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REVIEW ARTICLE

Different anthropometric adiposity measures and their association with cardiovascular disease risk factors: a meta-analysis

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Abstract
Objectives To investigate which anthropometric adiposity measure has the strongest association with cardiovascular disease (CVD) risk factors in Caucasian men and women without a history of CVD.
Design Systematic review and meta-analysis.
Methods We searched databases for studies reporting correlations between anthropometric adiposity measures and CVD risk factors in Caucasian subjects without a history of CVD. Body mass index (BMI), waist circumference, waist-to-hip ratio, waist-to-height ratio and body fat percentage were considered the anthropometric adiposity measures. Primary CVD risk factors were: systolic blood pressure, diastolic blood pressure, high density lipoprotein (HDL) cholesterol, triglycerides and fasting glucose. Two independent reviewers performed abstract, full text and data selection.
Results Twenty articles were included describing 21,618 males and 24,139 females. Waist circumference had the strongest correlation with all CVD risk factors for both men and women, except for HDL and LDL in men. When comparing BMI with waist circumference, the latter showed significantly better correlations to CVD risk factors, except for diastolic blood pressure in women and HDL and total cholesterol in men.
Conclusions We recommend the use of waist circumference in clinical and research studies above other anthropometric adiposity measures, especially compared with BMI, when evaluating CVD risk factors.

Keywords Meta-analysis · Cardiovascular disease risk factors · Anthropometric · Adiposity · Waist circumference

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Introduction

The World Health Organisation reported cardiovascular disease (CVD) to be death cause number one globally with 29% of all-cause deaths, which is 17.1 million people, in 2004 [1]. Researchers found these mortality rates to be closely associated to certain CVD risk factors [2–4]. These CVD risk factors are abdominal obesity, high blood pressure, low high-density lipoprotein cholesterol (HDL-C) levels, high triglyceride levels and high fasting glucose [2]. The criteria of the Adult Treatment Panel III (ATP III) of the National Cholesterol Education Program state that having three out of these five CVD risk factors defines the metabolic syndrome and involves an overall increase in all-cause and CVD death [2–4].

Adiposity has proven to be an important risk factor for cardiovascular disease and is strongly associated with CVD

risk factors [2, 5]. Most studies use anthropometric measures to measure adiposity. Waist circumference and waist-to-hip ratio have been used as measures of central obesity (where visceral adipose tissue is stored), and body mass index (BMI) (kg/m^2) has been used as a measure of general obesity [6]. Studies that analysed associations between anthropometric measures and abdominal visceral fat, measured with computed tomography, reported waist circumference to be a better measure of central obesity [6–9].

A recent systematic review investigated the importance of obesity and cardiorespiratory fitness related to the risks of and mortality due to CVD and diabetes type 2 [5]. They found BMI to be the most frequently used measure of adiposity in the included studies and raise a few questions about the overall applicability of the BMI. For instance, BMI neither gives an indication of the relation between fat and fat-free mass, nor does it indicate fat distribution. For a given BMI, physically fit individuals have less total and abdominal fat, compared with unfit individuals. A large muscle mass instead of fat mass will also place people in higher BMI categories. This is supported by a large study that investigated the diagnostic accuracy of BMI to detect adiposity [10]. They found limited diagnostic performance of the BMI in correctly identifying individuals with excess in body fat (BF), particularly in those with BMI<30. Although BMI has a good correlation with BF%, it failed to discriminate between BF% and lean mass [10]. In addition, BMI is also criticised because it makes no difference between men and women, even though we know fat distribution is significantly different between men and women [10, 11]. Also age and ethnicity have an effect on body fat distribution and are not differentiated in BMI [7, 11, 12]. Is it not wiser to use a different type of adiposity measurement?

Although relationships between anthropometric adiposity measures and CVD risk factors have been explored thoroughly in many studies around the world, results have to our knowledge never been combined quantitatively in a meta-analysis. To eliminate ethnic differences we choose to focus on studies that describe Caucasian populations.

Therefore the aim of this study was to study the following research question: which anthropometric adiposity measure has the strongest association with CVD risk factors in Caucasian men and women without a history of CVD?

Methods

Definitions

Cardiovascular disease risk factors

We chose to focus on the CVD risk factors reported by the ATP III definition [2]. High blood pressure (systolic blood pressure >130 mmHg and/or diastolic blood pressure >85 mmHg), low HDL-C (men <1.03 mmol/l; women <1.30 mmol/l), high triglycerides (>1.70 mmol/l) and fasting glucose (>6.1 mmol/l).

Anthropometric adiposity measures

We only considered simple measures that give an indication of fat mass or body fat distribution. The most frequently used measures were BMI, waist circumference, waist-to-hip ratio, waist-to-height ratio and BF% calculated from skin folds or bio-electrical impedance. Studies that describe anthropometric methods not commonly used in practice were excluded. Examples of such methods are magnetic resonance imaging or dual-emission X-ray absorptiometry techniques.

Body mass index

General obesity is widely measured with the BMI. BMI is calculated as weight in kg divided by squared height in meters (kg/m^2). There is consensus about the used cut-off points in a Caucasian population, which are described in Table 1 [11, 13].

Waist circumference

Waist circumference is reported as the better measurement for central obesity and therefore a good predictor of abdominal visceral fat [6–9]. There is general consensus about waist circumference cut-off points for increased CVD risk in a Caucasian population: >102 cm for men and >88 cm for women [2, 11, 13]. These cut-off points correspond to the BMI values for "obese class I" where >90 cm for men and >80 cm for women correspond to BMI values for "overweight/pre-obese" [14].

Waist-to-hip ratio

This ratio was developed because waist and hip circumferences measure different aspects of body composition and fat distribution and have independent and often opposite effects on CVD risk factors. A narrow waist and large hips

Table 1 BMI cut-off points

Classification	BMI (kg/m^2)
Underweight	<18.5
Normal weight	18.5–24.99
Overweight	≥25.00
- Pre-obese	25.00–29.99
- Obese I	30.00–34.99
- Obese II	35.00–39.99
- Obese III	≥40.00

may both protect against cardiovascular disease [15]. Cut-off points that indicate increased CVD risk for waist-to-hip ratio have been calculated by Dobbelsteyn et al. and are 0.9 and 0.8 for men and women, respectively [14].

Waist-to-height ratio

This simple measure adds the factor height to the waist circumference. Like the other anthropometric adiposity measurements, ethnic differences require different cut-off points. For Caucasian populations, however, we did not find any well-established cut-off points for waist-to-height ratio.

Body fat percentage

Two methods of anthropometric BF% measurement techniques have been developed and validated. First is the skin fold method where BF% can be calculated from skin fold measures at four sites on the body [16]. Second bio-electrical impedance can be used to estimate BF%. With this method a small alternating current is applied to the body. Different body tissues have different resistivity and therefore a calculation can be made with this method to estimate the BF% [17]. A BF% of >25% or >35% for men and women, respectively, is correlated to a BMI of 30 and chosen as cut-off-points for Caucasian people [12].

Caucasians

Defining who is Caucasian or not is problematic. Strictly, they might be the people who lived in the Caucasus, but in common use a Caucasian is referred to as a European or someone with European ancestry. This is somewhat hard to control when examining a large population, for example, in the US or Australia. In scientific literature Caucasians are also sometimes called whites. In this review we chose to include only Caucasians because of reported differences in anthropometric adiposity measures and their associations with CVD risk factors in different ethnicities. In selecting articles for this review we chose to exclude mainly the studies that comprised populations of which we knew they differ from Caucasian populations. For example Asians [2, 12, 18, 19], Africans [2, 12, 20], Aboriginal Australians [21] and Hispanics/Latin Americans [2, 22] have been studied and reported to differ from standards based on Caucasian populations.

We included studies that describe European, American, Canadian and Australian populations. No studies were found that reported big differences between these populations. This does not mean, however, that differences do not exist.

Search strategy

A search strategy was created by the first author (SvD) with the support of a medical librarian and critically reviewed and approved by the direct supervisor (HW). After approval published articles in the following databases were searched: PubMed (1966–Nov. 2009), CINAHL (1966–Nov. 2009), EMBASE (1947–Nov. 2009) and Cochrane Controlled Trials Register (CENTRAL) (The Cochrane Library 2009 issue 11). The search strategy did not have any limitations on ethnicity. Five potentially eligible articles were manually searched before applying the search strategy. When conducting the search strategy these five articles had to be found to ensure that the strategy covered all our criteria. This method fine-tuned the strategy and created a small certainty that we did not miss important articles.

Eligibility criteria

Types of participants

Only studies that described results on Caucasian adults without a history of CVD were included.

Types of studies

All types of research designs were included. Only studies for which a full-text article in the English or Dutch language was available were considered for inclusion.

Types of outcome measures

Included were studies that reported correlations between different anthropometric adiposity measures and CVD risk factors. At least two anthropometric measures had to be compared with at least three of four CVD risk factors. Secondary outcomes were total cholesterol and low-density lipoprotein cholesterol data. The possibilities are displayed in Fig. 1. The study had to report correlation coefficients between anthropometric adiposity measures and CVD risk factors. If these correlations were not reported, but could be calculated from given data, the study was considered for inclusion. Correlation coefficients had to be reported for men and women separately and in the case of multi-ethnic studies the data had to be reported for each ethnic group, in order to extract Caucasian data. When this was not the case this study was excluded.

Study selection

One reviewer (SvD) made a first selection of articles based on title only. Only study titles obviously not involving any study criteria for this review were excluded.

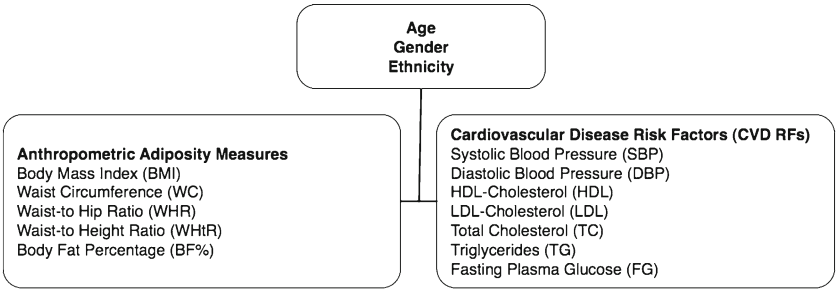

Fig. 1 Graphical display of all outcome measures

After exclusion based on title alone two independent reviewers (SvD and EP) selected articles based on the abstract. After selection, the reviewers independently applied the inclusion criteria on the full text articles and decided on inclusion or not. Disagreement with including articles was solved with discussion and a third reviewer was consulted if disagreement still persisted.

Study quality assessment

We chose not to assess methodological quality of the included studies. There is no consensus on which checklist to use and most checklists involve quality assessment of clinical trials [23]. Our research question can not be answered with results from clinical trials, so most available checklists will not be useful to us. Also we found no recommendations on how to incorporate a quality score in a meta-analysis.

Data extraction

In case of good but insufficient data presented in the studies, authors were mailed to gain more specific results that could be used in our meta-analysis. Data from included articles were summarised in a table. Two independent reviewers selected data on relevant characteristics to minimise potential bias or mistakes in the data extraction process. Characteristics described in the table were: first author and publication year, study name (acronym), baseline year(s), sample size, population age, population gender, population ethnicity, anthropometric adiposity measurements used, CVD risk factors assessed, association parameter used, statistical adjustments, association parameter results.

Data interpretation

Pearson correlations were interpreted according to magnitudes as proposed by Cohen et al. [24]. Very small: 0.0–0.1, small: 0.1–0.3, moderate: 0.3–0.5, large: 0.5–0.7, very large: 0.7–0.9 and almost perfect: 0.9–1.0.

Statistical analyses

We used a fixed-effects model for computing mean correlations. First, all correlations were converted to the Fisher's z-scale and weighted by the number of subjects to calculate the mean Fisher's Z as described by Field et al. in Eq. 2 [25]. These were inverted in the end to display an actual r-value. With use of standard deviations of these r-values and the number of studies performed, we calculated the 95% confidence interval (95% CI) for each of the mean correlations and plotted the results for each CVD risk factor in a forest plot. By examining the 95% CI we determined the statistical significance between the correlations for each of the anthropometric adiposity measures. When 95% CIs did not overlap we assumed a significant difference at the $p=0.05$ level. When 95% CIs overlapped, a 95% CI was calculated for the difference between the means and determined whether this 95% CI contained zero. If it did contain zero the difference was not significant and if it did not contain zero the difference was deemed significant [26]. All statistical analyses were performed in Microsoft Office Excel 2008 for Mac.

Results

Study selection

The search strategy yielded a total of 991 hits. Ninety-eight articles initially appeared to meet inclusion criteria, 78 of which were eventually excluded, resulting in a total of 20 definite inclusions. A flowchart displaying exact details on the definite inclusion is presented in Fig. 2. Most exclusions in the full-text selection were made because complete data were not available, other statistics than Pearson or Spearman correlations were used, a separate analysis was not performed for ethnic groups or gender and there were multiple publications describing the same study population.

Study characteristics

The oldest article included was published in the year 1986 and the most recent study was published in 2009. Most

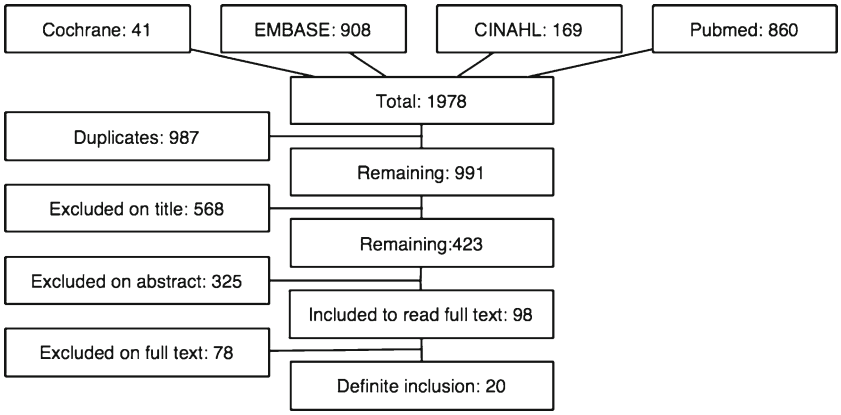

Fig. 2 Article flow chart

studies used cross-sectional designs and tested persons who voluntarily participated in preventive medical examinations. All studies together examined a total of 45,757 subjects; 21,618 males and 24,139 females. Nine studies, comprising 86% of all subjects together, included subjects roughly between 18 and 90 years of age. The other studies included only subjects within a smaller age spectrum.

Distribution of subjects in the four major regions was quite identical with 12,037 subjects from the USA (4 studies), 9820 subjects from Canada (3 studies), 11,247 subjects from Australia (1 study) and 12,653 subjects from Europe (12 studies).

BMI, waist circumference (WC), waist-to-hip ratio (WHR), waist-to-height ratio (WHtR) and BF% were described in 19, 16, 17, 6 and 1 study respectively. BF%, calculated from four skin folds, was only reported by Contaldo et al. [27] and therefore there was no manner to quantitatively analyse this data. Results of this study were not included into our analysis.

Twelve studies described all four primary CVD outcome measures [15, 28–37], eight described only three [9, 38–44]. The study by Seidell et al. [41] described five different European populations and reported data for each population separately. These data were therefore analysed as five different study populations.

All studies used a Pearson correlation coefficient to determine associations except for the study by Ohrvall et al. [35] who used a Spearman rank correlation coefficient. Studies varied in use of adjustments in calculation of the correlation coefficients but when we studied the data we found no obvious differences between adjusted and unadjusted data. More detailed information about the study characteristics are displayed in Table 2.

Study results for men

All data on men are displayed in Fig. 3. Moderate correlations were found for all anthropometric adiposity measures with triglycerides (TG). Also, moderate correlations were found for WC with systolic blood pressure (SBP), and for BMI and WC with diastolic blood pressure (DBP). All other correlations were small. We found the strongest correlations between WC and SBP, DBP, total cholesterol (TC), triglycerides (TG) and fasting glucose (FG). These correlations were significantly higher than those of other anthropometric adiposity measures for SBP and DBP. For HDL we found WC to correlate almost as well as BMI. For LDL we found WHR to have the best correlation, however not significant. We found WC to correlate significantly better than BMI with SBP, DBP, LDL, TG and FG. The weakest correlate to all the CVD risk factors was WHtR, significantly differing from other anthropometric adiposity measures for SBP, DBP, HDL, TC and FG.

Study results for women

All data on women are displayed in Fig. 4. Very small correlations were found for WHtR with LDL and TC. Moderate correlations were found for WC with SBP, WC and BMI with DBP, WC with HDL and BMI, WC and WHR with TG. All other correlations were small. For all CVD risk factors WC was the strongest correlate. This correlation was found to be statistically significant ($p<0.05$) for SBP only. For LDL, TC, TG and FG, WHR approached the WC correlation, making WC not the overall significantly better correlate. WC correlates significantly better with all CVD risk factors than BMI ($p<0.05$), except for DBP. We found WHtR to be the weakest correlate of all anthropometric adiposity measures.

Discussion

The aim of our study was to investigate which anthropometric adiposity measure had the strongest association with cardiovascular disease risk factors in Caucasian men and women without a history of cardiovascular disease. We found WC to have the strongest associations among almost all CVD risk factors for both men and women, although not always

Table 2 Study Characteristics

First Author and Year	Baseline year[a]	N	Age[b]	Male	Female	Country	BMI	WC	WHR	WHtR	BF%	SBP	DBP	HDL	LDL	TC	TG	FG	Adjustments[c]
Bertsias 2003 28	1989–2001	989	20–40	527	462	Greece	x	x	x	x	–	x	x	x	x	x	x	x	Unadjusted
Bosy-Westphal 2006 29		335	53.5±13.9	144	191	Germany	x	x	x	x	–	x	x	x	–	x	x	x	Age
Can 2009 30	2003	1 692	45.4±13.1	571	1 121	Turkey	x	x	x	x	–	x	–	x	x	x	x	x	Age
Contaldo 1986 27		246	20–59	132	114	Italy	x	–	–	–	xS	x	x	–	–	x	x	x	None specified
Dalton 2003 31	1999–2000	11 247	>25	5 050	6 197	Australia	x	x	x	–	–	x	–	x	–	–	x	x	None specified
Meigs 1997 32	1991–1993	2 458	26–82	1 150	1 308	USA	x	–	x	–	–	x	x	x	–	–	x	x	None specified
Mukuddem-Petersen 2006 33	1989–1992	826	56–83	389	437	Netherlands	x	x	x	x	–	x	x	x	–	–	x	x	Age
Mykkanen 1992 34	1986–1988	1 069	65–74	396	673	Finland	x	–	x	–	–	x	x	x	–	x	x	x	Unadjusted
Ohrvall 2000 35		885	19–66	588	297	Sweden	x	x	x	–	–	x	x	x	x	x	x	x	Unadjusted
Pouliot 1994 9		151	23–50	81	70	Canada	–	x	x	–	–	–	–	x	–	–	x	x	None specified
Reeder 1997 38	1989–1992	8 974	18–74	4 472	4 502	Canada	x	x	x	–	–	x	x	x	x	x	x	–	None specified
Sardinha 2000 39		62	31–46	62	0	USA	x	x	x	–	–	x	x	x	x	–	x	–	Unadjusted
Sattar 1998 40		191	18–69	93	98	UK	x	x	x	x	–	–	–	x	x	x	x	x	Age, smoking
Seidell 1989 41	1988–1989	450	38	0	450	Europe	x	x	x	–	–	x	x	x	–	x	x	–	Unadjusted
Seidell 1991 42	1988–1989	512	38	512	0	Europe	x	x	x	–	–	x	x	x	x	x	x	–	Unadjusted
Seidell 2001 15		695	>18	313	382	Canada	x	x	x	–	–	x	x	x	x	x	x	x	Unadjusted
Shen 2006 36		498	>18	206	292	USA	x	x	–	–	–	x	x	x	–	–	x	x	Divers
Tuomilehto 1990 43	1987	5 229	25–64	2 461	2 768	Finland	x	–	x	–	–	x	x	x	–	–	–	x	Age
Turcato 2000 37		229	67–78	83	146	Italy	x	x	x	x	–	x	x	x	–	x	x	x	Unadjusted
Zhu 2002 44	1988–1994	9 019	20–90	4 388	4 631	USA	x	x	–	–	–	x	x	x	x	–	–	x	Unadjusted

x indicates that it was measured, – indicates it was not measured

xS = BF% calculated from 4 skin folds

[a] The year(s) in which subjects were examined

[b] An age range is given or a population mean ± standard deviation (SD)

[c] Adjustments made in calculation of the Pearson correlation coefficient: non-specified means the study does not give any information on adjustments, unadjusted means the study gives information that the data are unadjusted

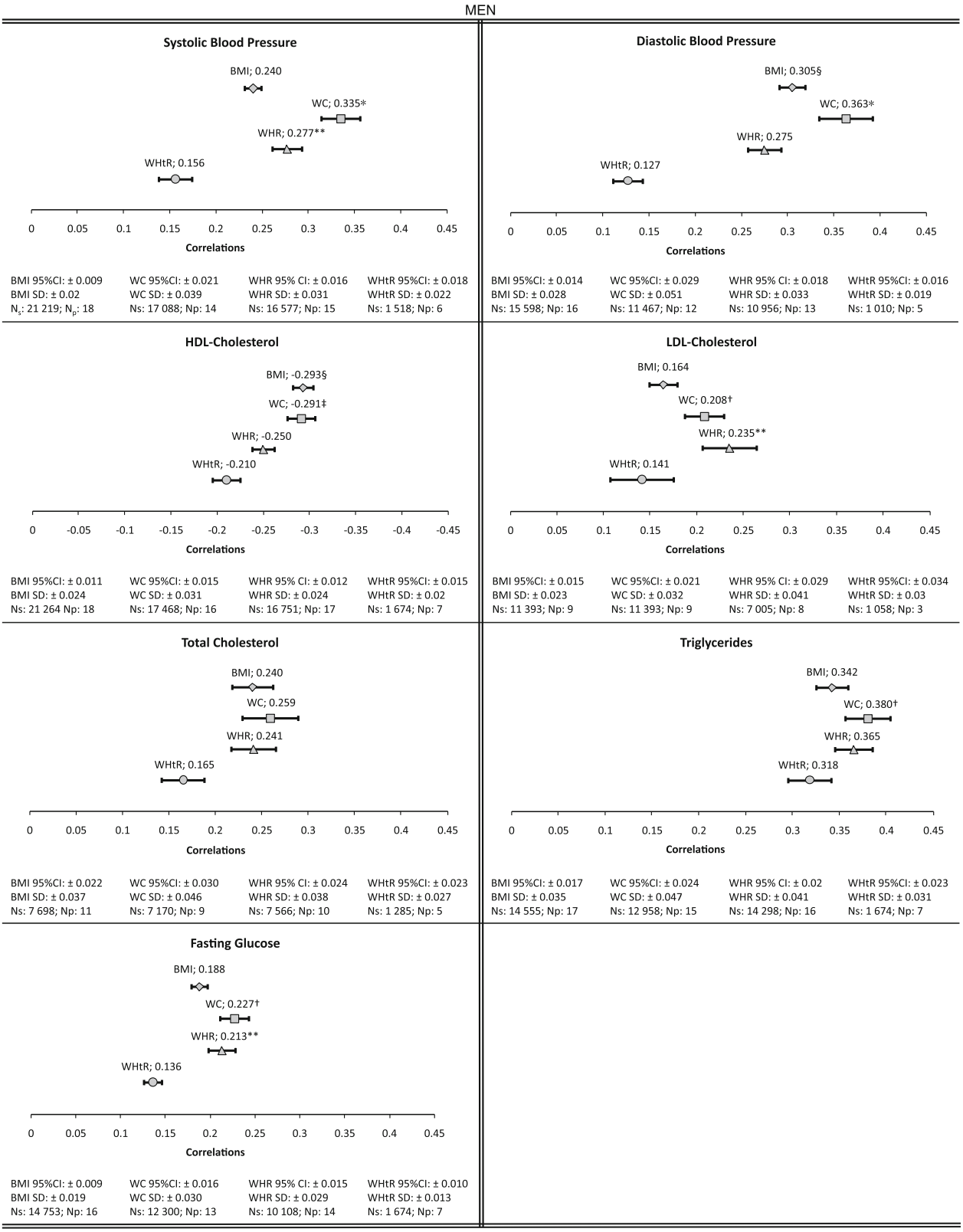

Fig. 3 Mean Pearson correlations and their 95% confidence intervals plotted for men. ∗WC correlates significantly better than BMI, WHR and WHtR ($P<0.05$). **WHR correlates significantly better than BMI and WHtR ($P<0.05$). †WC correlates significantly better than BMI and WHtR ($P<0.05$). ‡WC correlates significantly better than WHR and WHtR ($P<0.05$). §BMI correlates significantly better than WHR and WHtR ($P<0.05$). *SD* standard deviation; *Ns* number of subjects; *Np* number of populations

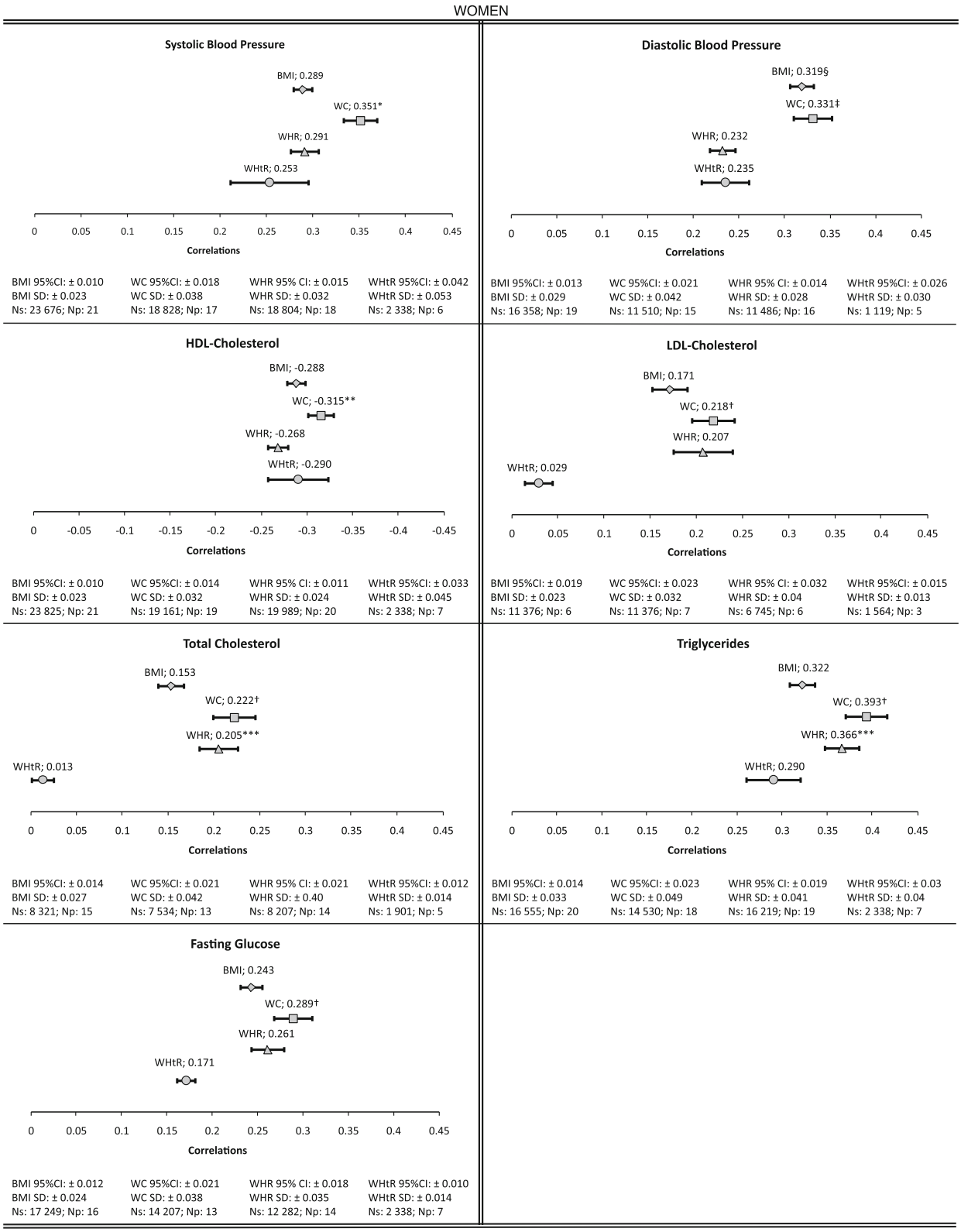

Fig. 4 Mean Pearson correlations and their 95% confidence intervals plotted. ∗WC correlates significantly better than BMI, WHR and WHtR ($P<0.05$). ∗∗ WC correlates significantly better than BMI and WHR ($P<0.05$). ***WHR correlates significantly better than BMI and WHtR ($P<0.05$). †WC correlates significantly better than BMI and WHtR ($P<0.05$). ‡WC correlates significantly better than WHR and WHtR ($P<0.05$). §BMI correlates significantly better than WHR and WHtR ($P<0.05$). *SD* standard deviation; *Ns* number of subjects; *Np* number of populations

significantly. Especially when BMI was compared with WC the latter holds significantly better correlations to CVD risk factors except for DBP in women and HDL and TC in men. Comparing BMI and WHR resulted in only small and mostly non-significant differences except for TC and TG in women and LDL in men in favour of WHR. The weakest correlations were found for WHtR.

Our study selection procedure yielded only one study that used a measure of BF% [27]. This study reported rather moderate and large correlations between BF% and CVD risk factors (0.54, 0.4, 0.37, 0.37 and 0.36 with SBP, DBP, TC, TG and FG respectively for women, 0.38, 0.46, 0.37, 0.42 and 0.31 with SBP, DBP, TC, TG and FG respectively for men). This study compared BF% with BMI and also found moderate and large correlations between BMI and CVD risk factors. Based on these data, BF% could be a competitor for the strongest correlations with CVD risk factors; however, more studies should be done before any conclusions can be drawn.

Janssen et al. [45] analysed the data from the NHANES III database to determine whether the prevalence of CVD risk factors is greater in individuals with high WC values compared with individuals with normal WC values within the same BMI category. Individuals with high WC values were reported to have significantly greater prevalence of CVD risk factors even within the same BMI category, thus underscoring the importance of WC. When evaluating the clustering of CVD risk factors in the metabolic syndrome, Schneider et al. [46] and Dervaux et al. [47] concluded that WC had a stronger association with the metabolic syndrome than BMI.

One should also consider some practical issues with anthropometric adiposity measures. The general idea behind using anthropometric adiposity measures is to predict a certain risk and to measure change over time when comparing interventions. The ability to detect change in the different anthropometric adiposity measures can play an important role here. Velthuis et al. [48] conducted a randomised controlled trial and investigated the effect of a 12-month moderate-to-vigorous exercise program combining aerobic and muscle strength training on body composition among 189 sedentary, postmenopausal women. Their data showed that the exercise program was able to reduce fat mass, increase lean body mass and reduce WC, although weight and BMI were not affected. Kwak et al. [49] found similar results in a randomised controlled trial with 553 male and female subjects. This further supports the use of alternative anthropometric adiposity measures next to BMI, such as WC, as a more responsive outcome.

This meta-analysis holds a few study limitations. Heterogeneity of study populations remains a subject of discussion. Whether Europeans differ amongst each other and can be compared with for example Canadians is not known. We found no studies describing objective differences among these populations and in order to reach sufficient power in our analysis we made the choice to compare all these populations. Although the subject inclusion criteria for all studies were almost the same it remains difficult to control for other known CVD risk factors, for example smoking status, physical activity or fitness levels, social status and nutrition.

Studies might have been missed by our search method even though we tried to validate the strategy. Studies describing associations between only one anthropometric adiposity measure and three or less CVD risk factors were not included although maybe holding valuable data for our analysis. Furthermore, a few large studies found with our strategy did not report correlation coefficients and were therefore excluded after attempting to get the data from authors by mail and failing. Calculating the needed correlation coefficients would be easily done and could alter or strengthen the results of our study.

A comment should also be made about the fact that we studied CVD risk factors and not cardiovascular diseases or mortality rates. As we found correlations between anthropometric adiposity measures and CVD risk factors were generally small to moderate, it can be expected that even weaker correlations with actual cardiovascular disease will be found. This was addressed in a recent large study performed by The Emerging Risk Factors Collaboration [50]. They concluded that BMI, WC, and WHR, whether assessed singly or in combination, did not importantly improve cardiovascular disease risk prediction in people in developed countries when additional information is available for systolic blood pressure, history of diabetes, and lipids [50].

Although relationships between anthropometric adiposity measures and CVD risk factors have been explored thoroughly in many studies around the world this is the first study to our knowledge to combine these results quantitatively in a meta-analysis. Waist circumference has been a widely used measure for adiposity for some time now and we believe the evidence supporting its use has been strengthened with the current study. The results of our study can, however, only be generalised to people of Caucasian descent.

Recommendations

Although overall correlations between CVD risk factors and anthropometric adiposity measures were small, they do appear to be significant. Given the extent of the cardiovascular disease problem in the industrialised world, it is important clinicians should use a measure that most accurately reflects CVD risk. From this study we concluded that the measurement of WC was more related to CVD risk factors in men and

women than BMI. We therefore recommend the use of WC in the clinic and in research studies.

Conflict of interest None declared.

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