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Indices of abdominal obesity are better discriminators of cardiovascular risk factors than BMI: a meta-analysis

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Abstract

Objective: To determine which simple index of overweight and obesity is the best discriminator of cardiovascular risk factors.

Study Design and Setting: This is a meta-analysis of published literature. MEDLINE was searched. Studies that used receiver-operating characteristics (ROC) curve analysis and published area under the ROC curves (AUC) for overweight and obesity indices with hypertension, type-2 diabetes, and/or dyslipidemia were included. The AUC for each of the four indices, with each risk factor, was pooled using a random-effects model; male and female data were analyzed separately.

Results: Ten studies met the inclusion criteria. Body mass index (BMI) was the poorest discriminator for cardiovascular risk factors. Waist-to-height ratio (WHtR) was the best discriminator for hypertension, diabetes, and dyslipidemia in both sexes; its pooled AUC (95% confidence intervals) ranged from 0.67 (0.64, 0.69) to 0.73 (0.70, 0.75) and from 0.68 (0.63, 0.72) to 0.76 (0.70, 0.81) in males and females, respectively.

Conclusion: Statistical evidence supports the superiority of measures of centralized obesity, especially WHtR, over BMI, for detecting cardiovascular risk factors in both men and women.

Keywords: Body mass index; Cardiovascular risk factors; Meta-analysis; Obesity; ROC curve; Waist-to-height ratio

1. Introduction

In recent years, there has been increasing speculation over which measure of overweight and obesity is best able to discriminate those individuals who are at increased cardiovascular risk. Body mass index (BMI) is used by the World Health Organization to define severity of overweight and obesity across populations [1]. But increasingly, measures of central adiposity, namely waist circumference (WC) and waist-to-hip ratio (WHR), have been adopted as more accurate predictors of obesity-related cardiovascular risk and have replaced BMI in several definitions for clinical diagnosis of metabolic syndrome [2].

The ability of BMI, WC, WHR, and waist-to-height ratio (WHtR) to discriminate major cardiovascular risk factors, namely hypertension, type-2 diabetes, and dyslipidemia, has largely been based upon receiver-operating characteristic (ROC) curve analysis [3–6]. Reported differences in the discriminatory capability between different indices of obesity with cardiovascular risk factors are small, and despite many studies not formally conducting any statistical comparison, claims have been made to suggest the superiority of some measures of obesity over others in the discrimination of cardiovascular risk [7–9]. To date, there has been no systematic attempt to compare how well these different measures of obesity perform at discriminating cardiovascular risk factors across diverse populations. If significant, and clinically relevant, differences were shown to exist between these measures, it would provide a strong rationale for the universal adoption of a single measure for defining obesity.

A meta-analysis was conducted to determine which of the four simple indices of overweight and obesity (BMI, WC, WHR, or WHtR) is the best discriminator of hypertension, type-2 diabetes, and dyslipidemia, separately for men and women. We also sought to evaluate whether the

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What is New?

- This meta-analysis supports previous claims that measures of central obesity, in particular the waist-to-height ratio, are better discriminators of cardiovascular disease risk factors compared with body mass index.
- Combining body mass index with any measure of central obesity does not improve upon its discriminatory capability.
- Further research is required to determine whether similar results hold for prediction of cardiovascular disease hard end points and whether the results here are consistent across ethnic groups.

combination of BMI with measures of abdominal obesity would increase the discriminatory capability of the model.

2. Methods

2.1. Identification of studies

We searched MEDLINE for relevant studies that were published from 1966 to December 1, 2006, using a combination of keywords: "receiver operating characteristic curve," "anthropometry," "diabetes," "hypertension," "dyslipidaemia," "obesity," "body mass index," "waist circumference," "waist-hip ratio," and "waist-height ratio." References from relevant studies were scanned visually to identify other relevant studies.

2.2. Inclusion criteria

We included studies on adults (aged ⩾18 years) that used ROC analysis to compare the discriminatory power of cardiovascular risk factors among all of the four indices and provided the area under the ROC curve (AUC) with 95% confidence intervals for BMI, WC, WHR, and WHtR for hypertension, type-2 diabetes, and/or dyslipidemia. Studies were included regardless of any differences in measurement methods used for WC. Attempts were made to include studies that had missing data in this meta-analysis by contacting corresponding authors of those studies.

2.3. Data analysis

The AUC for each of the four indices of overweight and obesity, with each of the three selected cardiovascular risk factors, was pooled using a random-effects model to determine the index that best discriminates each risk factor. When the available AUC from a study was stratified by age, a pooled AUC was first obtained using a random-effects model. The pooled AUC was then used to represent that study. An AUC of 1 is considered to have perfect discriminatory power, and an AUC of 0.5 suggests that the discriminatory power is no better than chance. AUC can only range from 0 to 1, thus to protect against nonnormality, we tried recommended transformations (log transformation and arcsine square root transformation) on the data before analysis. We found no important differences between transformed and untransformed results. As a consequence, all analyses were performed on untransformed data. Male and female data were analyzed separately. AUC for BMI combined with each of the three abdominal indices was pooled using a random-effects model to determine if the discriminatory capability is improved. Tests of heterogeneity were performed to determine if differences exist between studies, and between sexes by obtaining the Cochrane's Q statistics. Overall (sex-specific) AUC was compared between BMI and each of the remaining three indices using Wald chi-square tests [10]. Heterogeneity was concluded if $P < 0.10$. All statistical analyses were performed using Stata 9.1 (StataCorp., USA).

3. Results

A total of 25 studies that used ROC curve analysis to study at least one of the three cardiovascular risk factors were identified. Fifteen studies were excluded due to lack of data on at least one of the four indices (Fig. 1). Hence, 10 studies met the inclusion criteria; of those, nine were cross-sectional studies, and one was longitudinal (Table 1). Studies were conducted between 1990 and 2004, in nine countries. Six countries were from Asia, and one of each from the Caribbean, Europe, and the Middle East. The study size ranged from less than 600 to over 55,000 participants with a total of 88,514 subjects, of whom 54% were female. The age limits for inclusion into each of the individual studies ranged from 18 years to ⩾35 years.

3.1. Hypertension

Eight studies included hypertension as an outcome. WHtR had the highest, and BMI had the lowest, pooled AUC for both males (0.68 vs. 0.64) and females (0.73 vs. 0.69) (Fig. 2). Statistical comparison of the AUC scores between each of the measures of abdominal obesity with BMI indicated that only WHtR (in males) was slightly, but significantly, better at discriminating hypertension compared with BMI (AUC for BMI = 0.64 vs. AUC for WHtR = 0.68; $P = 0.04$). Females consistently had higher pooled AUCs, but significant difference between males and females was found only for BMI ($P = 0.06$). The combinations of BMI and abdominal obesity measures (WC, WHR, or WHtR), in turn, did not increase the discriminatory capability of BMI for hypertension.

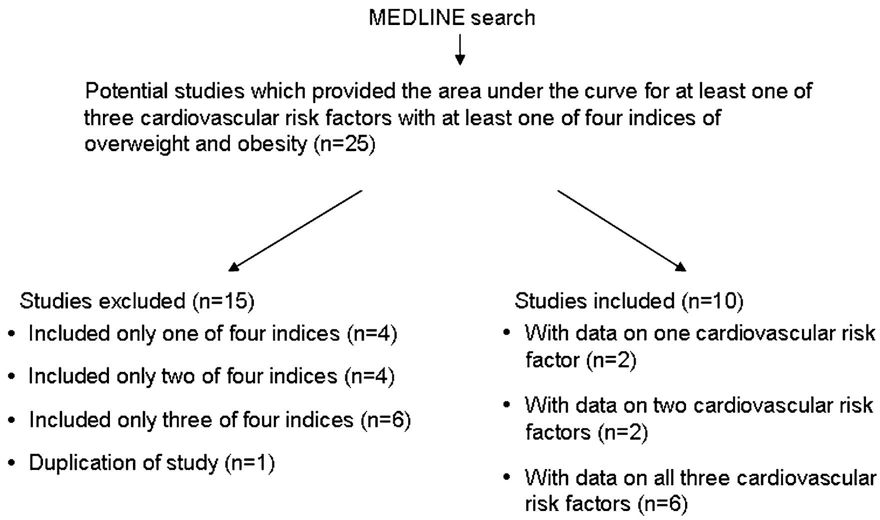

Fig. 1. Quality of reporting of meta-analyses flow diagram.

3.2. Type-2 diabetes

Data on type-2 diabetes were available for nine studies. Measures of abdominal obesity tended to give higher AUC compared with BMI, in both sexes, with the highest pooled AUC found for WHtR (0.73 for males and 0.76 for females) and the lowest pooled AUC found for BMI (0.67 for males and 0.69 for females) (Fig. 3). The tests for heterogeneity between each of the abdominal obesity measures with BMI showed significant differences between BMI and WHtR in males only (AUC for BMI = 0.67 vs. AUC for WHtR = 0.73; $P < 0.01$). As with hypertension, AUC values tended to be higher in females than in males; however, no statistically significant difference was observed between the two sexes. Similarly, the combinations of BMI and abdominal obesity measures (WC, WHR, or WHtR), in turn, did not increase the discriminatory capability of BMI for type-2 diabetes.

3.3. Dyslipidemia

Seven studies had information on dyslipidemia. Measures of abdominal obesity tended to give higher AUC compared with BMI, in both sexes, with the highest pooled AUC found for WHtR (0.67 for males and 0.68 for females) and the lowest pooled AUC (both 0.64) found for WC in males and BMI in females (Fig. 4), but the differences were not significant. With the exception of BMI, females tended to have higher (but not significantly higher) AUC values than males. The combinations of BMI and abdominal obesity measures (WC, WHR, or WHtR), in turn, did not increase the discriminatory capability of BMI for dyslipidemia.

4. Discussion

This meta-analysis, including data on more than 88,000 individuals from diverse populations, supports previous

Table 1
Included studies

Authors	Year the study was conducted	Country	Ethnicity	Design	Size (%*F*)	Age range	Risk factors[a]
Ko et al., 1999 [11]	1990	Hong Kong	Hong Kong Chinese	Cross-sectional	1,513 (40%)	18–65	HT, DM, DL
Lin et al., 2002 [7]	1998–2000	Taiwan	Taiwanese	Cross-sectional	55,563 (53%)	37 ± 11 (mean)	HT, DM, DL
Sargeant et al., 2002 [12]	1993–1996 and 1997–2000	Jamaica	African ancestry	Longitudinal	728 (60%)	25–74	DM
Ho et al., 2003 [8]	1995–1996	Hong Kong	Hong Kong Chinese	Cross-sectional	2,895 (51%)	25–74	HT, DM, DL
Mirmiran et al., 2004 [13]	1998–1999	Iran	Iranian	Cross-sectional	10,522 (58%)	18–74	HT, DM, DL
Tran, 2004 [14]	2004	Vietnam	Vietnamese	Cross-sectional	1,488 (52%)	20–60	HT, DM
Pua and Ong, 2005 [9]	2003	Singapore	Chinese, Malay, Indian	Cross-sectional	566 (100%)	18–68	HT, DM, DL
Aekplakorn et al., 2006 [15]	2000	Thailand	Thai	Cross-sectional	5305 (61%)	⩾35	HT, DM, DL
Sakurai et al., 2006 [16]	1996	Japan	Japanese	Cross-sectional	4,557 (36%)	35–59	HT
Schneider et al., 2006 [17]	2003	Germany	German	Cross-sectional	5,377 (63%)	20–79	DM, DL

[a] HT, hypertension; DM, diabetes mellitus; DL, dyslipidemia.

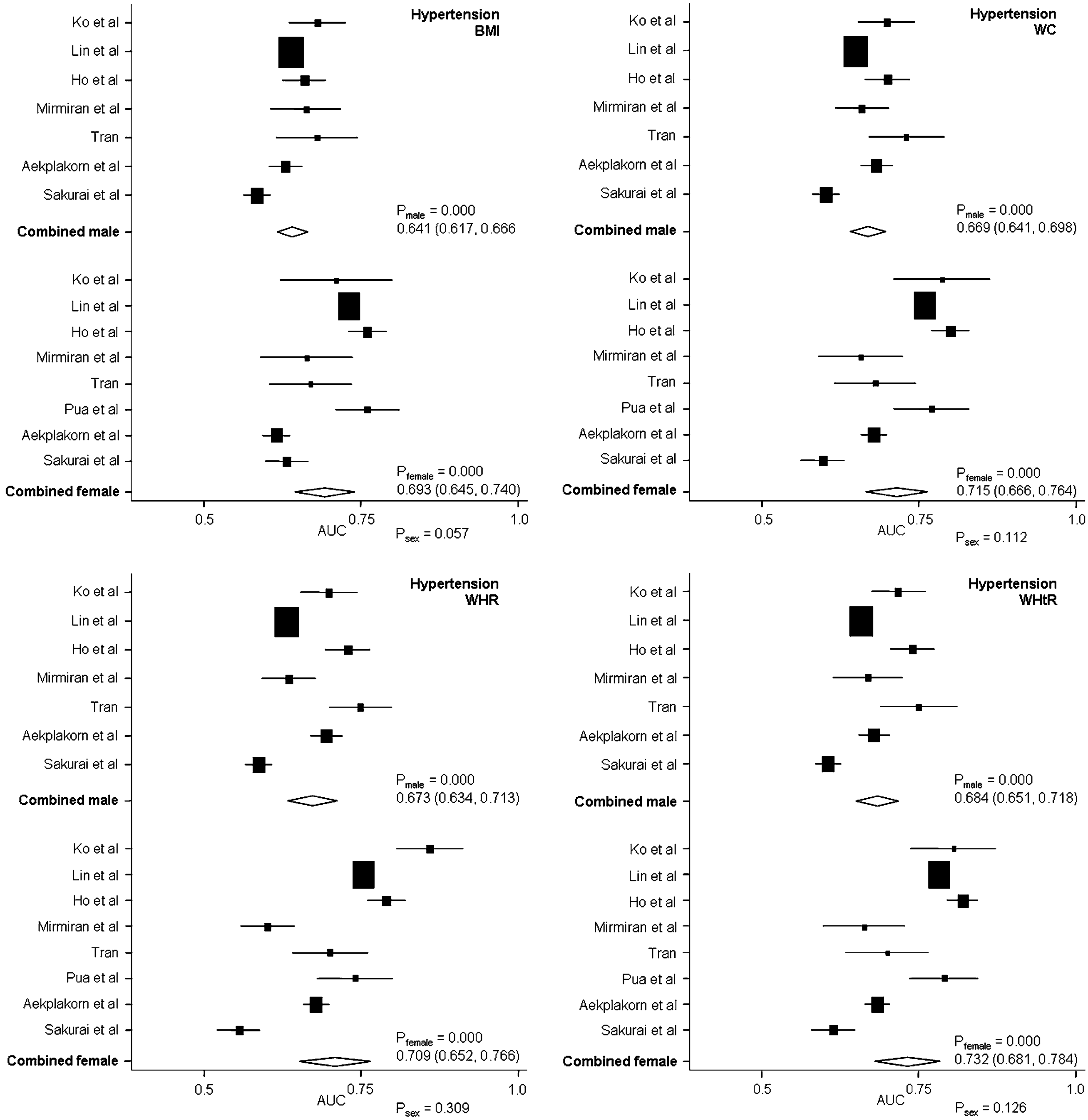

Fig. 2. Random-effects pooled area under the receiver-operating characteristics (ROC) curves (AUC) and test of heterogeneity for body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR), and waist-to-height ratio (WHtR) with hypertension by sex. Black boxes represent the statistical weight that each study contributed to the overall estimate; horizontal lines represent the 95% confidence interval; diamonds represent the overall estimates.

claims that measures of central obesity, in particular, the WHtR [7−9,18,19], provide a superior tool for discriminating obesity-related cardiovascular risk compared with BMI. However, the observed differences in the discriminatory capability between BMI with each of the individual measures of central obesity were observed to be small, and in general, statistically nonsignificant.

There are a number of mechanisms that support our findings. Unlike BMI, WHtR takes into account the distribution of body fat in the abdominal region, which has been shown to be more associated with cardiovascular risks than body weight [20]. BMI is also unable to distinguish between someone with excess adipose tissue and someone with high muscle mass; if both individuals have the same weight and height, they would be identified as having the same cardiovascular risks based on BMI alone [21]. Although WC is a simple measure of abdominal obesity, it assumes that people with the same WC would have the same cardiovascular

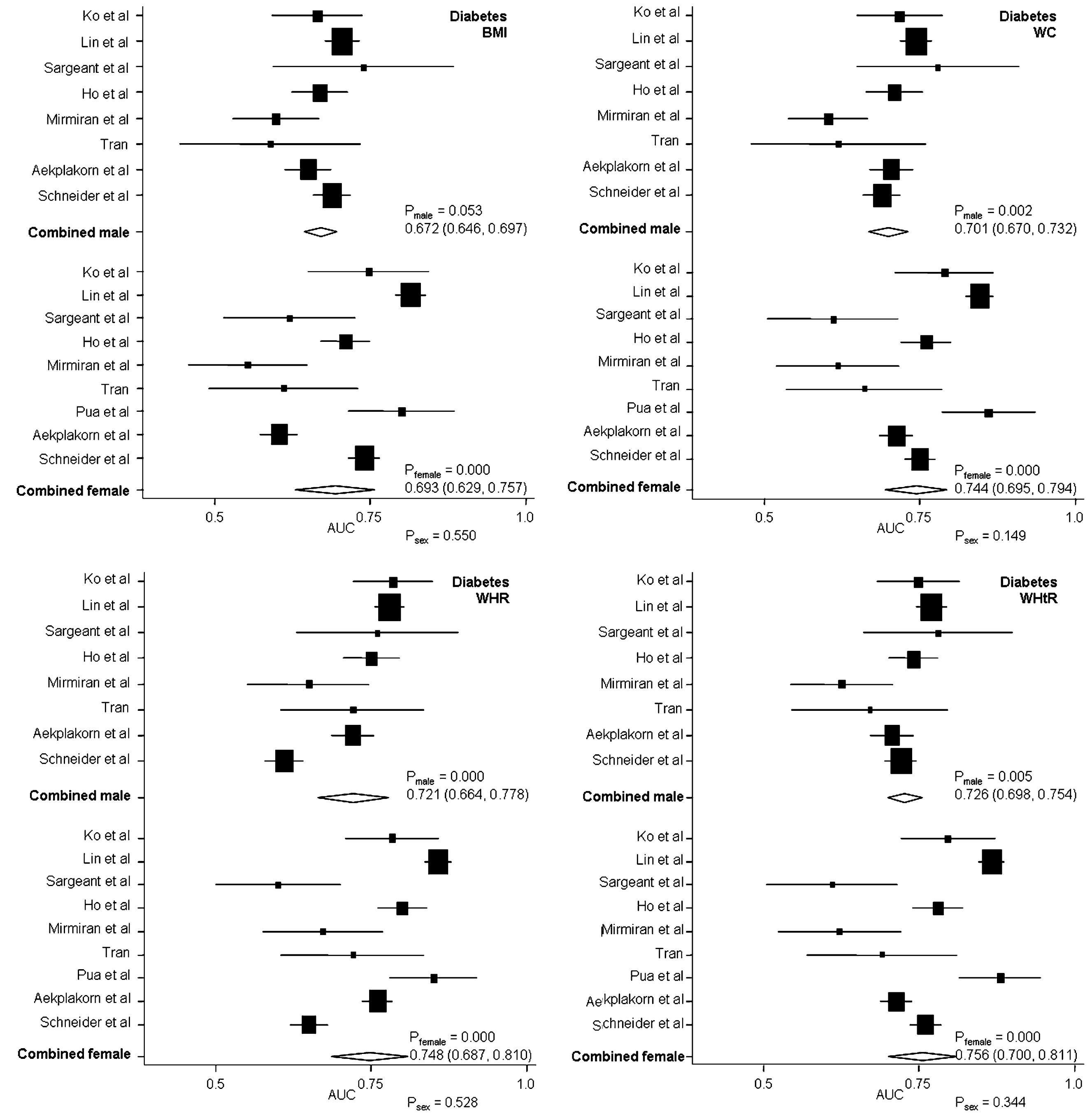

Fig. 3. Random-effects pooled area under the ROC curves (AUC) and test of heterogeneity for BMI, WC, WHR, and WHtR with diabetes by sex. Conventions as in Fig. 2.

risk regardless of differences in height. However, this assumption is invalid, as the percentage body fat and WHR are higher for shorter individuals compared with taller individuals with the same BMI [22]. Diabetes and hypertension have also been shown to be more prevalent in short-stature subjects compared with taller subjects even after adjusting for confounders [23], and a recent longitudinal study showed that the predictive power of WC for incident hypertension was improved when WC was corrected with height or hip circumference [24]. Lastly, WHR can remain the same even when there is a change in body size because WC and hip circumference can increase or decrease proportionately, whereas WHtR will change only when there is a change in waist, given that height remains constant in adults. Compared with the three indices, WHR is also more susceptible to measurement errors.

In addition, it has been previously suggested that combining BMI with WC increases the cardiovascular risk prediction than either measure alone [25]. However, we found that the discriminatory power for cardiovascular risk factors

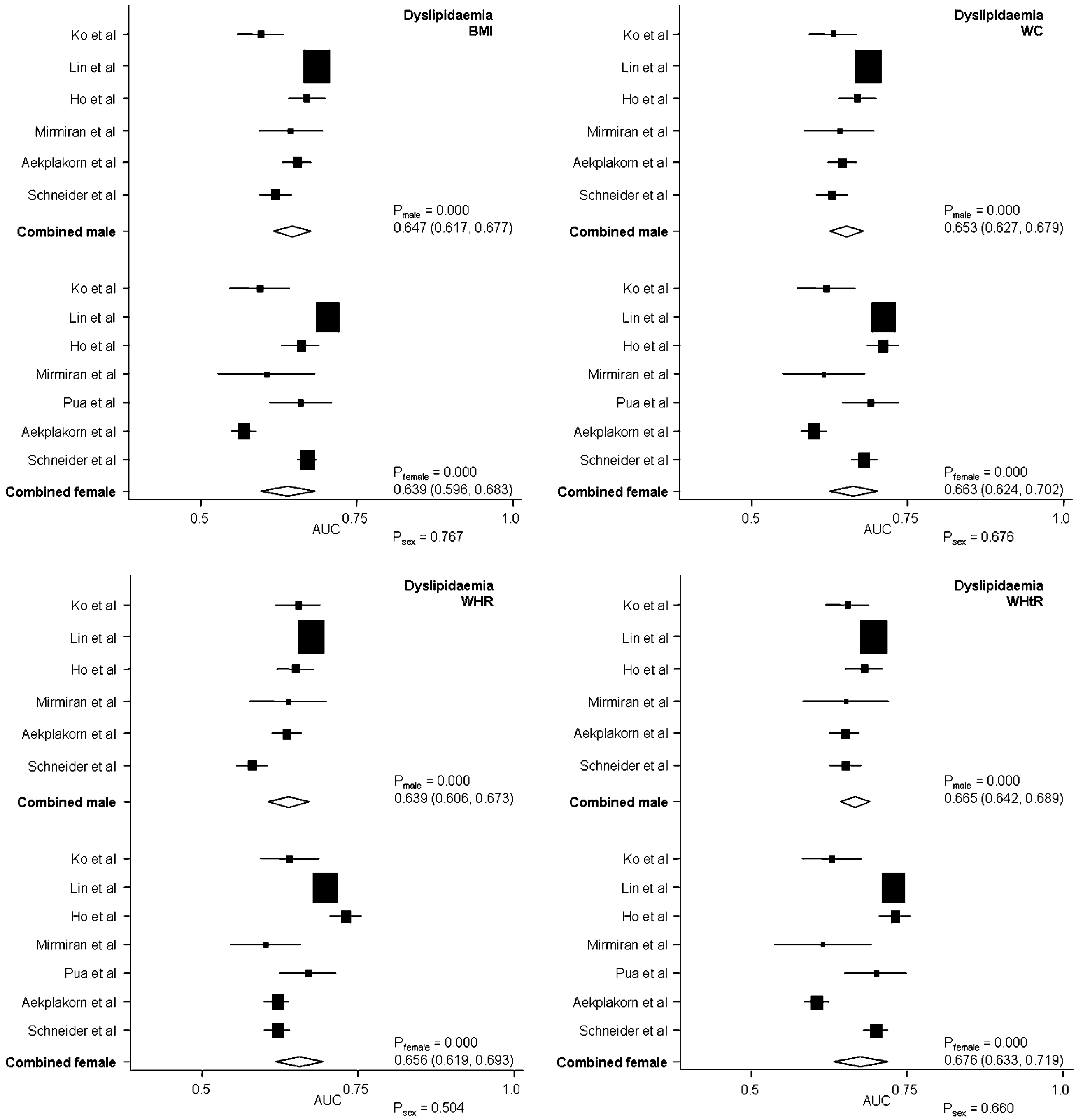

Fig. 4. Random-effects pooled area under the ROC curves (AUC) and test of heterogeneity for BMI, WC, WHR, and WHtR with dyslipidemia by sex. Conventions as in Fig. 2.

actually decreased when BMI was combined with either one of the three abdominal obesity measures, further supporting the use of WHtR as the sole measure of obesity. In resource-poor settings or large epidemiological surveys, WHtR has the added value of only requiring a tape measure rather than both a weighing scale and a tape measure, as required for BMI.

Our results suggest that separate analyses for males and females may be worthwhile. Significant heterogeneity between the sexes was found for BMI when discriminating hypertension, and the rankings of the overweight and obesity indices as best cardiovascular risk discriminators varied between males and females. Higher pooled AUCs were observed in females compared to males, suggesting that discrimination is more precise, on average, in women.

An important unknown concern is whether the same measure of adiposity performs equally well in discriminating cardiovascular risk in all ethnic groups, especially between Asian and Caucasian populations, where the most evidence for differences currently exists. We were unable to perform subgroup analysis as there were limited data on non-Asian studies. What is certain is the great disparity, both within and between ethnic groups, in the optimal cut-points used to predict cardiovascular risk factors for the four simple anthropometric indices: BMI ranging from 20 to 30 kg/m^2, WC from 71 to 101 cm, WHR from 0.77 to 0.97, and WHtR from 0.46 to 0.62 [3,6–9,11–13,26]. Whether universal cut-points should be used in favor of ethnic-specific cut-points is debatable and a matter for further research. It is also beyond the scope of the current study. However, as the optimal cut-points for WHtR were close to 0.5 in East Asians and 0.6 in some ethnic groups, the WHtR of 0.5 for action level one and 0.6 for action level two as suggested by Ashwell and Hsieh could be adopted [27].

Although results from this meta-analysis are more reliable than those from individual studies, some studies with similar research objectives had to be excluded due to the lack of required information for this meta-analysis. Currently, there are two large collaborations, the Collaborative Study of Obesity and Diabetes in Adults (CODA) [28] and the Obesity in Asia Collaboration (OAC) [29], that are attempting to address similar aims using individual participant data. This method is superior to the traditional meta-analysis of published data used here because raw data are more flexible to analyze, while standard analytical approaches can be used throughout [10]. CODA is studying the associations of indices of overweight and obesity (BMI and WC) with diabetes in Americans and Europeans; OAC is involved in the association of indices of overweight and obesity (BMI, WC, WHR, and WHtR) with cardiovascular risk factors (hypertension, diabetes, and dyslipidemia) in Asians and Australians. Preliminary results from CODA suggest that WC is slightly better than BMI, but that both are good predictors of diabetes [28]. As with our study, there was significant heterogeneity among the included studies. Contrary to our findings, larger AUCs were found in males than females [28].

Various type-2 diabetes and dyslipidemia definitions were used among studies. With limited available data, we were unable to determine if the different definitions have any effect on the discrimination of these risk factors by the four indices of obesity. However, the difference in the definitions used should not have affected the results because the aim of this meta-analysis was to discriminate between the presence and absence of cardiovascular risk factors. The different definitions used would be a concern if we were to determine the optimal cut-point for each of the four indices in the discrimination of the studied risk factors.

This meta-analysis supports previous claims that measures of central obesity, in particular the WHtR, are better discriminators of cardiovascular disease risk factors compared with BMI. However, the small differences in the discriminatory capabilities between the measures are perhaps of limited clinical relevance, and based on the data presented here, it is not possible to advocate for the adoption of any one measure of obesity over another. However, further research is required to determine whether similar results hold for prediction of cardiovascular disease hard end points and whether the results here are consistent across ethnic groups.

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