure.

* Summary score indicates the number of studies in which all the published analysis showed that the obesity measure was significant in predicting the outcome, out of the total number of studies for this outcome. Data analysed as odds or hazards ratio by cut-off or group of the specified obesity measure.

quintile 1 *v.* quintile 5 of 2·22 (95 % CI 1·94, 2·55) for men and 2·03 (95 % CI 1·76, 2·34) for women[42], but for WC, a RR of 2·05 (95 % CI 1·80, 2·33) for men and 1·78 (95 % CI 1·56, 2·04) for women[35].

Waist-to-height ratio and waist circumference as independent predictors of disease after adjustment or stratification for BMI. Three studies determined whether WHtR and WC were significant predictors of outcome after adjustment for BMI. Two studies[30,35] showed that both WHtR and WC were significant predictors of stroke and all-cause mortality, respectively. However, in the Shanghai Women's Health Study, analysed for a different outcome[31], neither WHtR nor WC was a significant predictor of fatal and non-fatal MI, after adjustment for BMI.

Cross-sectional studies in adults

Cross-sectional outcome measures considered in the present review are any of the risk factors related to CVD and diabetes: blood pressure, lipid outcomes and insulin indices. For adults these have been considered separately, but for children, they have been tabulated and discussed together.

A total of forty-four cross-sectional adult populations were identified, published in forty-three separate publications[9,10,43–83]. Of these forty-four papers, nineteen publications had calculated OR or similar[43–59,64,69] (Table 3), twenty-five papers presented correlation analyses[9,48,55,57–63,66–68,71,73–83], four presented linear regression[9,10,54,70], one random effects[72] and one paper compared means[65] (Table 4).

The majority of studies explored the relationship between the anthropometric indices and a wide range of disease risk factors, namely blood pressure, lipids and insulin indices, as continuous variables. A few studies explored the relationship between disease endpoints and the anthropometric indices and/or explored the relationship between disease endpoints and groups separated by boundary values for anthropometric indices (diabetes[43,49,51,55,56,58,69], coronary artery disease[46,57], hypertension[44,45,47,48,50,54,55,58,59,64,69] and dyslipidaemia[44,45,48,49,53,56,58,59]).

Table 5 shows the results of the cross-sectional studies with OR or similar analysis (categorical outcomes), and Table 6 shows the results of the studies with correlation or linear regression analysis (continuous outcomes).

Diabetes outcomes. OR analysis (Table 5) showed that WHtR was significantly associated with diabetes outcomes in six of seven studies, WC in six of six studies and BMI in six of seven studies. Two studies showed significantly increased odds of having diabetes for each 1 SD increase in WHtR, WC and BMI in German and Australian men and women, respectively[56,58]. The values of the OR were similar for WHtR, WC and BMI in these studies. One study showed significant increased odds of having diabetes across quartiles of WHtR, WC and BMI in Indian men and women[43], but the odds were slightly stronger for WHtR than other anthropometric indices (quartile 4 *v.* quartile 1 was 6·69 (95 % CI 5·25, 8·53) for WHtR, 5·88 (95 % CI 4·66, 7·42) for WC and 4·01 (95 % CI 3·23, 4·99) for BMI). Only one study showed variance in results between the three anthropometric indices: Iranian women with high WC had significantly greater odds of having diabetes, but those with high WHtR and BMI did not[49].

Correlation studies of fasting insulin (Table 6) showed strong and significant correlations in seven of seven studies for WHtR, WC and BMI. Correlations were not so often significant for fasting glucose (significant in twelve of eighteen studies for WHtR and BMI and ten of sixteen studies for WC).

CVD outcomes. Two cross-sectional studies (Table 5) determined odds of CVD and showed that odds of disease were significantly higher for increases in WHtR, WC and BMI[46,57], though BMI was not significant in men[57].

Hypertension outcomes. Of the studies determining odds of hypertension (Table 5), nine of ten showed WHtR to be significant in all analyses, eight of nine studies showed WC to be significant and ten of ten showed BMI to be significant. The results of the studies were consistent and showed increased odds of hypertension in different age[47], sex[54,59] and ethnic groups[50,58] for WHtR, WC and BMI. The many correlation studies (Table 6) gave results that were generally significant for all anthropometric indices, with similar coefficients for systolic blood pressure (SBP) and diastolic blood pressure (DBP)[47,55,66].

Lipid outcomes. Studies determining effects on various lipid outcomes were consistent in their results across the three anthropometric indices. Odds of dyslipidaemia (Table 5) were significantly increased for WHtR in three of four studies, for WC in four of four studies, and for BMI in three of four studies. Significant increased odds of dyslipidaemia were seen per 1 SD increase in WHtR, WC and BMI in men and women[56] and in different ethnic groups[58]. Similarly, increased odds were shown across quartiles of WHtR, WC and BMI for women and WHtR and WC for men[53]. However, Esmailzadeh *et al.* showed no significant increased odds of dyslipidaemia for a high WHtR, although the analysis was significant for WC and BMI[49].

Cross-sectional studies also determined odds of total cholesterol (TC) (two studies), TAG (three studies), LDL (two studies), HDL (three studies), and TC:HDL (two studies). Bertsias *et al.* showed similar results for WC and WHtR, with the odds being significant for LDL and TC:HDL in men and women and TC in men[45]. However, Azizi *et al.* showed no significant increased odds of any lipid outcome for WC, but increased odds of high TC, TAG and LDL with both WHtR and BMI[44].

Many correlation studies (Table 6) determined relationships with TC (sixteen studies), TAG (twenty-one studies), LDL (ten studies), HDL (nineteen studies), TC:HDL (three studies), LDL:HDL (three studies) and TAG:HDL (one study). Results tended to show stronger correlations for all anthropometric indices with TAG and HDL; a larger proportion of studies showed non-significant relationships with TC and LDL.

Waist-to-height ratio and waist circumference as independent risk factors for disease after adjustment or stratification for BMI. In order to determine whether WC

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Table 3. Details of cross-sectional studies in adults: OR analysis

			Population				
Study reference	Study design: analysis type	Outcomes	Subjects (*n*)	Country	Age (years)	Sex	Inclusion criteria
Ajay *et al.* (2008)[43]	OR, quartiles of WHtR, WC and BMI	Diabetes	10 930	India	20–69	M (*n* 6764); F (*n* 4166)	Industrial workers and their families
Azizi *et al.* (2004)[44]	OR, cut-offs of WHtR, WC and BMI	Cut-offs for hypertension, high TC, TAG, LDL, HDL, TC:HDL	9647	Iran	20–70	M (*n* 3622); F (*n* 5025)	
Bertsias *et al.* (2003)[45]	OR, cut-offs of WHtR, WC and BMI	Cut-offs for high SBP, DBP, FPG, TC, TAG, HDL, LDL, TC:HDL	989	Greece	20–40	M (*n* 527); F (*n* 462)	Third year students, University of Crete, School of Medicine
Brouwer *et al.* (2007)[46]	OR per 1 SD increase in WHtR, WC or BMI	CVD	315	The Netherlands	18–80	M (*n* 225); F (*n* 90)	SMART study All have PAD: *n* 79 CVD, *n* 236 no CVD
Cox *et al.* (1997)[47]	OR, quintiles of WHtR, WC and BMI	Hypertension (>140/90 mmHg or treatment)	5991	UK	18–39 (young) and 40–64 (old)	M (*n* 2712); F (*n* 3279)	
Esmaillzadeh *et al.* (2004)[48]	OR, cut-offs of WHtR, WC and BMI	One risk factor for hypertension, diabetes or DYSLIP	4449	Iran	18–74	M	
Esmaillzadeh *et al.* (2006)[49]	OR, cut-offs of WHtR, WC and BMI	Hypertension, diabetes, DYSLIP, MetS one risk factor	5073	Iran	18–74	F	No diabetes or dyslipidaemia medication
Ghosh & Bandyopadhyay (2007)[64]	OR, unit increase in WHtR, WC and BMI	Hypertension	180	India	20–61	M	
Harris *et al.* (2000)[50]	OR, quintiles of WHtR, WC and BMI	Hypertension	15 063	USA	45–64	M (*n* 5332 + 1523); F (*n* 5766 + 2442)	ARIC study
He *et al.* (2008)[51]	Prevalence ratio, above and below a cut-off of WHtR, WC and BMI	Glucose tolerance abnormalities (T2D, IFG or IGT)	50 905	China	18–79	M (*n* 23 980); F (*n* 26 925)	China National Nutrition and Health Survey
Hsieh *et al.* (2000)[52]	OR, split into groups by BMI and WHtR combined	Various metabolic risk factors	2668	Japan	21–85	M	
Jeong *et al.* (2005)[53]	OR, quartiles of WHtR, WC and BMI	DYSLIP	1032	Korea	≥50	M (*n* 356); F (*n* 676)	History of stroke or CVD excluded
Kaur *et al.* (2008)[69]	OR, quintiles of WHtR, WC and BMI	Hypertension and diabetes	2148	India	18–69	M	
Sakurai *et al.* (2006)[54]	Rate ratio per 1 SD increase in WHtR, WC or BMI	Hypertension	4557	Japan	35–59	M (*n* 2935) F (*n* 1622)	
Sayeed *et al.* (2003)[55]	OR, quartiles of WHtR, WC and BMI	Diabetes, IFG and systolic hypertension	1531	Bangladesh	≥20	M and F	
Schneider *et al.* (2007)[56]	OR, per 1 SD increase in WHtR, WC and BMI	Diabetes, MetS and DYSLIP	5377	Germany	20–79	M (*n* 2016) F (*n* 3361)	DETECT Without arteriosclerotic disease
Tseng (2008)[57]	OR per 1 SD increase in WHtR, WC and BMI	CVD	1345	Taiwan	≥18	M (*n* 646) F (*n* 699)	Inclusion of type 1 and 2 diabetics
Wang *et al.* (2007)[58]	OR per 1 SD increase in WHtR, WC or BMI Correlation	Diabetes, hypertension, DYSLIP SBP, DBP, glucose, TC, LDL, HDL, TAG	1186	Australia	Adult	M and F	Aboriginal (*n* 747) or Torres Strait Islanders (*n* 439)
Wu *et al.* (2007)[59]	OR, cut-off for WHtR, WC and BMI Correlation	Hypertension, high TAG, low HDL SBP, DBP, TAG, HDL, HbA1c, FPG	411	China	≥40	M (*n* 198); F (*n* 213)	Newly diagnosed type 2 diabetes, no history of diabetes or diabetic complications

WHtR, waist-to-height ratio; WC, waist circumference; M, male; F, female; TC, total cholesterol; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; SMART, Second Manifestations of ARTerial disease; PAD, peripheral artery disease; DYSLIP, dyslipidaemia; MetS, metabolic syndrome; ARIC, Atherosclerosis Risk in Communities Study; T2D, type 2 diabetes; IFG, impaired fasting glycaemia; IGT, impaired glucose tolerance; DETECT, Diabetes Cardiovascular Risk-Evaluation: Targets and Essential Data for Commitment of Treatment; HbA1c, glycated Hb.

Table 4. Details of cross-sectional studies in adults: correlation analysis

			Population				
Study reference	Study design: analysis type	Outcomes	Subjects (*n*)	Country	Age (years)	Sex	Inclusion criteria
Bosy-Westphal *et al.* (2006)[60]	Correlation	SBP, TC, TAG, HDL, HOMA-IR	335	Germany	28–84	M (*n* 144); F (*n* 191)	KOPS Three generations including one with overweight or obesity
Can *et al.* (2009)[61]	Correlation	SBP, FPG, HOMA-IR, TC, TAG, LDL, HDL	1692	Turkey	≥18	M (*n* 571); F (*n* 1121)	
Chehrei *et al.* (2007)[62]	Correlation	FPG, TC, TAG, LDL, HDL, TC:HDL, LDL:HDL	750	Iran	Mean 43·6 Mean 40·4	M (*n* 170) F (*n* 580)	Excluded hypertension and diabetes
Deshmukh *et al.* (2006)[63]	Correlation	SBP, DBP	2700	India	≥18	M (*n* 1059); F (*n* 1641)	Household recruitment
Esmaillzadeh *et al.* (2004)[48]	Correlation	SBP, DBP, FPG, TC, TAG, HDL, LDL	4449	Iran	18–74	M	
Ho *et al.* (2003)[66]	Correlation	SBP, DBP, FPI, FPG, 2hrG, TC, TAG, LDL, HDL	2895	Hong Kong	25–74	M (*n* 1412); F (*n* 1483)	Exclusion of all with serious diseases, for example, cancer or hospitalised subjects
Hsieh *et al.* (2003)[67]	Correlation	MetS score	8278	Japan	Mean 49·5 Mean 51·9	M (*n* 6141) F (*n* 2137)	
Hsieh & Muto (2005)[68]	Correlation	Sum of coronary risk factors	6521	Japan	Adult	M (*n* 4668); F (*n* 1853)	BMI $< 25\,kg/m^2$
Kotchen *et al.* (2008)[71]	Correlation	SBP, DBP	2747	USA, African-American	18–55	M and F	BMI $< 36\,kg/m^2$, non-diabetic, non-pregnant
Kotchen *et al.* (2008)[71]	Correlation	SBP, DBP	3090	USA	18–55	M and F	NHANES Non-anti-hypertensive treatment, non-pregnant
Lopatynski *et al.* (2003)[73]	Correlation	FPG and 2hrG	1965	Poland	≥35	M and F	
Lovegrove *et al.* (2002)[74]	Correlation	FPI, FPG, TC, TAG, LDL, HDL	28	UK	Adult	F	HRT, BMI < 18 or $> 37\,kg/m^2$, age > 80 years excluded
Maher *et al.* (2009)[75]	Correlation	SBP, DBP, HOMA-IR, HbA1c, FPG, FPI, TC, TAG, LDL, HDL	100	Ireland	≥18	M (*n* 29); F (*n* 71)	Inclusion of never smokers, no history of vascular events, no hypertension, T2D or familial hypercholesterolaemia
Mukuddem-Petersen *et al.* (2006)[76]	Correlation	SBP, DBP, FPG, 2hrG, HbA1c, TAG, HDL	826	Holland	56–83	M (*n* 389); F (*n* 437)	Hoorn Study Excluded if taking lipid-lowering, anti-hypertensive or anti-diabetic medication
Paniagua *et al.* (2008)[77]	Correlation	SBP, DBP, FPG, TAG, HDL	1391	Thailand	≥35	M (*n* 451); F (*n* 940)	Excluded if taking anti-diabetic, anti-hypertensive or lipid-lowering medication
Patel *et al.* (1999)[78]	Correlation	2hrG, FPG, HDL	1606	UK	25–64	M and F	Chinese, European and South Asian
Rissanen *et al.* (1997)[79]	Correlation	FPI, FPG, 2hrG, TAG, LDL, HDL	43	Finland	29–64	F	BMI $28–42\,kg/m^2$ Excluded with diabetes, thyroid, liver, kidney diseases or DBP ≥ 105 mmHg

Sattar *et al.* (1998)[80]	Correlation	MAP, FPI, FPG, TC, TAG, LDL, HDL, LDL:HDL	191	UK	18–69	M (*n* 93); F (*n* 98)	Healthy
Sayeed *et al.* (2003)[55]	Correlation	SBP, DBP, FPG, TC, TAG, HDL:TAG, HDL:TC	4923	Bangladesh	≥20	M and F	
Thomas (1999)[81]	Correlation	DBP	50	Hong Kong	20–55	M and F	Hypertensive (sibling pair analysis not used)
Tseng (2008)[57]	Correlation	SBP, DBP, FPG, HbA1c, TC, TAG	1345	Taiwan	≥18	M (*n* 646); F (*n* 699)	Inclusion of type 1 and 2 diabetics
Turcato *et al.* (2000)[82]	Correlation	SBP, DBP, FPG, 2hrG, TC, TAG, HDL	229	Italy	67–78	M (*n* 83); F (*n* 146)	
Wang *et al.* (2007)[58]	Correlation	SBP, DBP, FPG, TC, TAG, LDL, HDL	1186	Australia	Adult	M and F	Aboriginal (*n* 747) or Torres Strait Islanders (*n* 439)
Wu *et al.* (2007)[59]	Correlation	SBP, DBP, FPG, HbA1c, TAG, HDL,	411	China	≥40	M (*n* 198); F (*n* 213)	Newly diagnosed T2D, no history of diabetes or diabetic complications
Yasmin & Mascie-Taylor (2000)[83]	Correlation	SBP, DBP, TC, HDL, LDL, TC:HDL, HDL:LDL	368	UK	40–69	M (*n* 165); F (*n* 202)	
Gracey *et al.* (2007)[65]	Compared means above and below a cut-off	SBP, DBP, FPI, FPG, TC, TAG, LDL, HDL	401	Australia, Aborigine	Adult	M (*n* 173); F (*n* 228)	
Hsieh & Yoshinaga (1995)[9]	Linear regression	SBP, DBP, FPG, HbA1c, TC, TAG, HDL	1077	Japan	20–78	F	
Hsieh & Yoshinaga (1995)[10]	Linear regression	SBP, DBP, FPG, HbA1c, TC, TAG, HDL, risk factor index	3131	Japan	22–82	M	
Lee *et al.* (2008)[72]	Random effects	SBP, DBP, IFG, HOMA-IR, TAG, HDL	1572	Korea	≥30	M (*n* 577); F (*n* 995)	Twin study Same-sex twins
Khan *et al.* (2008)[70]	Linear regression	SBP, DBP	400	Pakistan	Adult	M (*n* 247); F (*n* 153)	Normotensive
Sakurai *et al.* (2006)[54]	Linear regression	Hypertension	4557	Japan	35–59	M (*n* 2935); F (*n* 1622)	

SBP, systolic blood pressure; TC, total cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; M, male; F, female; KOPS, Kiel Obesity Prevention Study; FPG, fasting plasma glucose; DBP, diastolic blood pressure; FPI, fasting plasma insulin; 2hrG, 2 h blood glucose; MetS, metabolic syndrome; NHANES, National Health and Nutrition Examination Survey; HRT, hormone replacement therapy; HbA1c, glycated Hb; T2D, type 2 diabetes; MAP, mean arterial pressure; IFG, impaired fasting glycaemia.

Table 5. Summary of the results of all cross-sectional studies in adults, analysing data with OR, by outcome*

	WHtR			WC			BMI		
Outcome	Summary score†	Significant in all analyses	Significant in some or none of the analyses	Summary score†	Significant in all analyses	Significant in some or none of the analyses	Summary score†	Significant in all analyses	Significant in some or none of the analyses
Diabetes	6/7	In men and women[43,51,55,56], in men[69] and in different ethnic groups[58]	Not in women[49]	6/6	Significant in men and women[43,51,56], in women[49], in men[69] and in different ethnic groups[58]		6/7	In men and women[43,51,55,56], in men[69] and in different ethnic groups[58]	Not in women[49]
CVD	2/2	In men and women[46,57]		2/2	In men and women[46,57]		1/2	In men and women[46]	In women but not men[57]
Hyperten-sion	9/10	In men and women[54,55,59], young and old men and women[47], in women[49], in men[64,69] and in different ethnic groups[50,58]	In women but not men[44]	8/9	In men and women[54,59], young and old men and women[47], in women[49], in men[64,69] and in different ethnic groups[50,58]	Not in whole study population[44]	10/10	In men and women[44,54,55,59], young and old men and women[47], in women[49], in men[64,69] and in different ethnic groups[50,58]	
SBP	0/1		Not in whole study population[45]	0/1		Not in whole study population[45]	0/1		Not in whole study population[45]
DBP	0/1		In women but not men[45]	0/1		Not in whole study population[45]	0/1		In men but not women[45]
DYSLIP	3/4	In men and women[53,56] and in different ethnic groups[58]	Not in women[49]	4/4	Significant in men and women[53,56], in women[49] and in different ethnic groups[58]		3/4	In men and women[56] and in women[49] and in different ethnic groups[58]	In women but not men[53]
TC	1/2	In men and women[44]	In men but not women[45]	0/2		Not in whole study population[44], in men but not women[45]	1/2	In men and women[44]	Not in whole study population[45]
TAG	2/3	In men and women[44,59]	Not in whole study population[45]	0/3		Not in whole study population[44,45,59]	2/3	In men and women[44,59]	Not in whole study population[45]
LDL	2/2	In men and women[44,45]		1/2	In men and women[45]	Not in whole study population[44]	1/2	In men and women[44]	Not in whole study population[45]
HDL	1/3	In men and women[59]	In men but not women[44], in women but not men[45]	1/3	In men and women[59]	Not in whole study population[44], in men but not women[45]	1/3	In men and women[44]	Not in whole study population[45], in women but not men[59]
TC:HDL	1/2	In men and women[45]	In men but not women[44]	1/2	In men and women[45]	Not in whole study population[44]	0/2		Not in whole study population[45], in women but not men[44]

WHtR, waist-to-height ratio; WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; DYSLIP, dyslipidaemia; TC, total cholesterol.

* Harris *et al.* (2000)[50] OR before adjustment for BMI. Hsieh *et al.* (2000)[52] not included since no relationship of WHtR, WC and BMI separately. Brouwer *et al.* (2007)[46] model 1 quoted. Tseng (2008)[57] model 1 quoted. Metabolic risk score outcome not included in this table[48,56].

† Summary score indicates the number of studies in which all the published analysis showed that the obesity measure was significantly associated with the outcome, out of the total number of studies for this outcome. Data analysed by odds of having the specified outcome by either cut-off or group of the specified obesity measure.

Table 6. Summary of the results of all cross-sectional studies in adults, analysing data with correlation or regression, by outcome

	WHtR			WC			BMI		
Outcome	Summary score*	Significant in all analyses	Significant in some or none of the analyses	Summary score*	Significant in all analyses	Significant in some or none of the analyses	Summary score*	Significant in all analyses	Significant in some or none of the analyses
FPI	7/7	In the population as a whole[65,74,75,79] and divided by sex[66,72,80]		7/7	In the population as a whole[65,74,75,79] and divided by sex[66,72,80]		7/7	In the population as a whole[65,74,75,79] and divided by sex[66,72,80]	
FPG	12/18	In the population as a whole[10,55,65,75,79] and analyses divided by ethnicity[58], age[48], sex[66,72,73,77] or age and sex[76]	Not in whole study population[57,62,74,80], in women, but not men[61,82]	10/16	In the population as a whole[65,75,79] and analyses divided by ethnicity[58], age[48], sex[66,72,73,77] or age and sex[76]	Not in whole study population[57,62,74,80], in women, but not men[61,82]	12/16	In the population as a whole[10,55,65,75] and analyses divided by ethnicity[58], age[48], sex[66,72,73,77,82] or age and sex[76]	Not in whole study population[57,62,74], in women but not men[61]
HOMA-IR	4/4	In the population as a whole[60,75] and divided by sex[61,72]		4/4	In the population as a whole[60,75] and divided by sex[61,72]		4/4	In the population as a whole[60,75] and divided by sex[61,72]	
2hrG	4/6	In analyses divided by sex[66,73,76,78]	Not in whole study population[79], in women, but not men[82]	3/6	In analyses divided by sex[66,73,78]	Not in whole study population[79], in women, but not men[82], in women and young men, but not old men[76]	3/5	In analyses divided by sex[66,73,78]	In women, but not men[82], in old women and young men, but not old men and young women[76]
HbA1c	3/6	In the population as a whole[9,10] and divided by sex[59]	Not in whole study population[75], in women, but not men[57,76]	2/4	In the population as a whole[75] and divided by sex[59]	In women, but not men[57], in women and young men, but not old men[76]	3/6	In the population as a whole[9,10] and divided by sex[59]	Not in whole study population[57,75], in women, but not men[76]
SBP	21/22	In the population as a whole[9,10,55,57,60,63,65,75] and analyses divided by ethnicity[58], age[48], sex[54,59,61,66,70,72,77,82,83] or age and sex[47,76]	In non-hypertensives but not hypertensives[71]	16/19	In the population as a whole[57,60,63,65,75] and analyses divided by ethnicity[58], age[48], sex[54,59,61,66,72,77,83] or age and sex[47,76]	In non-hypertensives but not hypertensives[71], in men but not women[70], in women but not men[82]	19/22	In the population as a whole[9,10,55,57,60,63,65,75] and analyses divided by ethnicity[58], age[48], sex[54,61,66,70,72,77,83] or age and sex[47,76]	In non-hypertensives but not hypertensives[71], in men but not women[59], in women but not men[82]
DBP	18/21	In the population as a whole[9,10,55,57,63,65,75,81] and analyses divided by ethnicity[58], age[48], sex[54,59,66,70,72,77,82,83] or age and sex[47]	In non-hypertensives but not in hypertensives[71], significant in men but not women[70], in young women, but not men or old women[76]	15/19	In the population as a whole[57,63,65,75,81] and analyses divided by ethnicity[58], age[48], sex[54,59,66,70,77,83] or age and sex[47]	In non-hypertensives but not hypertensives[71], significant in men but not women[70], in women but not men[82], in young men and women, but not in old men and women[76]	19/21	In the population as a whole[9,10,55,57,63,65,75,81] and analyses divided by ethnicity[58], age[48], sex[54,59,66,70,72,77,82,83] or age and sex[47]	In non-hypertensives but not hypertensives[71], in women, but not in men[76]
TC	8/16	In the population as a whole[9,10,55,60,62,65] and analyses divided by age[48] or sex[66]	Not in whole study population[57,58,74,75,82], in men but not women[61,80,83]	5/13	In the population as a whole[60,62,65] and analyses divided by age[48] or sex[66]	Not in whole study population[57,58,74,75,82], in men but not women[61,80,83]	8/16	In the population as a whole[9,10,55,60,62,65] and analyses divided by age[48] or sex[66]	Not in whole study population[57,58,74,75,80,82,83], in men but not women[61]
TAG	19/21	In the population as a whole[9,10,55,60,62,65,75,78,79] and analyses divided by ethnicity[58], age[48], sex[59,61,66,72,77,80,82] or age and sex[76]	Not significant in whole study population[74], significant in women but not men[57]	16/18	In the population as a whole[60,62,65,74,75,78,79] and analyses divided by ethnicity[58], age[48], sex[59,61,66,72,77,80,82] or age and sex[76]	Not in whole study population[79], in women but not men[57]	20/20	In the population as a whole[9,10,55,60,62,65,74,75,78] and analyses divided by ethnicity[58], age[48], sex[57,59,61,66,72,77,80,82] or age and sex[76]	
LDL	4/10	In the population as a whole[62,75] and analyses divided by age[48] or sex[66]	Not in whole study population[61,65,74,79], in Torres Islanders but not Aboriginals[58], in men but not women[80]	5/10	In the population as a whole[62,75,79] and analyses divided by age[48] or sex[66]	Not in whole study population[61,65,74], in Torres Islanders but not Aboriginals[58], in men but not women[80]	5/9	In the population as a whole[62,65,75] and analyses divided by age[48] or sex[66]	Not in whole study population[58,61,74], in men but not women[80]

Table 6. *Continued*

	WHtR			WC			BMI		
Outcome	Summary score*	Significant in all analyses	Significant in some or none of the analyses	Summary score*	Significant in all analyses	Significant in some or none of the analyses	Summary score*	Significant in all analyses	Significant in some or none of the analyses
HDL	17/19	In the population as a whole[9,10,60,65,75,78,79] and analyses divided by ethnicity[58], age[48], sex[59,61,66,72,77,80,82] or age and sex[76]	Not in whole study population[62,74]	14/17	In the population as a whole[60,62,65,75,79] and analyses divided by ethnicity[58], age[48], sex[59,61,66,72,77,82] or age and sex[76]	Not significant in whole study population[74], significant in women, but not men[76,80]	14/18	In the population as a whole[9,10,60,65,75] and analyses divided by ethnicity[58], age[48], sex[61,66,72,77,80,82] or age and sex[76]	Not in whole study population[59,62,74], in women, but not men[78]
TC:HDL	2/3	In the population as a whole[55,62]	In men but not women[83]	1/2	In the population as a whole[62]	In men but not women[83]	2/3	In the population as a whole[55,62]	In men but not women[83]
LDL:HDL	3/3	In the population as a whole[62] and divided by sex[80,83]		3/3	In the population as a whole[62] and divided by sex[80,83]		2/3	In the population as a whole[62] and divided by sex[80]	In men but not women[83]
TAG:HDL	1/1	In the population as a whole[55]					1/1	In the population as a whole[55]	

WHtR, waist-to-height ratio; WC, waist circumference; FPI, fasting plasma insulin; FPG, fasting plasma glucose; HOMA-IR, homeostasis model assessment of insulin resistance; 2hrG, 2 h blood glucose; HbA1c, glycated Hb; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol.

* Summary score indicates the number of studies in which all the published analysis showed that the obesity measure was significantly associated with the outcome, out of the total number of studies for this outcome. Data analysed by correlation or regression of the specified obesity measure with the specified outcome. Metabolic risk score outcome not included in this table[10,67].

and WHtR serve as independent risk factors, some cross-sectional studies have determined OR or relationships after adjustments for BMI. Harris *et al.* showed that odds of hypertension increased after adjustment for BMI through quintiles of WHtR and WC in White and African-American women, and in some groups of men[50]. OR were similar for WHtR and WC. Two other studies determined odds of various risk factors in groups with low or high BMI and/or low or high WHtR and showed that the group with high BMI and high WHtR were at the highest risk[51,52].

Prospective and cross-sectional studies in children

A total of thirteen cross-sectional studies were conducted in children[84–96], with one study also including a prospective analysis[87] (Table 7). Seven studies reported correlations, two linear regression and four reported OR above a particular boundary value. In general, studies showed good agreement in the magnitude and outcome of their analysis between WHtR, WC and BMI and outcomes of metabolic risk (Table 8).

For SBP, WHtR, WC and BMI were significantly associated in six of eight, five of six and five of seven studies, respectively. For DBP, WHtR, WC and BMI were significantly associated in three of six, three of four and three of five studies, respectively. Where relationships for SBP and DBP were determined in the same studies, relationships tended to be significant and stronger for SBP than DBP[85,87,89].

For fasting plasma insulin, WHtR and BMI were significantly associated, in four of four studies, for all children, with WC significant in two of two studies. In one study, homeostasis model assessment of insulin resistance (HOMA-IR) was significantly correlated with WHtR, WC and BMI. The relationship between fasting plasma glucose and WHtR, WC and BMI was less convincing in the few studies where it was reported.

For TAG, WHtR was significantly associated in seven of seven studies, WC in three of four studies, and BMI in five of six studies. For HDL, WHtR was negatively associated in three of five studies, WC in three of three studies, and BMI in three of four studies. Of the lipid outcomes, similar to the results in adults, relationships with the anthropometric indices tended to be stronger for TAG and HDL. Hara *et al.* [85] and Kahn *et al.* [95] showed the only significant relationships for TC and WHtR, with three other studies showing non-significant relationships. For LDL, WHtR was significantly associated in six of seven studies, WC in two of four studies and BMI in two of six studies.

In addition to the results in Table 7, four studies determined the relationship between WHtR, WC and BMI and a 'metabolic factor score'. This was significant for WHtR in four of four studies, WC in three of three studies and for BMI in two of three studies.

Summary of results for anthropometric indices as significant predictors of disease risk

The data presented in the present systematic review, from both cross-sectional and prospective datasets, show that WHtR, WC and BMI are useful predictors of CVD and diabetes risk. The balance of evidence suggests that WHtR

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Table 7. Details of cross-sectional studies in children

			Population				
Study reference	Study design: analysis type	Outcomes	Subjects (*n*)	Country	Age (years)	Sex	Inclusion criteria
Botton *et al.* (2007)[84]	Correlation	SBP, DBP, FPI, FPG, TC, TAG, LDL, HDL	452	France	8–17	M (*n* 235); F (*n* 217)	
Hara *et al.* (2002)[85]	Correlation	SBP, DBP, TC, TAG, LDL, HDL, atherogenic index, CVD risk score	888	Japan	9–13	M (*n* 447); F (*n* 433)	
Manios *et al.* (2008)[86]	Correlation	FPI, HOMA-IR	248	Greece	10–12	M and F	
Mirzaei *et al.* (2007)[87]	Prospective (3 years) and correlation	SBP, DBP	1230, 628	Australia	8–9	M (*n* 314); F (*n* 314)	
Ruiz *et al.* (2007)[88]	Correlation	SBP, DBP, MAP	873	Estonia and Sweden	9–10	M (*n* 429); F (*n* 444)	
Sung *et al.* (2007)[89]	Correlation	SBP, DBP, FPI, FPG, TAG, HDL, LDL	1055	Hong Kong	6–12	M (*n* 566); F (*n* 489)	Randomly selected plus some overweight children
Teixeira *et al.* (2001)[90]	Correlation	TC, TAG, HDL, LDL, TC:HDL	159	Portugal	10–15	M (*n* 72); F (*n* 87)	
Kahn *et al.* (2005)[95]	Linear regression	Heart rate, SBP, FPG, TC, TAG, LDL, TC:HDL	6652, 821	USA	4–17	M and F	NHANES III Without diabetes
Mesa *et al.* (2006)[96]	Linear regression	Lipid risk factor score	524	Spain	15·3 ± 1·4 years	F (*n* 259); M (*n* 265)	
Freedman *et al.* (2009)[91]	OR, tertiles	Metabolic score, TAG, LDL, HDL, FPI, SBP, DBP	2501	USA	5–17	M (*n* 1200); F (*n* 1301)	Bogalusa Heart Study
Garnett *et al.* (2008)[92]	OR, cut-offs	CVD risk cluster	164	Australia	Mean 14·9 (SD 0·2)	M (*n* 86); F (*n* 78)	
Maffeis *et al.* (2008)[93]	OR, obesity ± WHtR/WC category	Metabolic syndrome	1479	Italy	5–15	M (*n* 740); F (*n* 739)	
Savva *et al.* (2000)[94]	OR, >75th percentile	High SBP, high TC, high LDL, or high TAG	1987	Cyprus	10–14	M (*n* 1037); F (*n* 950)	

SBP, systolic blood pressure; DBP, diastolic blood pressure; FPI, fasting plasma insulin; FPG, fasting plasma glucose; TC, total cholesterol; M, male; F, female; HOMA-IR, homeostasis model assessment of insulin resistance; MAP, mean arterial pressure; WHtR, waist-to-height ratio; WC, waist circumference; NHANES III, Third National Health and Nutrition Examination Survey.

Table 8. Summary of the results of all cross-sectional studies in children (OR and correlation), by outcome

	WHtR			WC			BMI		
Outcome	Summary score*	Significant in all analyses	Significant in some or none of the analyses	Summary score*	Significant in all analyses	Significant in some or none of the analyses	Summary score*	Significant in all analyses	Significant in some or none of the analyses
FPI	4/4	In girls and boys[84,86,89,91]		2/2	In girls and boys[86,89]		4/4	In girls and boys[84,86,89,91]	
FPG	2/3	In girls and boys[89,95]	In girls but not boys[84]	0/1		In girls but not boys[89]	1/3	In girls and boys[95]	In girls but not boys[84,89]
HOMA-IR	1/1	In girls and boys[86]		1/1	In girls and boys[86]		1/1	In girls and boys[86]	
SBP	6/8	In girls and boys[85,87,89,91,94,95]	In girls but not boys[88], in boys but not girls[84]	5/6	In girls and boys[85,87,89,94]	In girls but not boys[88]	5/7	In girls and boys[87–89,94,95]	In boys but not girls[84], not in girls or boys[91]
DBP	3/6	In girls and boys[84,85,89]	In boys but not girls[87], in girls but not boys[88], not in girls or boys[91]	3/4	In girls and boys[85,87,89]	In girls but not boys[88]	3/5	In girls and boys[84,87,89]	In girls but not boys[88], not in girls or boys[91]
TC	2/5	In girls and boys[85,95]	In girls but not boys[84], in boys but not girls[94] not in girls or boys[90]	0/3		Not in girls or boys[85,90], in boys but not girls[94]	1/4	In girls and boys[95]	Not in girls or boys[84,85], in boys but not girls[94]
TAG	7/7	In girls and boys[84,85,89–91,94,95]		3/4	In girls and boys[85,89,94]	Not in girls or boys[90]	5/6	In girls and boys[84,85,89,94,95]	Not in girls or boys[91]
LDL	6/7	In girls and boys[84,85,89,91,94,95]	Not in girls or boys[90]	2/4	In girls and boys[85,94]	In boys but not girls[89], not in girls or boys[90]	2/6	In girls and boys[85,94]	In girls but not boys[84], in boys but not girls[89], not in girls or boys[91,95]
HDL	3/5	In girls and boys[84,85,89]	Not in girls or boys[90,91]	3/3	In girls and boys[85,89,90]		3/4	In girls and boys[84,85,89]	Not in girls or boys[91]
TC:HDL	1/2	In girls and boys[95]	Not in girls or boys[90]	0/1		Not in girls or boys[90]	2/2	In girls and boys[90,95]	

WHtR, waist-to-height ratio; WC, waist circumference; FPI, fasting plasma insulin; FPG, fasting plasma glucose; HOMA-IR, homeostasis model assessment of insulin resistance; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol.* Summary score indicates the number of studies in which all the published analysis showed that the obesity measure was significantly associated with the outcome, out of the total number of studies for this outcome. Results not tabulated are those where the outcome was not a commonly reported one: lipid factor risk score[96], risk factor cluster[92], metabolic syndrome[93], total risk factors[91], atherogenic index and CVD risk score[85].

and WC are stronger predictors than BMI. In studies where adjustment has been made, WHtR and WC were also predictors of outcomes independent of BMI.

Collating results for all prospective studies (Table 9) showed that WHtR and WC were a significant risk factor in 72 % of all outcomes, and BMI in 58 % of all outcomes. The collations of data from the cross-sectional studies in adults indicate that the WHtR is a significant predictor in 77 % of all outcomes, WC is a significant predictor in 72 % of all outcomes and BMI in 77 % of all outcomes. Similar collations of data from the cross-sectional studies in children indicate the WHtR is a significant predictor in 73 % of all outcomes, WC is a significant predictor in 66 % of all outcomes and BMI in 64 % of all outcomes. Combining all cross-sectional studies in adults and children (Table 9) indicates that the WHtR is a significant predictor in 76 % of all outcomes, WC is a significant predictor in 71 % of all outcomes and BMI in 74 % of all outcomes.

Limitations of prospective and cross-sectional analyses of anthropometric indices. From the evidence presented so far, WHtR and WC appear to be as good, if not better than BMI in predicting metabolic risk. However, while some prospective studies show higher OR or RR with one or other measure, it is difficult to determine whether there is an advantage for clinical practice from this type of analysis of data since most statistical analysis is derived from either continuous relationships or boundary values based on the data itself (per 1 SD, by tertiles, quartiles, quintiles), rather than practical boundary values for diagnostic or screening purposes, for example, BMI $\geq 30\,kg/m^2$, WC ≥ 88 or 102 cm and WHtR $\geq 0{\cdot}5$. Further analysis is therefore required to determine whether either WC or WHtR has an advantage over the other for practical purposes.

Practical use of anthropometric indices for screening purposes

Information from receiver operating characteristic analysis. ROC data provide important information, assessing and comparing the diagnostic accuracy of different tests, for a particular outcome. In conducting the above systematic review, a number of studies undertaking ROC analyses and reporting area under ROC (AUROC) curve data were found. This information was used to further compare the usefulness of WHtR and WC as practical diagnostic tools.

At the stage of searching full papers, thirty-one papers with AUROC analysis were identified, twenty of which[1,23,24,26,28,32,34,36,48,51,54,56,60,61,63,65,66,72,73,77] also met criteria for the review and eleven[97–107] of which were excluded from the systematic review at that stage (as they did not report the required analysis type and usually instead focused on AUROC analysis). Of these thirty-one papers with AUROC analysis, four did not report AUROC values[48,63,98,107], but only reported the optimum cut-off values and one did not report values for WC[100], leaving twenty-six studies reporting full ROC information for different ethnic groups and age ranges. Details of the eighteen studies that met the criteria for the full review are included in the appropriate Tables 1, 3 or 7. Details of the other eight studies are included in Table 10.

Comparison of receiver operating characteristic values: support for waist-to-height ratio as a screening tool. A direct comparison of the AUROC values for WHtR and WC in the twenty-six papers included a total of 147 separate analyses, seventy-one in men, seventy-two in women, and four not divided by sex for a variety of outcomes related to diabetes and CVD risk. These four studies were included in

Table 9. Broad summary of the results of all prospective studies in adults and cross-sectional studies in adults and children by outcome (by number of significant/total number of studies, and percentage)

Study design	Outcome	WHtR	WC	BMI
Prospective: adults	Diabetes	6/9	6/9	5/9
		67 %	67 %	56 %
	CVD events (fatal and non-fatal)	7/9	7/9	6/8
		78 %	78 %	75 %
	All stroke	2/2	2/2	1/2
		100 %	100 %	50 %
	Hypertension, SBP and DBP	3/5	3/5	2/5
		60 %	60 %	40 %
All prospective studies	Total	18/25	18/25	14/24
		72 %	72 %	58 %
Cross-sectional: adults	Diabetes	36/48	32/43	35/45
		75 %	74 %	78 %
	Lipid	64/89	51/79	60/86
		72 %	65 %	70 %
	CVD, hypertension, SBP, DBP	50/57	41/51	49/57
		88 %	80 %	86 %
	Total	150/194	124/173	144/188
		77 %	72 %	77 %
Cross-sectional: children	All health outcomes	35/48	19/29	27/42
		73 %	66 %	64 %
All cross-sectional studies	Total	185/242	143/202	171/230
		76 %	71 %	74 %

WHtR, waist-to-height ratio; WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure.

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Table 10. Details of studies contributing data to the receiver operator characteristic (ROC) analysis (not previously tabulated)

	Study design		Population				
Study reference	Anthropometric indices analysed in ROC	Outcomes	Subjects (*n*)	Country	Age (years)	Sex	Comments
Aekplakorn *et al.* (2006)[97]	WHtR, WC and BMI	SBP, DBP, FPG, TC, TAG, HDL, LDL, TC:HDL, MetS	5305	Thailand	>35	M (*n* 2093); F (*n* 3212)	Inter Asia national cross-sectional survey
Berber *et al.* (2001)[98]	WHtR, WC and BMI	Diabetes, hypertension, DYSLIP	8365	Mexico	>20	M (*n* 2426); F (*n* 5939)	Cross-sectional study of general hospital workers (1994 to 2000)
Diaz *et al.* (2007)[99]	WHtR, WC and BMI	Diabetes	11 624	USA, England	>40 for ROC	M (*n* 5561); F (*n* 6063)	National cross-sectional surveys in USA (NHANES) and England (HSE) (2003–4)
Ko *et al.* (1999)[102]	WHtR, WC and BMI	Diabetes, hypertension, DYSLIP	1513	Hong Kong	37·5 ± 9·2	M (*n* 910); F (*n* 603)	Cross-sectional study in Hong Kong Chinese working population, 1991
Lin *et al.* (2002)[103]	WHtR, WC and BMI	SBP, DBP, FPG, TC, TAG, HDL, LDL, TC:HDL, MetS	55 563	Taiwan	M 37·3 ± 10·9; F 37·0 ± 11·1	M (*n* 26 359); F (*n* 29 204)	Cross-sectional study in health screening centres 1998 to 2000
Mansour & Al-Jazairi (2007)[105]	WHtR, WC and BMI	Diabetes, hypertension	12 986	Iraq	45·6 ± 15·7	M (*n* 6693); F (*n* 6293)	Community-based cross-sectional study
Mirmiran *et al.* (2004)[106]	WHtR, WC and BMI	Diabetes, hypertension, DYSLIP, MetS	10 522	Iran	18–74	M (*n* 4449); F (*n* 6073)	Cross-sectional study within framework of Tehran Lipid and Glucose Study
Shimajiri *et al.* (2008)[107]	WHtR, WC	MetS	5571	Japan	M 47 ± 12; F 44 ± 13	M (*n* 3148); F (*n* 2423)	Cross-sectional study at health centre check-ups

WHtR, waist-to-height ratio; WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; TC, total cholesterol; M, male; F, female; MetS, metabolic syndrome; DYSLIP, dyslipidaemia; NHANES, National Health and Nutrition Examination Survey; HSE, Health Survey for England.

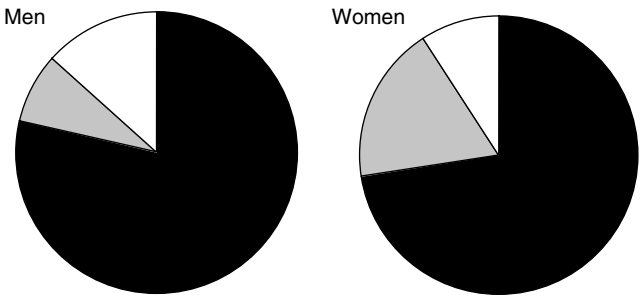

Fig. 2. Ranking of area under receiver operator characteristic (AUROC) values in twenty-six study populations, for 147 separate outcome analyses (seventy-one men, seventy-two women, four included in both). (■), Waist-to-height ratio (WHtR) AUROC > waist circumference (WC) AUROC; (▨), WHtR AUROC = WC AUROC; (□), WC AUROC > WHtR AUROC.

the data for both men and women, giving a total of seventy-five and seventy-six analyses in men and women, respectively. In order to describe the AUROC analyses, we grouped the studies according to whether AUROC values were higher for WHtR, higher for WC or equal for the two outcomes. Figure 2 shows that WHtR, compared with WC, had a higher AUROC value in the vast majority of studies, higher in fifty-eight of seventy-four analyses in men (78 %) and for fifty-four of seventy-five analyses in women (72 %). In several cases, AUROC was the same for WHtR and WC and so WHtR was higher than or equal to WC in sixty-four of seventy-four analyses in men (86 %) and for sixty-eight of seventy-five analyses in women (91 %).

Mean AUROC calculations were weighted for study size. Across the 147 individual analyses in the thirty-one papers, in men and women, the mean AUROC values were 0·704, 0·693 and 0·670 for WHtR, WC and BMI, respectively. Analyses were then grouped by outcome: diabetes, CVD, insulin resistance, hypertension, dyslipidaemia, and the metabolic syndrome. Figure 3 shows the mean AUROC values within each of these categories for men (Fig. 3(a)) and women (Fig. 3(b)). For all outcome categories, in men and women, WHtR showed the highest AUROC value followed by WC, then BMI, indicating that WHtR provides a good screening tool overall for metabolic risk and also for diabetes, CVD and their respective risk factors.

Use of receiver operator characteristic data to suggest boundary values for anthropometric indices

ROC curves can also be used to derive and suggest 'boundary' or 'cut-off' values for anthropometric indices when they are used for practical screening purposes. We prefer the term boundary values, because they are used within a continuous relationship, and hence use it here.

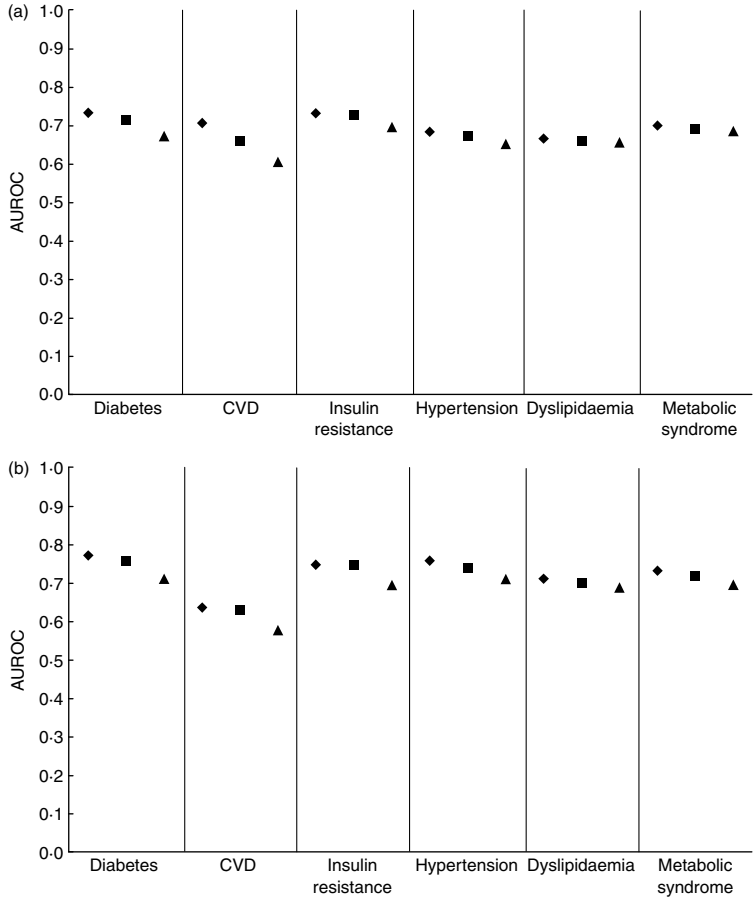

Fig. 3. Mean (weighted for sample size) area under receiver operator characteristic (AUROC) values for waist-to-height ratio (◆), waist circumference (■) and BMI (▲), divided by outcome in men (a) and women (b).

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In a ROC curve, the sensitivity (relating to the ability of the anthropometric indices to predict health outcomes in this case) is plotted against the reciprocal of specificity. The AUROC is then calculated and the higher mean value for AUROC indicates better discrimination by the anthropometric index. If the mean AUROC value is less than 0·5, this indicates very poor discriminatory power and so AUROC values are useful to compare different ROC curves and diagnostic tools.

The AUROC value that represents the best compromise between sensitivity and specificity, for any tool often the so-called turning point in the graph, is converted back to suggest a 'real' boundary value for the appropriate diagnostic tool.

Figure 4 shows the boundary values, as derived and suggested by authors themselves, for WHtR (Fig. 4(a)) and WC (Fig. 4(b)) for screening different metabolic outcomes. These thirty-five analyses arise from sixteen papers from several investigators studying populations in many different countries covering a wide age range and several ethnic groups[24,26,32,36,56,63,66,73,97–99,102,103,105–107]. Within these study populations, there were subjects with Caucasian, Asian, Afro-Caribbean and Central American ethnic backgrounds.

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 hypertension outcomes, 0·49 and 0·49 for lipid outcomes and 0·50 and 0·49 for metabolic syndrome outcomes. The mean of all suggested boundary values for WHtR over thirty-four individual analyses covering all outcomes was 0·50 in men and 0·50 in women.

The mean of proposed boundary values for WC, weighed for study size, in men and women respectively, was 88 and 83 cm for diabetes, 92 and 79 cm for CVD, 85 and 79 cm for hypertension outcomes, 84 and 77 cm for lipid outcomes and 83 and 77 cm for metabolic syndrome outcomes. The mean of all suggested boundary values for WC over the same thirty-four different analyses covering all outcomes (data not shown) was for 86 cm in men and 79 cm in women.

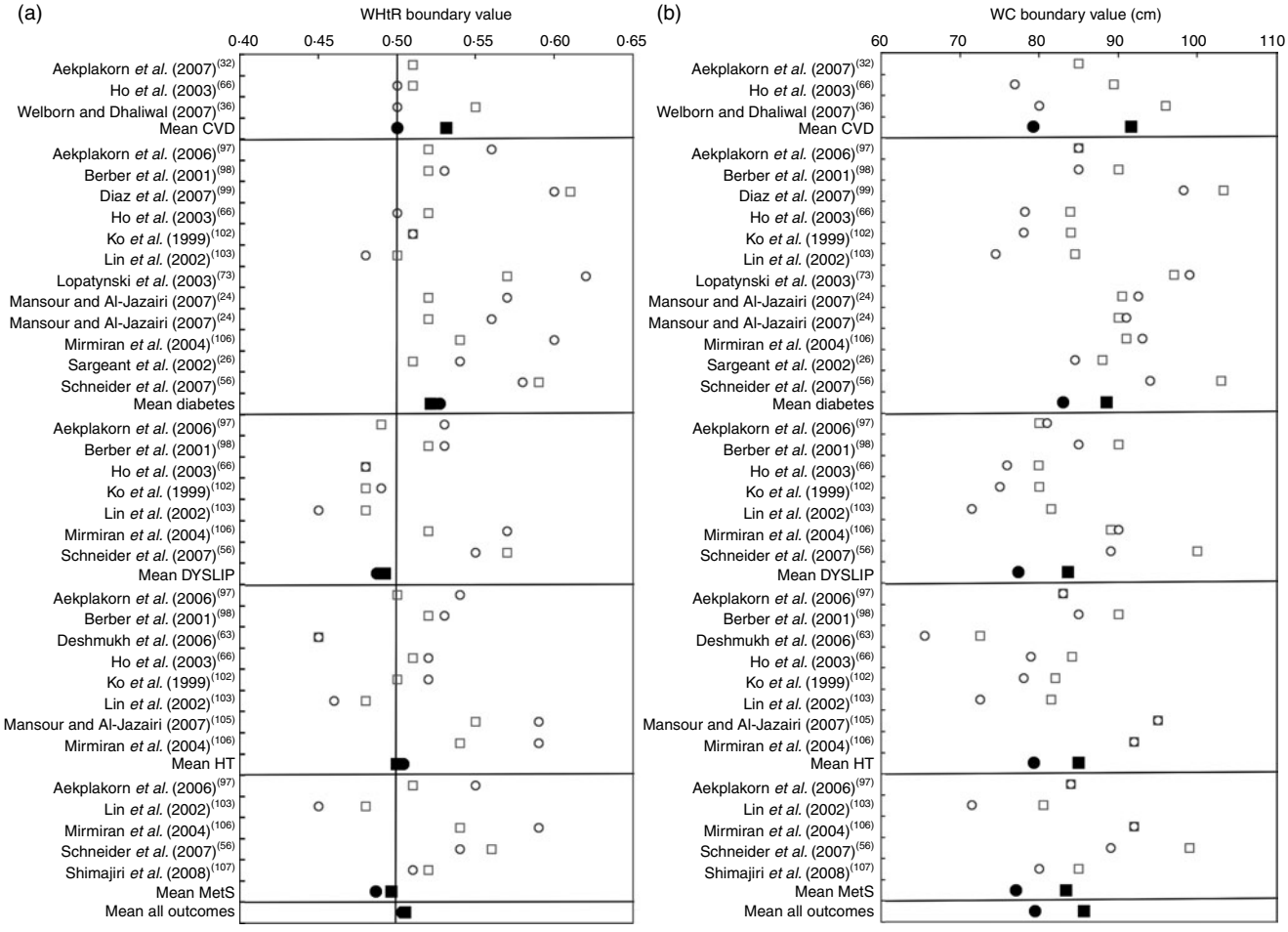

Fig. 4. Proposed boundary value for waist-to-height ratio (WHtR) (a) and waist circumference (WC) (b) from area under receiver operator characteristic (AUROC) analysis for men and women, by outcome. Mean boundary value in men (□) and women (○) in individual studies and as a mean by outcome in men (■) and women (●). Overall mean boundary values are weighted for individual study sample sizes. WC was measured at four different anatomical sites across studies; the minimum WC[26,98,106], WC at or 1 cm from the umbilicus[24,32,73,97,105,107], WC at the midpoint between the xiphisternum and the umbilicus[66] or using the WHO definition of halfway between the lower rib and the iliac crest[56,63,99,102,103]. The studies were performed in the following population groups: Asian[32,63,66,97,102,103,107]; Middle Eastern[105,106]; North American[99]; Central American[98]; Caribbean[26]; European[56,73,99]. DYSLIP, dyslipidaemia; HT, hypertension; MetS, metabolic syndrome.

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Discussion

The present review is the first systematic review of the evidence supporting the use of WHtR, a proxy for abdominal fatness, as a predictor for cardiometabolic risk (i.e. predicting risk factors for CVD and diabetes). It draws on evidence from prospective and cross-sectional studies in both adults and children. Moreover, it puts the relationship between WHtR and disease into context with other proxies for obesity and abdominal obesity, namely BMI and WC. As an additional analysis, results of ROC analyses have also been summarised to indicate sensitivity and specificity of the potential predictors and to investigate possible boundary values for WHtR.

The systematic review included data from some very large, nationally representative cohorts, in a variety of ethnic groups. Importantly, results are consistent between adults and children.

The 'summary scores' in Tables 2, 5, 6 and 8 represent our attempt, in the absence of a full meta-analysis, to summarise the outcomes of the different types of studies. We acknowledge the limitations of these 'summary scores' and that statistical significance depends on many factors such as size of the study population and the incorporation of demographic or physiological adjustment variables. Each of the three anthropometric indices is more likely to appear 'significant' in the largest study populations even though the effect size (strength) of the associations could be quite different. In cross-sectional studies, there was a tendency for very large populations to produce significant findings.

We also acknowledge that the conclusions from a systematic review can only be as good as the studies included within it. We have relied on studies published in the English language and acknowledge that publication bias may have influenced the present results. Some studies showing different results may not have been submitted for publication by their authors and some submitted studies showing different results may have been denied publication. However, the strength of any systematic review is that it is a comprehensive, transparent and an inclusive process which overcomes many other sources of bias which are sometimes found in narrative reviews.

Prospective studies in adults indicate that WHtR and WC are similarly useful as predictors of diabetes and CVD, being significant predictors with similar OR or HR. In some studies WHtR and WC have higher OR or HR than BMI or remain significant predictors after adjustment for BMI, indicating that they are possibly better predictors than BMI. Cross-sectional studies in adults and children supported the observations in prospective studies, with WHtR, WC and BMI all showing a similar proportion of significant relationships with risk factors for diabetes and CVD.

Determination of specificity and sensitivity from ROC analysis clearly showed that WHtR has high AUROC values for all the outcome measures related to diabetes and CVD. From this, we suggest that WHtR would be a good screening tool, probably better than WC (see Fig. 2).

In their paper 'Six reasons why the waist-to-height ratio is a rapid and effective global indicator for health risks of obesity and how its use could simplify the international public health message on obesity'[14] Ashwell & Hsieh presented a narrative review of evidence to support their six reasons which they listed as follows:

(1) WHtR is more sensitive than BMI as an early warning of health risks.
(2) A boundary value of WHtR of 0·5 indicates increased risk for men and women.
(3) A boundary value of WHtR of 0·5 may indicate increased risk for individuals in different ethnic groups.
(4) WHtR is cheaper and easier to measure and calculate than BMI.
(5) WHtR may allow the same boundary values for children and adults.
(6) WHtR boundary values can be converted into a consumer-friendly chart.

Point number (1) focused on the likelihood that WHtR, as an anthropometric index which is a proxy for central obesity, could be more useful than BMI in the prediction of health risks (the word sensitive was not used in relation to any particular boundary value in this case). The present systematic review has provided supportive evidence for this point, with WHtR (and WC) being a risk factor more often than BMI. Further, the AUROC analysis has provided good evidence that WHtR is probably a better diagnostic predictor than BMI or WC. To provide further statistical support for this statement a meta-analysis is required. However, this is beyond the scope of the present systematic review. The AUROC data have also provided good evidence that the suggestion made in point number (2) that a WHtR of 0·5 is a good boundary value for men and women across many ethnic groups. Comparison of the summary lines covering all health outcomes in Fig. 4(a) and (b) and the suggested mean boundary values for WHtR and WC show clearly that the same boundary value of WHtR can be used for men and women (0·5), whilst distinct WC boundary values must be used.

Thus, these analyses support the proposal that WHtR may be advantageous because it avoids the need for age-, sex- and ethnic-specific boundary values[14] and helps to avoid the confusion whereby many different boundary values for WC have been published for different ethic groups[107]. If the suggested boundary value of WHtR 0·5 were to be adopted, this would simplify the application of this diagnostic tool to provide the health message 'keep your waist circumference to less than half your height'. Further studies are required in men, women and children of different ethnic groups to add support to point number (5).

In relation to point (4), WC can be measured more cheaply and less intrusively than BMI, since measuring weight requires accurate scales and often requires some degree of subject undressing. However, it is recognised that WC can be measured at a variety of different sites (indicated in the legend for Fig. 4(a) and (b)) and that this will affect the boundary value. Importantly, comparison of WC measured at a variety of sites indicates that all are highly reproducible and are similarly correlated with total body fat in a sex-dependent manner[108]. While measuring the narrowest WC would be expected to give smaller values of WC than other techniques, it is interesting in Fig. 4(a) and (b) that the studies using this method did not give the smallest boundary value for WHtR or for WC.

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In relation to point number (6), the principle of a Shape Chart, to replace a Weight Chart, was proposed as early as 1995[109]. Prototypes of charts for adults based on boundary values for WHtR were suggested shortly afterwards[110,111], followed by the publication in 2005[14]. The AUROC data have confirmed that 0·5 is an appropriate boundary value for increased risk in men and women from many ethnic groups. Further corroboration of 0·6, originally proposed pragmatically as a boundary value for higher risk[111], and the appropriate boundary value for risk in children, awaits further studies.

Final conclusions

Observations of seventy-eight prospective and cross-sectional studies suggest that while WHtR, WC, and BMI are all predictors of CVD, diabetes and related risk factors, WHtR and WC are more probably reliable predictors than BMI. A meta-analysis is now required to provide further statistical support for these suggestions. The AUROC analysis and the calculation of a weighted mean WHtR of 0·5 suggests that WHtR is a suitable screening tool applicable to a wide variety of populations. Its simplicity and its conversion to the easily remembered public health message 'keep your waist circumference to less than half your height' argues for its practical adoption.

It is pleasing that various authoritative bodies recognise the importance of central obesity by recommending the use of WC as a useful screening tool in many primary care situations. However, there is the problem that at least five different cut-off levels of WC, for different sexes, ethnic groups and even different countries, have been proposed (summarised in Alberti *et al.* 2009[112]) to account for the effect of height on metabolic risk within different populations. The use of WHtR, with a simple global boundary value of 0·5, could overcome this confusing situation, with obvious benefit to the public health promotion message.

The early phase of the systematic literature search indicated that the number of papers that reported relationships between WHtR and health outcomes is miniscule in the context of those which report other simple obesity measures and health outcomes: they are only 2 % of WC papers, and 0·2 % of BMI papers. It is, perhaps, surprising that, up to the cut-off point for our systematic review (end of 2008), as many as seventy-eight 'included' papers had calculated WHtR as well as WC when they were investigating the effect of central obesity on a variety of health outcomes. We have noticed a substantial increase in WHtR papers in 2009 and the first part of 2010[113–118], many of which provide data to support the use of the boundary value of 0·5, or use 0·5 as the boundary value to divide their population and assess risk. We hope that the evidence summarised here for WHtR as a predictor of diabetes, CVD and related risk factors, and the usefulness of the global boundary value of 0·5, will encourage the use of this index in existing and future studies. This would provide more data and allow further consideration and confirmation of clinically relevant boundary values for WHtR in children as well as adults.

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L. M. B. was involved in study design, collected the data and prepared the manuscript, M. A. and S. D. H. were involved in study design, preparation and review of the manuscript.

There are no conflicts of interest to declare.

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