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Effectiveness of body roundness index in predicting metabolic syndrome: A systematic review and meta-analysis

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Summary

Body roundness index (BRI) is a new anthropometric index developed to predict both body fat and the percentage of visceral adipose tissue. Our aim was to investigate whether BRI is superior to traditional anthropometric indices in predicting metabolic syndrome (MetS). This systematic review and meta-analysis was conducted using Pubmed, Scopus and Web of Sciences databases. The estimated pooled areas under curve (AUCs) for BRI predicting MetS was higher than body mass index (BMI), waist-to-hip ratio (WHR), body shape index (ABSI) and body adiposity index (BAI), similar to waist circumference (WC) and lower than waist-to-height ratio (WHtR). However, the difference between BRI and BMI, WC and WHtR predicting MetS was statistically non-significant. Similar results were found with the summary receiver operating characteristic curve (AUC-SROC). In addition, the non-Chinese population had pooled AUCs greater than the Chinese population for all indices. Pooled ORs showed that BRI is associated with an increased MetS risk. In conclusion, BRI had good discriminatory power for MetS in adults of both sexes from diverse populations (AUC > 0.7; AUC-SROC>0.7). However, WC and WHtR offer the best performance when screening for MetS, and non-significant differences were found with BRI. In contrast, BRI was superior to BMI, WHR, ABSI and BAI in predicting MetS.

KEYWORDS
anthropometric indices, body roundness index, metabolic syndrome, review

1 | INTRODUCTION

Metabolic syndrome (MetS) is defined by a clustering of several risk factors for cardiovascular morbidity and mortality,[1–3] including obesity, dyslipidaemia, elevated blood pressure and glucose metabolism disorders. Those are an important risk factors for subsequent development of cardiovascular disease (CVD) and/or type 2 diabetes (T2DM).[4] Mets has become a major health concern in both developing and developed countries affecting a third of adults according the National Health and Nutrition Examination Survey (NHANES).[5]

Obesity, characterized by excess body fat and increased mortality,[6] has been demonstrated to be the main cause of MetS development.[3,7] It is also known that the accumulation of visceral fat, unlike subcutaneous fat, increases the risk of metabolic and cardiovascular disease.[8] Therefore, it is accepted that the body fat distribution, as opposed to the total amount of fat tissue, is a crucial factor of metabolic abnormalities.[9] In this context, the most effective way to assess adiposity is by direct measurement through magnetic resonance imaging or computed tomography.[10] However, the limited accessibility and high cost of these methods hamper their use in daily clinical practice. Consequently, body fat has been habitually determined by a series of anthropometric indices in most studies.

Sergio Rico-Martín and Julían F. Calderón-García contributed equally to this work.

Anthropometric measures are considered as simple, low-cost, non-invasive tools for population screening and early detection.[11] Body mass index (BMI), calculated as weight in kilograms divided by the square of the height in metres (kg/m^2), is the most commonly used anthropometric index to categorize overweight and obesity in epidemiological and clinical studies.[12–14] BMI has been shown to be a risk factor for various cardiovascular and metabolic disorders and mortality.[15–19] However, it does not discriminate between lean mass and fat mass, and it does not differentiate the location of peripheral/central fat[20,21]; moreover, there is evidence that higher muscle mass reduces risk, whereas greater fat mass is associated with an increased risk of early death.[22] Waist circumference (WC) is a common anthropometric measure for testing central obesity, is a diagnostic constituent of MetS[7,23–25] and is strongly associated to CVD.[26–28] The main limitation of WC is that it does not take into account the subject's weight and height[29] and can underestimate or overestimate obesity in short or tall individuals.[27]

Alternatively, abdominal obesity indices, such as waist-to-hip ratio (WHR) and waist-to-height ratio (WHtR), have been suggested to be better predictors of metabolic and cardiovascular abnormalities because of addressing the limitations of WC and BMI. WHtR, WHR and WC have been reported to better discriminate CVD risks than BMI.[26,27] WC and WHR were reported to have similar associations with hypertension[30,31] and T2DM.[32,33] Furthermore, WHtR has been shown to be statistically more important than BMI and WC in predicting diabetes.[27] Nevertheless, assessing height in addition to WC appeared to have no extra benefit.[34]

Recently, novel anthropometric indices combining traditional measures (height, weight, WC and hip circumference) have been explored.[35–40] Thus, in the last decade, body roundness index (BRI), body shape index (ABSI) [36] and body adiposity index (BAI)[38] have been suggested as an alternative to traditional anthropometric indices. BRI, defined as $364.2 - 365.5 \times \{1 - [(WC/2\pi)/(0.5 \times \text{height})]^2\}^{0.5}$ was proposed in 2013.[35] BRI is a predictor of body fat percentage and visceral adiposity tissue, and its values range from 1 to 16.[35] Although studies have compared the prediction of MetS by BRI with traditional and novel anthropometric indices,[41–55] there is currently no meta-analysis indicating whether BRI is a better predictor of MetS than BMI, WC, WHR, WHtR, ABSI or BAI. Therefore, this meta-analysis aims to investigate whether BRI is superior to BMI WC, WHR, WHtR, ABSI or BAI in predicting MetS.

2 | METHODS

This systematic review and meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[56]

2.1 | Search strategy and study selection

A systematic search was performed in PubMed, Scopus and Web of Science (WOS) databases up until 31 October 2019. We used the following keywords: 'Body roundness index' or 'BRI' and 'Metabolic Syndrome'. All articles with Spanish or English abstracts and full texts were assessed. We did not utilize a year limit or filters.

Two independent researchers (C.F.A and P.R.S) conducted title and abstract selection and identified potentially eligible articles for the full-text review. Studies that had unclear titles were read entirely. Disagreements were solved by consensus with the third reviewer (J.F.S. M.T). The following inclusion criteria were used:

1. Study design: observational studies observational (including cohort, case–control and cross-sectional studies) published in peer review journals up until 31 October 2019.
2. Participants: individuals aged ≥18 years
3. Anthropometric measurement: BRI
4. Objective: to assess the predictive value of BRI for MetS
5. For the meta-analysis: studies reporting predictive measures: area under curve (AUC) or odds ratio (OR) with 95% confidence interval (95% CI).

Studies that met any of the following criteria were excluded:

1. Review articles, protocol studies, letters to the editor or conference abstracts
2. Studies of children or adolescents
3. Studies that reported no predictive statistics for BRI for metabolic syndrome
4. Papers without an abstract and full text in English or Spanish.

2.2 | Data extraction

Two independent reviewers (J.F.C.G and S.R.M) extracted the following relevant data from each included study: first author identification (year of publication), country, study design, sample size (proportion of males), population characteristics, age range of participants (and/or mean ± standard deviation or median [IQ range[), follow-up duration (if a longitudinal study), MetS criteria, adjusted confounders, statistical method and predictive measure (OR, correlation coefficient and/or AUC) of the anthropometric indices (BRI, BMI, WC, WHR, WHtR, ABSI and BAI).

2.3 | Risk of bias

Two independent reviewers (S.R.M and M.M.A) assessed the methodological quality of selected articles using the Observational Cohort and Cross-sectional Studies from the Heart, Lung and Blood Institute[57] criteria. This tool contains 14 items. For each item, a score of 1 was allocated if 'yes' was the answer and a score of 0 was allocated if 'no' or other (i.e., 'cannot be assessed', 'not applicable' or 'not available'). For each study, the overall score (ranging from 0 to 14) was estimated by summing scores across all criteria. Disagreements were solved by consensus with the third reviewer (J.F.S.M.T).

2.4 | Statistical analysis

For the meta-analysis, studies with AUC (95% CI) or OR (95% CI) were included. Male and female data were analysed separately. We estimated the pooled effect size of BRI, BMI, WC, WHR, WHtR, ABSI and BAI for predicting MetS. Where articles gave values adjusted for covariates, these values were preferred to unadjusted values. The data on AUC and OR for each study were pooled using the mean value and standard error (SE) and were weighted by the inverse variance method. SEs were calculated with this measure (SE = upper limit of 95% CI − AUC or OR/1.96). For ORs, the pooled size effect was estimated by how it was reported in the study (i.e., tertiles, quartiles or uncategorized). In addition, a more robust analysis was conducted using studies that published sensitivity and specificity values. We constructed the summary receiver operating characteristic (SROC) curve, which was a measure of the diagnostic accuracy of the anthropometric indices.[58,59] AUC-SROC values were analysed to describe test accuracy. We classified the anthropometric indices in relation to their discriminatory power by the AUC and AUC-SROC using values proposed by Swets,[60] with ≤0.5 considered to have no discriminatory power, >0.5 and ≤ 0.7 to have low discriminatory power, >0.7 and ≤ 0.9 to have good discriminatory power, and 1 to be a perfect test. The heterogeneity of results across studies was evaluated using the I^2 statistic,[61] which was interpreted accordingly: 0% to ≥25 (modest), 25% to 50% (moderate), 50% to 75% (substantial) and 75% to 100% (considerable). A random-effect model was estimated when ≥50% heterogeneity was present and a fixed-effect model was estimated when <50% heterogeneity was present.

The pooled AUC/OR values of different indices predicting MetS were compared by I^2 statistics and p-values. Subgroup analysis was performed to examine whether the heterogeneity of studies could be explained by involving a Chinese or non-Chinese population. Publication bias was assessed by Egger's test.[62] All analyses were performed using Meta-DiSc version 1.4 (Universidad Complutense, Madrid, Spain) and Review Manager software (RevMan V.5.3.5), and $p < 0.05$ was considered statistically significant.

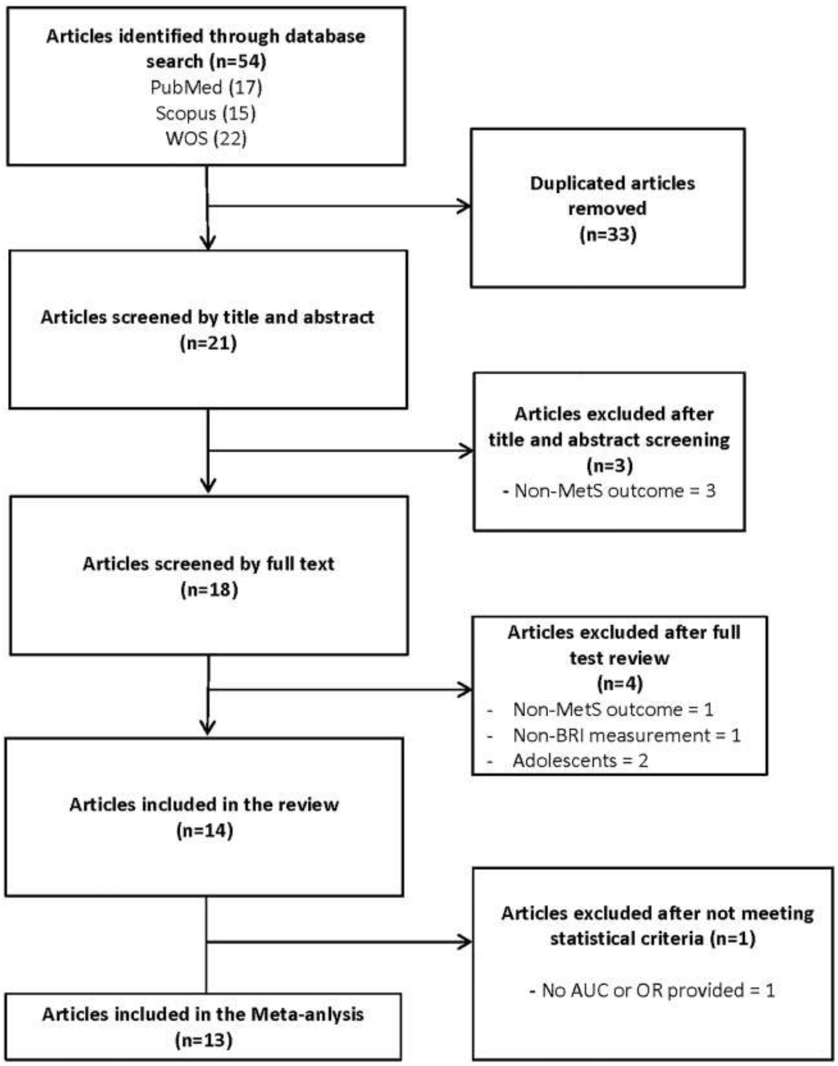

FIGURE 1 Study selection flow chart. AUC, area under curve; BRI, body roundness index; MetS, metabolic syndrome; OR, odds ratio; WOS, World of Science

TABLE 1 Basic characterizes of the studies included in the review

Ref	Author (year)	Country	Study design	Sample size (% male)	Population chararsterics	Age range and/or mean ± SD or median (IQ range)	Follow-up years	MetS criteria	Adjustment
1	Adejumo EJ (2019)[42]	Nigeria	Cross-sectional	535 (27.3%)	-	≥18 47.05 ± 14.34	-	IDF	-
2	Barazzoni R (2019)[48]	Italy	Prospective cohort	1,965 (46.4%)	-	−48.5 ± 13.0	5.0	NCEP ATP-III	Age, gender. HOMA, MAP, Tryglicerides, diabetes, hypertension, hyperlipidemia.
3	Gil LLinás (2019)[49]	Spain	Cross-sectional	61,283 (57.2%)	Workers	18–69 39.79 ± 10.35	-	IDF	-
4	Gómez Marcos MA (2019)[50]	Spain	Cross-sectional	2,478 (61.3%)	Intermediate CVR	35–74 62 (56–67)	-	NCEP ATP-III	Age, gender, smoking Status, alcohol consumption, adherence to the Mediterranean diet, physical activity Status, antihypertensive drugs, Antidiabetic drugs and lipid-lowering drugs
5	Li G (2019)[51]	China	Cross-sectional	1,442 (41.3)	Obeses and overweight adults	≥35	-	IDF	Age, gender, family income, educational level, smoking, drinking, abdominal circimference, physical activity, SBP, DBP, UA, TG, TC, HDL-C, LDL-C, fasting plasma glucose, fasting plasma insulin.
6	Liu B (2019)[52]	China	Cross-sectional	585 (57.9%)	Diabetics-T2	20–79	-	Chinese Diabetes Society	Age, history of diabetes, and body mass index
7	Liu PJ (2016)[53]	China	Cross-sectional	817 (0.0%)	Postmenopausical women	44–70	-	NECP ATP-III	Age, total colesterol, low-density lipoprotein colesterol, uric acid, high-sensitivity C-reactive protein
8	Ramírez-Vélez R, (2019)[54]	Colombia	Cross-sectional	1,502 (39.7%)	Older adults	70 ± 7.6	-	IDF	Ethnicity, socio-economic status, smoking status, alcohol intake, physical activity 'proxy', and medical conditions (i.e., presence or absence of osteoporosis, cardiovascular diseases, hypertension, diabetes, cancer, or respiratory disease)
9	Stefanescu A (2019)[55]	Peru	Cross-sectional	1,518 (37.3%)	-	39.3 ± 15.0	-	NCEP ATP-III	Age, smoking status and alcohol
10	Suliga E (2019)[43]	Poland	Cross-sectional	12,328 (33.2%)	-	37–66	-	IDF harmonized	Age, education, physical activity, alcohol consumption and smoking status

TABLE 1 (Continued)

Ref	Author (year)	Country	Study design	Sample size (% male)	Population chararsterics	Age range and/or mean ± SD or median (IQ range)	Follow-up years	MetS criteria	Adjustment
11	Tian S (2016)[41]	China	Cross-sectional	8,126 (46.5%)	-	18–85	-	IDF harmonized	Age, smoking, alcohol status
12	Wang H (2017)[44]	China	Prospective cohort	379 (52.3%)	-	40–65	4.5	IDF harmonized	-
13	Zhang J (2018)[45]	China	Cross-sectional	59,029 (61.2%)	-	18–80	-	IDF harmonized	Age
14	Zhou C (2019)[46]	China	Cross-sectional	1,603 (59.3%)	Haemodialysis patients	54.6 ± 16.0	-	IDF	Age, sex, educational status and history of smoking

Abbreviations: CVR: cardiovascular risk; DBP, diastolic blood pressure; HDL-C, high-density lipoprotein cholesterol; HOMA, homeostatic model assessment; IDF, International Diabetes Federation; IQ, interquartile; LDL-C, low-density lipoprotein cholesterol; MAP, mean arterial pressure; MetS, metabolic syndrome; NCEP ATP-III, National Cholesterol Education Program Adult Treatment Panel III; SD, standard deviation; SBP, systolic blood pressure; UA, urinalysis; TG, triglycerides; TC, Total cholesterol.

3 | RESULTS

3.1 | Selection of studies

Figure 1 shows the article selection process. The literature search identified 58 references through keyword search, including 17 articles from PubMed, 15 from Scopus and 22 from WOS. Of these, 33 were duplicates, resulting in 21 articles. After screening titles and abstracts, three studies were excluded. Eighteen papers were retained for review after full-text evaluation. Of these, four articles were excluded. Therefore, 14 studies met the inclusion criteria and were included in the systematic review, and 13 articles had sufficient data for the meta-analysis.

3.2 | Characteristics of studies

Table 1 shows details about the 14 papers included in the systematic review. Of these, 13 reported cross-sectional studies, and two reported prospective studies.[44,48] The longest follow-up was 5 years.[48] All included papers were published between 2016 and 2019. These studies were conducted in 7 countries including China (n = 7), Spain (n = 2), Nigeria (n = 1), Italy (n = 1), Colombia (n = 1), Peru (n = 1) and Poland (n = 1). The number of subjects varied substantially between the studies (range from 379 to 61,283) with a mean of 10,970 and a median of 1,510. Regarding of the characteristics of the population, seven studies assessed the general population, and seven assessed populations with specific characteristics, including workers, intermediate cardiovascular risk, obese and overweight adults, Type 2 diabetes, postmenopausal women, older adults and haemodialysis patients. The age limits for inclusion into each of the individual studies ranged from 18 years to ≥60 years. Papers used different MetS diagnostic criteria: four studies used National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP-III) criteria; five used International Diabetes Federation (IDF) criteria; four used IDF harmonized criteria, and one used Chinese Diabetes Society criteria. Among the 14 included studies, 10 adjusted for health-related characteristics (e.g., diabetes, smoking status, alcohol intake, physical activity, hypertension and others).

Table 2 summarizes the predictive measures used in the 14 included studies. In 12 papers, the information was stratified by sex. All studies assessed BRI, 13 also assessed BMI; 10 assessed WC; 5 assessed WHR; 11 assessed WHtR; 12 assessed ABSI, and four assessed BAI. Predictive measures included were AUC, OR and multiple regression analysis (β coefficient). The longitudinal study provided baseline and follow-up data.

3.3 | Meta-analysis

A meta-analysis was conducted to assess the performance of BRI in predicting MetS and to assess whether it was a better predictor than BMI, WC, WHR and WHtR.

TABLE 2 Measures of the studies included in the review

First author (year)	Outcome assesment	BRI	BMI (kg/m^2)	WC (cm)	WHR	WHtR	ABSI	BAI
Adejumo EJ (2019)[42]	AUC (95%CI)	Men: 0.740 (0.635–0.846) Women: 0.742 (0.689–0.796)	Men: 0.807 (0.717–0.898) Women: 0.768 (0.715–0.821)	Men: 0.814 (0.721–0.907) Women: 0.819 (0.771–0.867)		Men: 0.773 (0.673–0.874) Women: 0.787 (0.737–0.837)	Men: 0.616 (0.491–0.740) Women: 0.554 (0.482–0.625)	Men: 0.722 (0.595–0.850) Women: 0.766 (0.712–0.819)
Barazzoni R (2019)[48]	Coefficient (SE)	Baseline all population β = 0.785 (0.062); p < 0.001 Baseline overweight/obese β = 0.599 (0.069) p < 0.001 Follow-up overweight/obese β = 0.347 (0.110); p = 0.002	Baseline all population β = 0.251 (0.020); p < 0.001 Baseline overweight/obese β = 0.204 (0.024); p < 0.001 Follow-up overweight/obese β = 0.140 (0.041); p < 0.001	Baseline all population β = 0.079 (0.007); p < 0.001 Baseline overweight/obese β = 0.064 (0.004); p < 0.001 Follow-up overweight/obese β = 0.048 (0.016); p = 0.002		Baseline all population β = 18.881 (1.444); p < 0.001 Baseline overweight/obese β = 15.129 (1.650); p < 0.001 Follow-up overweight/obese β = 8.933 (2.672); p = 0.001	Baseline all population β = 6.459 (1.411); p < 0.001 Baseline overweight/obese β = 8.803 (1.905); p < 0.001 Follow-up overweight/obese β = 0.917 (3.091); p = 0.767	
Gil LLinás M (2019)[49]	AUC (95%CI)	IDF definition Men: 0.937 (0.935–0.940) Women: 0.924 (0.919–0.928) NECPT ATP III definition Men: 0.871 (0.863–0.878) Women: 0.873 (0.862–0.885)	IDF definition Men: 0.830 (0.824–0.836) Women: 0.857 (0.849–0.866) NECPT ATP-III definition Men: 0.793 (0.785–0.800) Women: 0.839 (0.828–0.850)		IDF definition Men: 0.813 (0.806–0.820) Women: 0.769 (0.756–0.781) NECPT ATP-III definition Men: 0.775 (0.765–0.784) Women: 0.756 (0.739–0.772)	IDF definition Men: 0.937 (0.935–0.940) Women: 0.924 (0.919–0.928) NECPT ATP-III definition Men: 0.871 (0.863–0.878) Women: 0.874 (0.862–0.885)	IDF definition Men: 0.706 (0.697–0.715) Women: 0.595 (0.578–0.612) NECPT ATP-III definition Men: 0.676 (0.665–0.686) Women: 0.610 (0.590–0.630)	IDF definition Men: 0.734 (0.727–0.742) Women: 0.762 (0.750–0.774) NECPT ATP-III definition Men: 0.716 (0.708–0.725) Women: 0.756 (0.741–0.771)
Gómez Marcos MA (2019)[50]	OR (95% CI)	Men: 5.96 (4.66–7.63) Women: 4.15 (3.09–5.58)	Men: 5.98 (4.70–7.60) Women: 4.14 (3.07–5.58)			Men: 5.93 (4.63–7.58) Women: 4.15 (3.09–5.58)	Men: 1.65 (1.31–2.07) Women: 1.81 (1.37–2.39)	
	AUC (95%CI)	Men: 0.761 (0.738–0.785) Women: 0.735 (0.704–0.767)	Men: 0.773 (0.749–0.796) Women: 0.718 (0.686–0.750)			Men: 0.761 (0.738–0.785) Women: 0.735 (0.704–0.767)	Men: 0.567 (0.538–0.596) Women: 0.569 (0.554–0.626)	
Li G (2019)[51]	OR (95% CI)	Men: Q1: Ref Q4: 1.986 (1.175–3.356) Women: Q1: Ref Q4: 1.679 (1.283–2.197)	Men: Q1: Ref Q4: 1.239 (0.674–2.276) Women: Q1: Ref Q4: 1.008 (0.654–1.556)	Men: Q1: Ref Q4: 3.276 (1.706–6.293) Women: Q1: Ref Q4: 2.908 (2.000–4.228)	Men: Q1: Ref Q4: 0.797 (0.403–1.577) Women: Q1: Ref Q4: 0.604 (0.381–0.957)		Men: Q1: Ref Q4: 1.686 (0.958–2.381) Women: Q1: Ref Q4: 2.206 (0.976–2.897)	
	AUC (95%CI)	Men: 0.745 (0.704–0.785) Women: 0.727 (0.693–.761)	Men: 0.725 (0.684–0.767) Women: 0.678 (0.642–0.714)	Men: 0.764 (0.724–0.804) Women: 0.738 (0.704–0.772)	Men: 0.652 (0.607–0.697) Women: 0.637 (0.599–0.674)		Men: 0.636 (0.590–0.683) Women: 0.609 (0.559–0.658)	

TABLE 2 (Continued)

First author (year)	Outcome assesment	BRI	BMI (kg/m^2)	WC (cm)	WHR	WHtR	ABSI	BAI
Liu B (2019)[52]	OR (95% CI)	Men: T1: Ref T2: 5.035 (2.560–9.904) T3: 7.195 (2.576–20.099) Women: T1: Ref T2: 4.616 (2.056–10.363) T3: 3.772 (1.345–10.577)						
	AUC (95%CI)	Men: 0.824 (0.775–0.874) Women: 0.775 (0.702–0.848)		Men: 0.842 (0.794–0.891) Women: 0.798 (0.726–0.870)		Men: 0.825 (0.776–0.875) Women: 0.775 (0.702–0.848)		
Liu PJ (2016)[53]	OR (95% CI)	Women: T1: Ref T2: 2.068 (1.414–3.022) T3: 2.812 (1.882–4.200)	Women: BMI < 24.0: Ref BMI 24.0–27.9: 2.474 (1.780–3.437) BMI ≥ 28.0: 3.348 (2.000–5.602)	Women: WC < 80: Ref WC ≥ 80: 2.392 (1.739–3.289)	Women: WHR <0.85: Ref WHR ≥ 0.85: 1.741 (1.272–2.382)	Women: WHtR <0.5: Ref WHtR ≥0.5: 2.347 (1.713–3.215)		Women: T1: Ref T2: 1.003 (0.699–1.439) T3: 1.240 (0.840–1.833)
	AUC (95% CI)	Women: 0.683 (0.647–0.720)	Women: 0.683 (0.647–0.719)	Women: 0.691 (0.655–0.727)	Women: 0.670 (0.633–0.707)	Women: 0.692 (0.656–0.729)		Women:0.567 (0.527–0.607)
Ramírez-Vélez R (2019)[54]	AUC	Men: 0.77 Women: 0.77	Men: 0.76 Women: 0.71			Men: 0.77 Women: 0.77	Men: 0.60 Women: 0.62	
Stefanescu A (2019)[55]	OR (95% CI)	Men: 2.43 (1.95–3.02) Women: 1.89 (1.68–2.12)	Men: 1.38 (1.28–1.48) Women: 1.21 (1.17–1.26)	Men: 1.15 (1.12–1.19) Women: 1.11 (1.09–1.13)			Men: 0.99 (0.95–1.04) Women: 1.07 (1.04–1.10)	
	AUC (95%CI)	Men: 0.81 (0.77–0.85) Women: 0.83 (0.80–0.85)	Men: 0.81 (0.77–0.86) Women: 0.78 (0.75–0.81)	Men: 0.85 (0.81–0.89) Women: 0.83 (0.81–0.86)			Men: 0.57 (0.51–0.63) Women: 0.65 (0.61–0.69)	
Suliga E (2019)[43]	OR (95%CI)	Men: Q1: Ref Q5: 11.81 (9.25–15.09) Women: Q1: Ref Q5: 16.44 (13.32–20.29)	Men: Q1: Ref Q5: 17.52 (13.57–22.62) Women: Q1: Ref Q5: 12.76 (10.53–15.46)			Men: Q1: Ref Q5: 24.87 (18.85–32.82) Women: Q1: Ref Q5: 25.61 (20.26–202.4)	Men: Q1: Ref Q5: 2.46 (1.99–3.04) Women: Q1: Ref Q5: 3.45 (2.94–4.05)	
	AUC (95%CI)	Men: 0.728 (0.713–0.743) Women: 0.748 (0.737–0.758)	Men: 0.754 (0.739–0.769) Women: 0.731 (0.720–0.742)			Men: 0.764 (0.749–0.778) Women: 0.758 (0.748–0.768)	Men: 0.603 (0.586–0.620) Women: 0.639 (0.627–0.651)	

(Continues)

TABLE 2 (Continued)

First author (year)	Outcome assesment	BRI	BMI (kg/m²)	WC (cm)	WHR	WHtR	ABSI	BAI
Tian S (2016)[41]	OR (95% CI)	Men: Q1: Ref Q4: 7.53 (6.03–9.39) Women: Q1: Ref Q4: 4.74 (3.82–5.88)	Men: Q1: Ref Q4: 9.22 (7.35–11.56) Women: Q1: Ref Q4: 5.7 (4.64–7.01)	Men: Q1: Ref Q4: 8.06 (6.46–10.05) Women: Q1: Ref Q4: 4.79 (3.88–5.91)	Men: Q1: Ref Q4: 5.11 (4.15,6.3) Women: Q1: Ref Q4: 3.4 (2.77,4.19)	Men: Q1: Ref Q4: 7.53 (6.03,9.39) Women: Q1: Ref Q4: 4.74 (3.82,5.88)	Men: Q1: Ref Q4: 1.63 (1.33–1.99) Women: Q1: Ref Q4: 1.30 (1.06–1.60)	
	AUC (95% CI)	Men: 0.710 (0.693–0.727) Women: 0.703 (0.687–0.719)	Men: 0.717 (0.7–0.734) Women: 0.692 (0.675,0.708)	Men: 0.672 (0.654–0.689) Women: 0.699 (0.683–0.715)	Men: 0.672 (0.654–0.689) Women: 0.657 (0.641–0.674)	Men: 0.71 (0.693–0.727) Women: 0.703 (0.687–0.719)	Men: 0.572 (0.553–0.591) Women: 0.586 (0.569–0.604)	
Wang H (2017)[44]	AUC (95% CI)	Baseline: Men: 0.76 (0.69–0.83) Women: 0.80 (0.71–0.88) Follow-up: Men: 0.74 (0.65–0.82) Women: 0.71 (0.63–0.79)	Baseline: Men: 0.73 (0.65–0.80) Women: 0.75 (0.67–0.84) Follow-up: Men: 0.77 (0.68–0.85) Women: 0.71 (0.63–0.78)	Baseline: Men: 0.79 (0.72–0.86) Women: 0.79 (0.71–0.87) Follow-up: Men: 0.76 (0.67–0.84) Women: 0.71 (0.64–0.79)	Baseline: Men: 0.72 (0.64–0.79) Women: 0.75 (0.67–0.83) Follow-up: Men: 0.73 (0.64–0.81) Women: 0.68 (0.59–0.75)		Baseline: Men: 0.70 (0.62–0.78) Women: 0.62 (0.52–0.72) Follow-up: Men: 0.58 (0.49–0.68) Women: 0.55 (0.47–0.64)	Baseline: Men: 0.67 (0.59–0.75) Women: 0.69 (0.59–0.79) Follow-up: Men: 0.59 (0.49–0.68) Women: 0.64 (0.56–0.72)
Zhang J (2018)[45]	OR (95% CI)	Men:: 2.410 (2.346–2.477) Women: 2.250 (2.160–2.344)	Men: 2.423 (2.359–2.489) Women: 2.241 (2.157–2.329)	Men: 2.399 (2.335–2.464) Women: 2.254 (2.165–2.347)		Men: 2.455 (2.389–2.523) Women: 2.348 (2.251–2.448)	Men: 1.238 (1.120–1.267) Women:1.224 (1.180–1.269)	
	AUC (95%CI)	Men: 0.727 (0.721–0.732) Women: 0.782 (0.776–0.789)	Men: 0.719 (0.714–0.724) Women: 0.760 (0.753–0.767)	Men: 0.721 (0.716–0.726) Women: 0.770 (0.763–0.777)		Men: 0.727 (0.721–0.732) Women: 0.782 (0.776–0.789)	Men: 0.585 (0.579–0.591) Women: 0.648 (0.640–0.657)	
Zhou C (2019)[46]	OR (95% CI)	Q1: Ref Q4: 26.33 (16.42–42.22)	Q1: Ref Q4: 12.35 (8.17–18.65)	Q1: Ref Q4: 28.27 (17.62–45.35)		Q1: Ref Q4: 23.23 (12.89–41.86)	Q1: Ref Q4: 2.89 (2.02–4.15)	
	AUC (95%CI)	Men: 0.78 (0.74–0.81) Women: 0.79 (0.75–0.82)	Men: 0.76 (0.73–0.79) Women: 0.76 (0.72–0.80)	Men: 0.79 (0.76–0.82) Women: 0.81 (0.77–0.84)		Men: 0.78 (0.74–0.81) Women: 0.79 (0.75–0.83)	Men: 0.60 (0.57–0.64) Women: 0.65 (0.61–0.69)	

Abbreviations: AUC, area under curve; BMI, body mass index; BRI, body roundness index; CI, confidence interval; IDF, International Diabetes Federation; NECP ATP-III, National Cholesterol Educational Program Adult Treatment Panel III; Q, quartile; T, tertile; OR, odds ratio; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

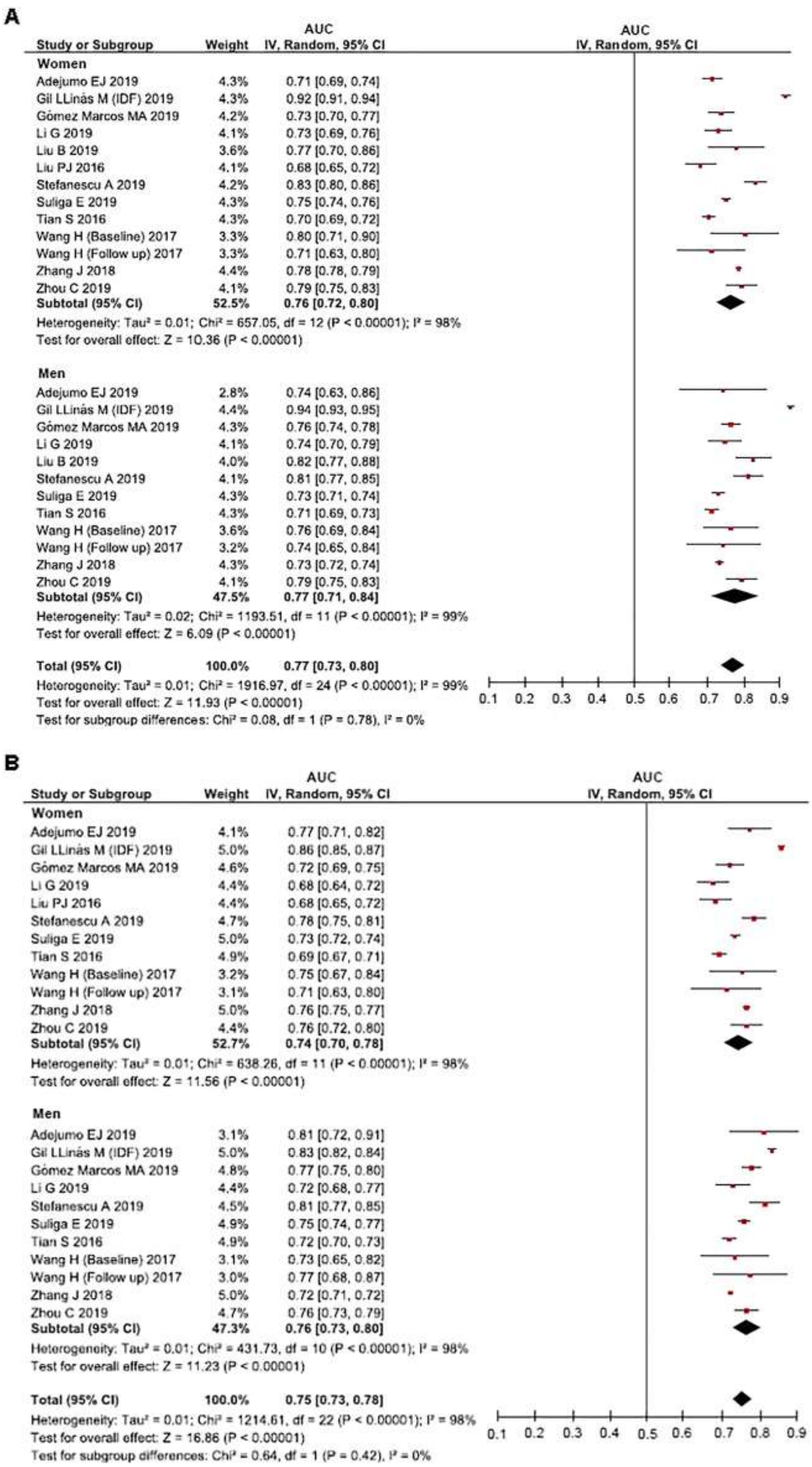

FIGURE 2 Estimated pooled AUC for BRI (A), BMI (B), WC (C), WHR (D), WHtR (E), ABSI (F) and BAI (G). ABSI, body shape index; AUC, area under curve; BAI, body adiposity index; BMI, body mass index; BRI, body roundness index; CI, confidence interval; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio

Figure 2A–G shows the forest plots of the pooled AUC values and lower and upper 95% CIs of BRI, BMI, WC, WHR, WHtR, ABSI and BAI for MetS for both sexes. For all indices, pooled AUC values were greater than 0.70 (good discriminatory power), except for ABSI (AUC = 0.61 for men, women and all subjects), WHR and BAI in women (AUC = 0.69 and AUC = 0.68, respectively). The pooled AUCs for BRI were 0.76 (0.72–0.80) in women, 0.77 (0.71–0.84) in men and 0.77 (0.73–0.80) for all subjects. WHtR had pooled AUCs greater than

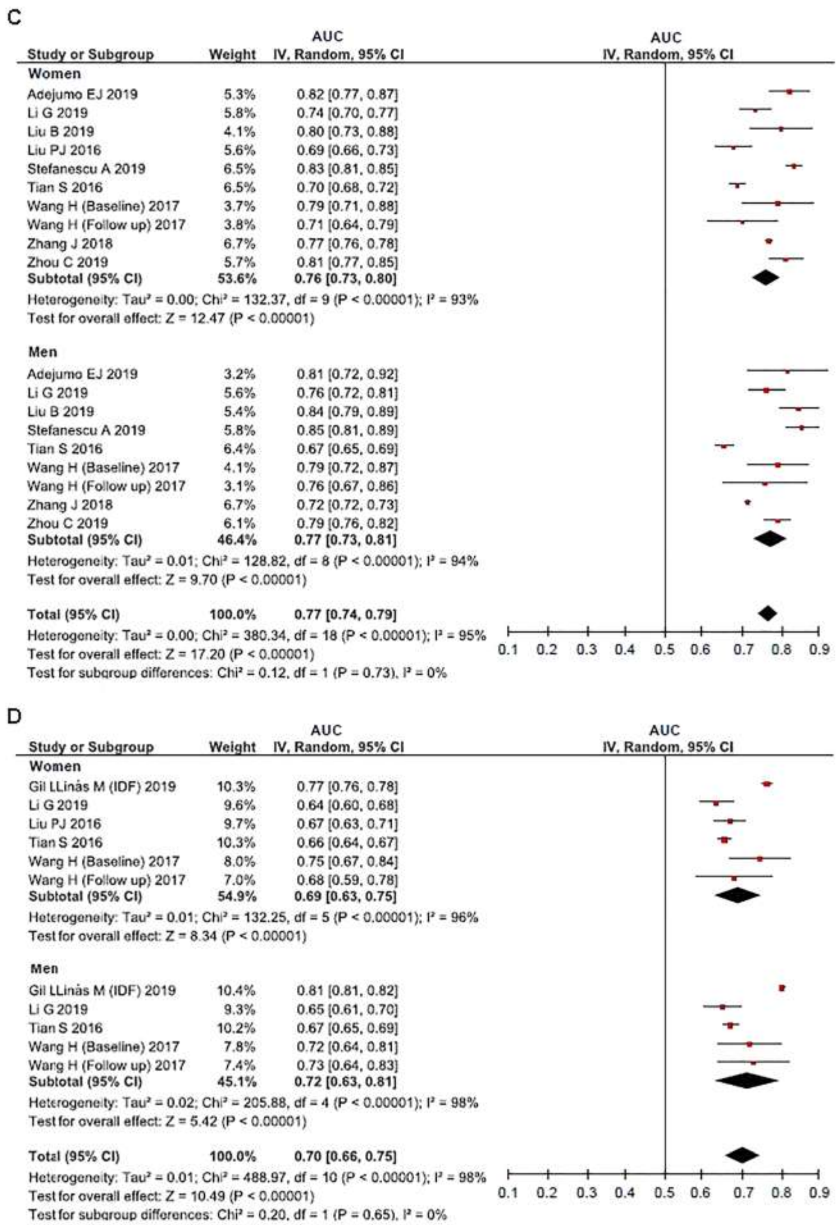

FIGURE 2 (Continued)

0.77 (0.73–0.82) in women, 0.78 (0.69–0.88) in men and 0.78 (0.72–0.83) in all subjects. The estimated pooled AUC for BRI predicting MetS was 0.07 (95% CI [0.01–0.13]; I^2 = 82.0%; p = 0.02), which was higher than that of WHR and BAI for all subjects, but not for men or women separately. Moreover, pooled AUCs for BRI were significantly greater that AUCs for ABSI, 0.16 (95% CI [0.12–0.2]; I^2 = 98.0%; p < 0.001) in both women and men. The difference between BRI and BMI, WC and WHtR in predicting MetS was not statistically significant

The pooled AUC values for anthropometric indices for Chinese populations and non-Chinese populations were examined to explore differences across populations (Table 3). Non-Chinese populations had a pooled AUC greater than the Chinese populations for all indices. Using BRI for women in non-Chinese populations, the estimated pooled AUC was 0.05 (95% CI [0.01–0.10]; I^2 = 73.0%; p = 0.04), which was higher than for women in the Chinese population, but there were no significant differences between subgroups for men or for all subjects. Pooled AUCs of WC and BAI were significantly different in both men and women. Pooled AUCs for WHR were significantly different in the entire population, but only one study was included in the non-Chinese population, and pooled BMI was significantly different in men and the entire population. There were no significant differences between subgroups for WHtR and ABSI. When we compared pooled AUCs for BRI with the other anthropometric indices in the Chinese population, we observed that pooled AUCs for BRI were significantly greater that AUCs for WHR in men, 0.07 (95% CI [0.03–0.11]; I^2 = 90.0%; p < 0.001), women, 0.08 (95% CI [0.04–0.12]; I^2 = 95.0%; p < 0.001), and all subjects, 0.08 (95% CI

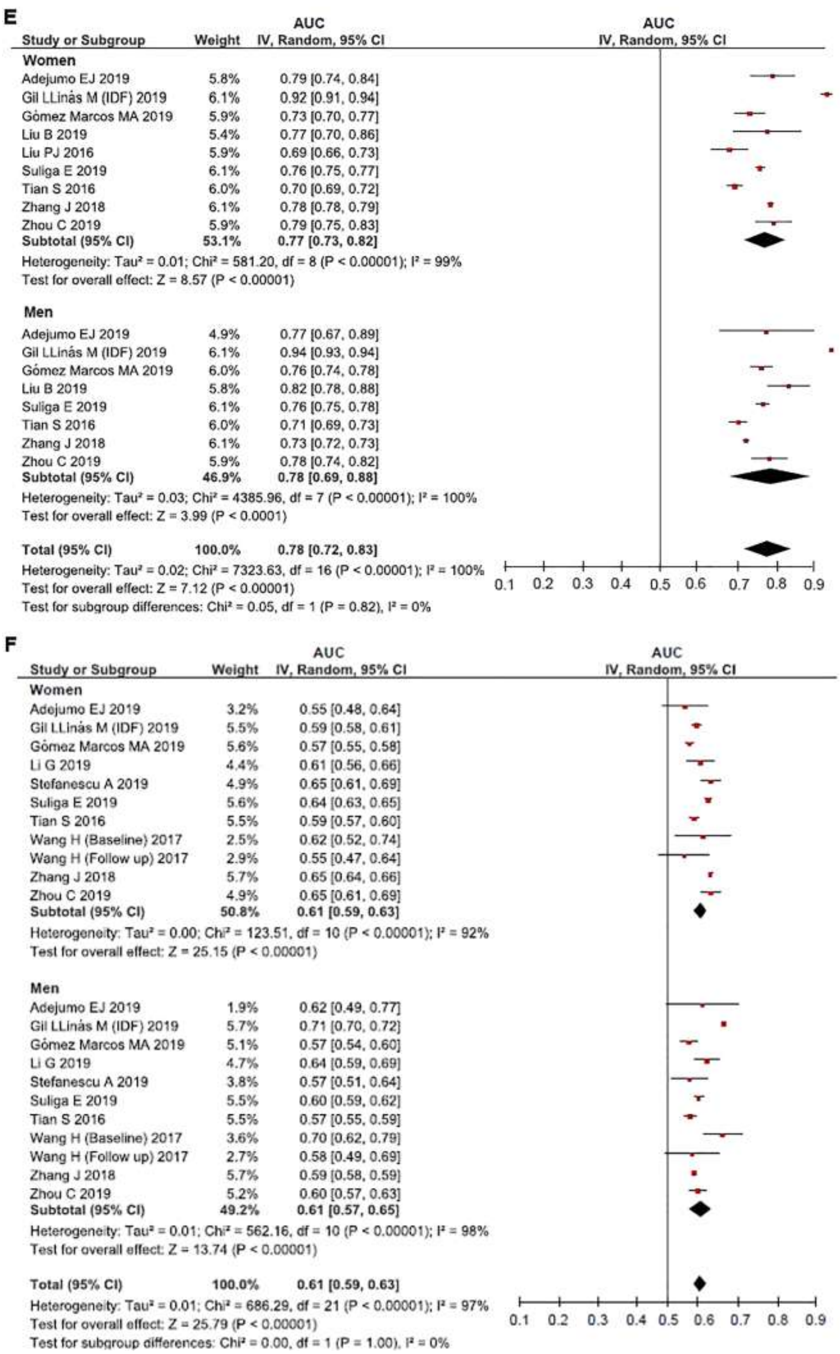

FIGURE 2 (Continued)

[0.05–0.11]; I^2 = 97.0%; p < 0.001). Further, pooled AUCs for BRI were significantly higher that AUCs for ABSI in men, 0.13 (95% CI [0.10–0.16]; I^2 = 99.0%; p < 0.001), women, 0.12 (95% CI [0.07–0.17]; I^2 = 98.0%; p < 0.001) and all subjects 0.13 (95% CI (0.09–0.17); I^2 = 99.0%; p < 0.001). Between BRI and BMI in all subjects, the difference in AUC was 0.03 (95% CI (0.01, 0.05); I^2 = 86.0%; p = 0.009). However, in the non-Chinese population, there were no significant differences between BRI and the other anthropometric indices analysed, except for ABSI, where pooled AUCs for BRI were significantly greater in men, 0.18 (95% CI [0.07–0.29]; I^2 = 89.0%; p= 0.003), women, 0.19 (95% CI [0.15–0.23]; I^2 = 98.0%; p < 0.001), and all subjects, 0.18 (95% CI [0.11–0.25]; I^2 = 96.0%; p < 0.001).

Among the 13 included studies, seven reported values for sensitivity and specificity (Table 4). We constructed the SROCs to estimate the pooled AUC-SROCs (Figure 3–5). For both sexes, the SROC was not calculated for WHR because only two studies reported data necessary for estimation. The pooled AUC-SROCs (95% CI) for BRI was 0.77 (0.73–0.83) for females, 0.79 (0.74–0.87) for males, and 0.80 (0.76–0.84) for all subjects. These values were greater that pooled AUCs estimated by the inverse variance method. The pooled AUC-SROC for BRI was significantly greater than the AUC-SROC for ABSI

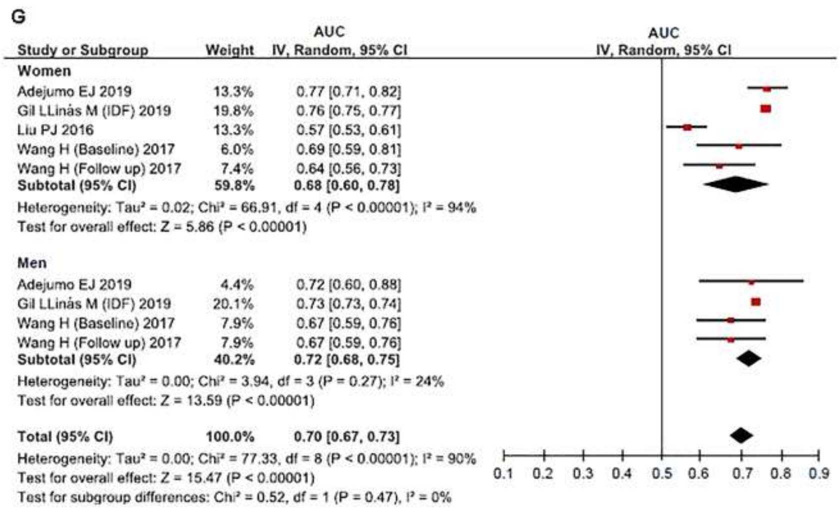

FIGURE 2 (Continued)

in men, 0.17 (95% CI [0.11–0.23]; I^2 = 96.0%; p < 0.001), women, 0.15 (95% CI [0.10–0.20]; I^2 = 97.0%; p < 0.001) and all subjects, 0.16 (95% CI [0.12–0.20]; I^2 = 100.0%; p < 0.001). Further, pooled AUC-SROCs for BRI were non-significantly higher that AUC-SROCs for BMI and BAI but lower for WC and WHtR. In the entire population, an SROC was possible (Figure 5D). The pooled AUC-SROC for WHR was lower than the AUC-SROC for BRI, but significant differences were not found.

Table 5 shows pooled odds ratios. For both sexes and types of population, increased BRI was associated with increased odds of MetS. Pooled ORs in tertiles were only obtained for BRI in women. Pooled ORs could not be summarized for BAI. In the non-Chinese population, uncategorized pooled ORs could not be calculated for WC, WHR or WHtR in men, women or all subjects. In addition, for WHR, they could not be obtained for either population (Chinese or non-Chinese population). For WHtR, pooled OR quartiles could not be calculated. In women, men and all subjects, pooled ORs for BRI were greater than BMI (quartiles and uncategorized), WC (quartiles) WHR (quartiles) and ABSI (quartiles and uncategorized) but were lower that WC and WHtR (Chinese and non-Chinese population, uncategorized pooled ORs). However, significant differences were not found between BRI and the other anthropometric indices analysed, except for ABSI, where pooled ORs for BRI were significantly greater in women (Chinese and non-Chinese population, uncategorized pooled ORs), men (uncategorized) and all the subjects (quartiles and uncategorized).

3.4 | Quality of studies and publication bias

The results of the quality assessment using the Observational Cohort and Cross-sectional Studies from the Heart, Lung and Blood Institute are shown in Table S1. The included studies on average scored 9.21 out of 14, with a range from 8 to 14. Only one study scored a 14. Because of the characteristics of the included studies (86% were cross-sectional studies), the most frequent limitations were the lack of sample size justification and repeated evaluation of anthropometric indices during the study period. Evidence of publication bias was not found by Egger's test (p > 0.1).

4 | DISCUSSION

This meta-analysis, including data on more than 150,000 individuals, showed that BRI had good discriminatory power for MetS in adults of both sexes from diverse populations (71,981 Chinese). The estimated pooled AUCs for BRI predicting MetS were higher than for BMI, WHR, ABSI and BAI, similar to WC and lower than WHtR. However, the differences between BRI and BMI, WC and WHtR in predicting MetS were not statistically significant. In addition, the non-Chinese population had pooled AUCs greater than the Chinese population for all indices. The pooled AUC-SROCs were greater than pooled AUCs, but no significant differences were found with the rest of the anthropometric indices, except for ABSI. Finally, pooled ORs showed that increased BRI was associated with increased MetS risk.

BRI was developed to predict both body fat and the percentage of visceral adipose tissue using WC in relation to height, which allows estimation of the shape of the human body figure as an ellipse or oval.[35] However, BRI is limited in predicting percentage of fat mass in elite athletes when compared with other commonly and readily available field methods such as bio-impedance analysis or skinfold prediction models.[63] Several recent studies have shown that BRI could be used as an adipose indicator for determining the presence of eccentric left ventricular hypertrophy,[64] hyperuricaemia,[41,65] arterial stiffness,[66–69] CVD,[70,71] diabetes,[41,72–75] dyslipidaemia,[41,76–78] hypertension[41,79,80] and MetS.[41–55]

This study is the first study to systematically review scientific evidence regarding the performance of BRI predicting MetS. Up to now, only one meta-analysis had used anthropometric measurements to predict MetS in adults.[27] Researchers assessed the discriminatory

TABLE 3 Pooled area under the curve categorized by Chinese population or non-Chinese population

		BRI			BMI			WC			WHR			WHtR		
		N	AUC (95%CI)	I^2	*N*	AUC (95%CI)	I^2	*N*	AUC (95%CI)	I^2	*N*	AUC (95%CI)	I^2	*N*	AUC (95%CI)	I^2
Chinese population (*n* = 71,981)	Women	8	0.74 (0.71–0.78)	93%	8	0.72 (0.68–0.75)	92%	8	0.75 (0.71–078)	91%	5	0.66 (0.64–0.69) †††	41%	5	0.75 (0.70–0.80)	96%
	Men	7	0.75 (0.72–0.78)	80%	7	0.73 (0.71–0.75)	41%	7	0.76 (0.72–0.80)	93%	4	0.68 (0.65–0.70)†††	14%	4	0.75 (0.72–0.78)	89%
	Total	15	0.75 (0.73–0.77)	93%	13	0.72 (0.71–0.73)††	91%	15	0.75 (0.73–0.77)	94%	9	0.67 (0.65–0.68)†††	33%	9	0.75 (0.72–0.78)	97%
Non-Chinese population (*n* = 78,142)	Women	5	0.79 (0.75–0.83)*	99%	5	0.77 (0.70–0.84)	99%	2	0.83 (0.81–0.85)***	0%	1	-	-	4	0.80 (0.70–0.91)	99%
	Men	5	0.79 (0.69–0.91)	99%	5	0.79 (0.75–0.84)**	94%	2	0.85 (0.81–0.88)***	0%	1	-	-	4	0.81 (0.70–0.93)	99%
	Total	10	0.79 (0.73–0.85)	99%	10	0.78 (0.75–0.82)***	98%	4	0.83 (0.82–0.85)***	0%	2	0.79 (0.75–0.84)***	97%	8	0.80 (0.74–0.88)	100%

		ABSI			BAI		
		N	AUC (95%CI)	I^2	*N*	AUC (95%CI)	I^2
Chinese population (n = 71,981)	Women	6	0.62 (0.58–0.65)†††	88%	3	0.62 (0.55–0.70)†††	68%
	Men	6	0.60 (0.58–0.62)†††	68%	2	0.67 (0.61–0.73)†	0%
	Total	12	0.61 (0.59–0.64)†††	94%	5	0.64 (0.59–0.70)†††	62%
Non-Chinese population (n = 78,142)	Women	5	0.60 (0.57–0.64)†††	93%	2	0.76 (0.75–0.77)***	0%
	Men	5	0.61 (0.55–0.69)†††	97%	2	0.73 (0.72–0.74)*	0%
	Total	10	0.61 (0.57–0.67)†††	97%	4	0.75 (0.73–0.77)***	82%

Abbreviations: ABSI, body shape index; AUC, area under curve; BMI, body mass index; BRI, body roundness index; CI, confidence interval; IDF, International Diabetes Federation; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

Differences between Chinese population and non-Chinese population:

$^{*}p < 0.05$,

$^{**}p < 0.01$.

$^{***}p < 0.001$.

Differences between BRI and BMI, WC, WHR or WHtR:

$^{\dagger}p < 0.05$·

$^{\dagger\dagger}p < 0.01$,

$^{\dagger\dagger\dagger}p < 0.001$

TABLE 4 Baseline sensitivity and specificity data of included studies

		Women							Men						
	Study	Cut-off	Sen	Spe	TP	TN	FN	FP	Cut-off	Sen	Spe	TP	TN	FN	FP
BRI	Adejumo EJ 2019[42]	12.56	0.705	0.664	71	192	30	97	11.90	0.440	0.934	54	21	69	2
	Gil Llinás M 2019[49]	3.25	0.946	0.784	1,456	19,366	83	5,336	4.30	0.907	0.838	3,721	25,927	382	5,012
	Gómez Marcos MA 2019[50]	5.77	0.702	0.666	332	323	141	162	5.67	0.675	0.717	437	626	210	247
	Ramírez Vélez R 2019[54]	6.20	0.652	0.761	166	496	88	156	4.71	0.836	0.589	118	268	23	187
	Whang H 2017[44]	3.58	0.710	0.660	52	71	21	37	3.47	0.810	0.580	104	40	25	29
	Zhang J 2018[45]	3.18	0.735	0.689	2,686	13,282	968	5,995	3.55	0.748	0.584	9,776	13,449	3,293	9,580
	Zhou C 2019[46]	3.91	0.690	0.780	260	215	117	61	3.84	0.660	0.790	249	453	128	121
BMI	Adejumo EJ 2019[42]	28.30	0.705	0.688	71	199	30	90	27.20	0.640	0.909	79	21	44	2
	Gil Llinás M 2019[49]	26.00	0.855	0.698	1,316	17,242	223	7,460	27.30	0.847	0.659	3475	20,389	628	10,550
	Gómez Marcos MA 2019[50]	28.02	0.740	0.606	350	294	123	191	28.96	0.702	0.714	454	623	193	250
	Ramírez Vélez R 2019[54]	28.40	0.695	0.641	177	418	77	234	25.20	0.844	0.547	119	249	22	206
	Whang H 2017[44]	25.14	0.590	0.780	43	84	30	24	24.94	0.690	0.750	89	52	40	17
	Zhang J 2018[45]	23.03	0.704	0.688	2,572	13,263	1,082	6014	24.64	0.709	0.613	9266	14,117	3,803	8,912
	Zhou C 2019[46]	21.85	0.670	0.760	253	209	124	66	21.97	0.740	0.680	279	390	98	184
WC	Adejumo EJ 2019[42]	91.75	0.875	0.635	88	184	13	105	89.50	0.880	0.711	108	16	15	7
	Gil Llinás M 2019[49]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Gómez Marcos MA 2019[50]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ramírez Vélez R 2019[54]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Whang H 2017[44]	80.00	0.820	0.600	60	65	13	43	84.00	0.950	0.540	123	37	6	32
	Zhang J 2018[45]	77.25	0.726	0.677	2653	13,051	1001	6226	87.25	0.703	0.621	9,188	14,301	3,881	8,728
	Zhou C 2019[46]	79.90	0.790	0.780	298	215	79	61	89.95	0.560	0.890	211	511	166	63
WHR	Adejumo EJ 2019[42]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Gil Llinás M 2019[49]	0.78	0.771	0.600	1,187	14,821	352	9,881	0.90	0.840	0.619	3447	19151	656	11788
	Gómez Marcos MA 2019[50]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ramírez Vélez R 2019[54]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Whang H 2017[44]	0.81	0.910	0.370	66	40	7	68	0.89	0.760	0.640	98	44	31	25
	Zhang J 2018[45]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Zhou C 2019[46]	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 4 (Continued)

	Study	Women							Men						
		Cut-off	Sen	Spe	TP	TN	FN	FP	Cut-off	Sen	Spe	TP	TN	FN	FP
WHtR	Adejumo EJ 2019[42]	0.59	0.761	0.684	76	198	24	91	0.54	0.640	0.777	79	18	44	5
	Gil Llinás M 2019[49]	0.50	0.906	0.819	1,394	20,231	145	4471	0.53	0.962	0.750	3947	23204	156	7735
	Gómez Marcos MA 2019[50]	0.61	0.702	0.666	332	323	141	162	0.61	0.675	0.717	437	626	210	247
	Ramírez Vélez R 2019[54]	0.63	0.644	0.767	164	500	90	152	0.56	0.836	0.586	118	267	23	188
	Whang H 2017[44]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Zhang J 2018[45]	0.49	0.735	0.689	2,686	13,282	968	5,995	0.51	0.748	0.584	9776	13,449	3,293	9,580
	Zhou C 2019[46]	0.53	0.690	0.880	260	242	117	33	0.52	0.660	0.890	249	511	128	63
ABSI	Adejumo EJ 2019[42]	12.900	0.523	0.611	52	177	48	112	14.150	0.520	0.736	64	17	59	6
	Gil Llinás M 2019[49]	0.069	0.644	0.462	991	11,412	548	13,290	0.078	0.685	0.629	2,811	19,461	1,292	11,478
	Gómez Marcos MA 2019[50]	0.080	0.622	0.638	294	309	179	176	0.080	0.592	0.501	383	437	264	436
	Ramírez Vélez R 2019[54]	0.080	0.687	0.516	174	336	80	316	0.083	0.695	0.536	98	244	43	211
	Whang H 2017[44]	0.080	0.320	0.810	23	87	50	21	0.082	0.290	0.880	37	61	92	8
	Zhang J 2018[45]	0.077	0.565	0.655	2065	12,626	1,589	6,651	0.079	0.586	0.540	7,658	12,436	5,411	10,593
	Zhou C 2019[46]	0.084	0.580	0.680	219	187	158	88	0.081	0.760	0.430	287	247	90	327
BAI	Adejumo EJ 2019[42]	58.08	0.784	0.588	78	170	22	119	51.42	0.720	0.653	89	15	34	8
	Gil Llinás M 2019[49]	30.40	0.752	0.603	1.157	14.895	382	9.807	26.21	0.720	0.624	2954	19.306	1.149	11.633
	Gómez Marcos MA 2019[50]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ramírez Vélez R 2019[54]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Whang H 2017[44]	30.38	0.530	0.740	39	80	34	28	27.44	0.400	0.870	52	60	77	9
	Zhang J 2018[45]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Zhou C 2019[46]	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Abbreviation: BMI: body mass index; BRI: body roundness index; FN: false negative value; FP: false positive value; Sen; sensitivity; Spe: specificity; TP: true positive value; TN: true negative value; WC: waist circumference; WHR: waist-to-hip ratio; WHtR: waist-to-height ratio.

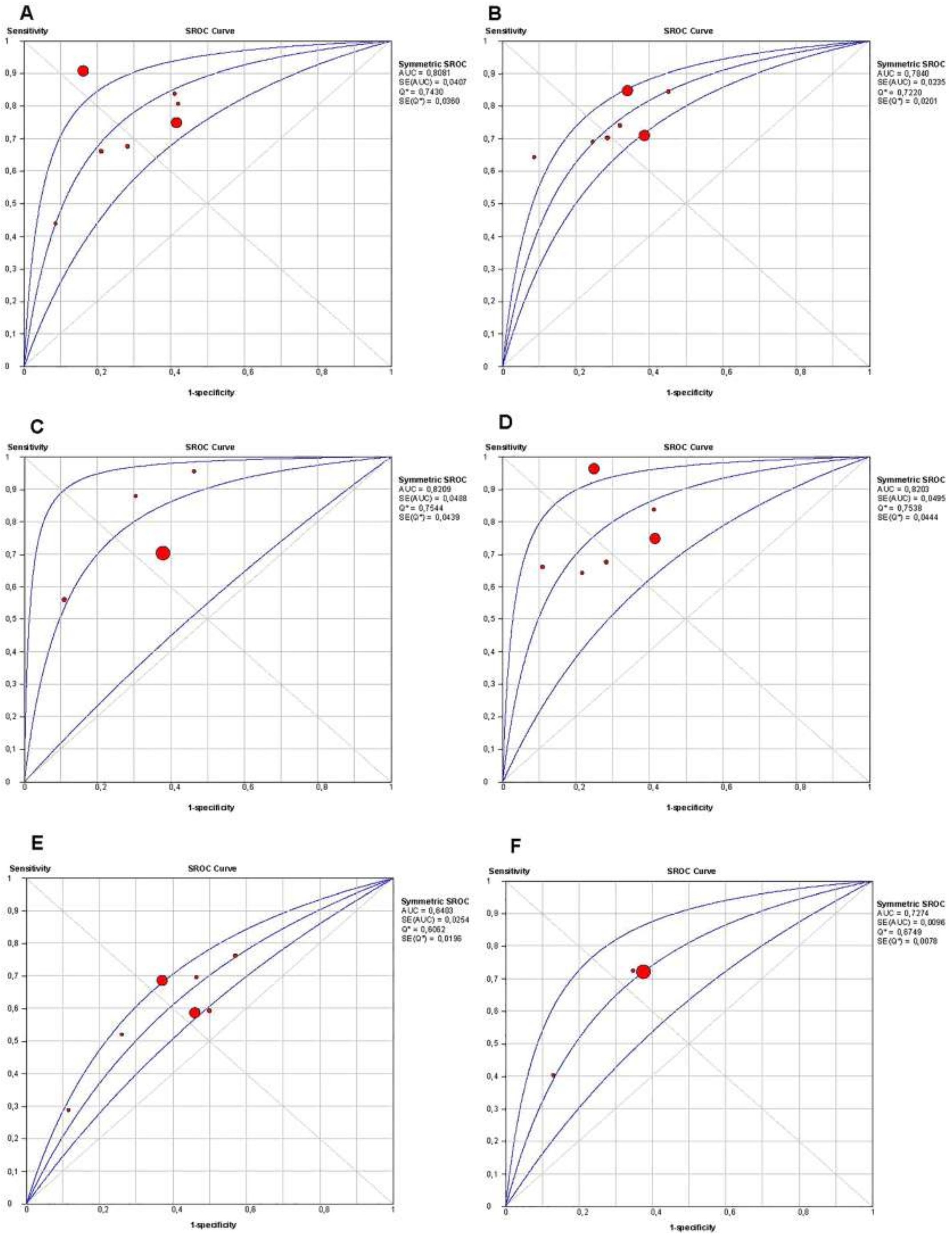

FIGURE 3 Estimated pooled AUC-SROC in men for BRI (a), BMI (B), WC (C), WHtR (D), ABSI (E) and BAI (F). AUC, area under curve; SROC; summary receiver operating characteristic curve; BAI, body adiposity index; BMI, body mass index; BRI, body roundness index; SE, standard error; WC, waist circumference; WHtR, waist-to-height ratio

power of BMI, WC and WHtR in distinguishing MetS and cardiometabolic risk factors. For MetS, pooled AUCs for WHtR were greater that BMI and WC. Among men in 12 study groups, the difference in AUCs between indices was not statistically significant. However, among women (13 study groups included), BMI was significantly poorer than WHtR (0.72 vs. 0.76; $p = 0.047$). Lo et al[81] published another similar meta-analysis in a paediatric population. In contrast to the adult population, the authors observed that WC performed better that WHtR in screening for MetS. In this meta-analysis, WHtR and WC were the best predictors of MetS compared with other anthropometric measurements. Pooled AUCs for WHtR were greater that WC for women, men and all subjects, but differences were not statistically significant. However, in the Chinese population, both pooled AUCs were similar, and in the non-Chinese population, pooled AUCs for WC

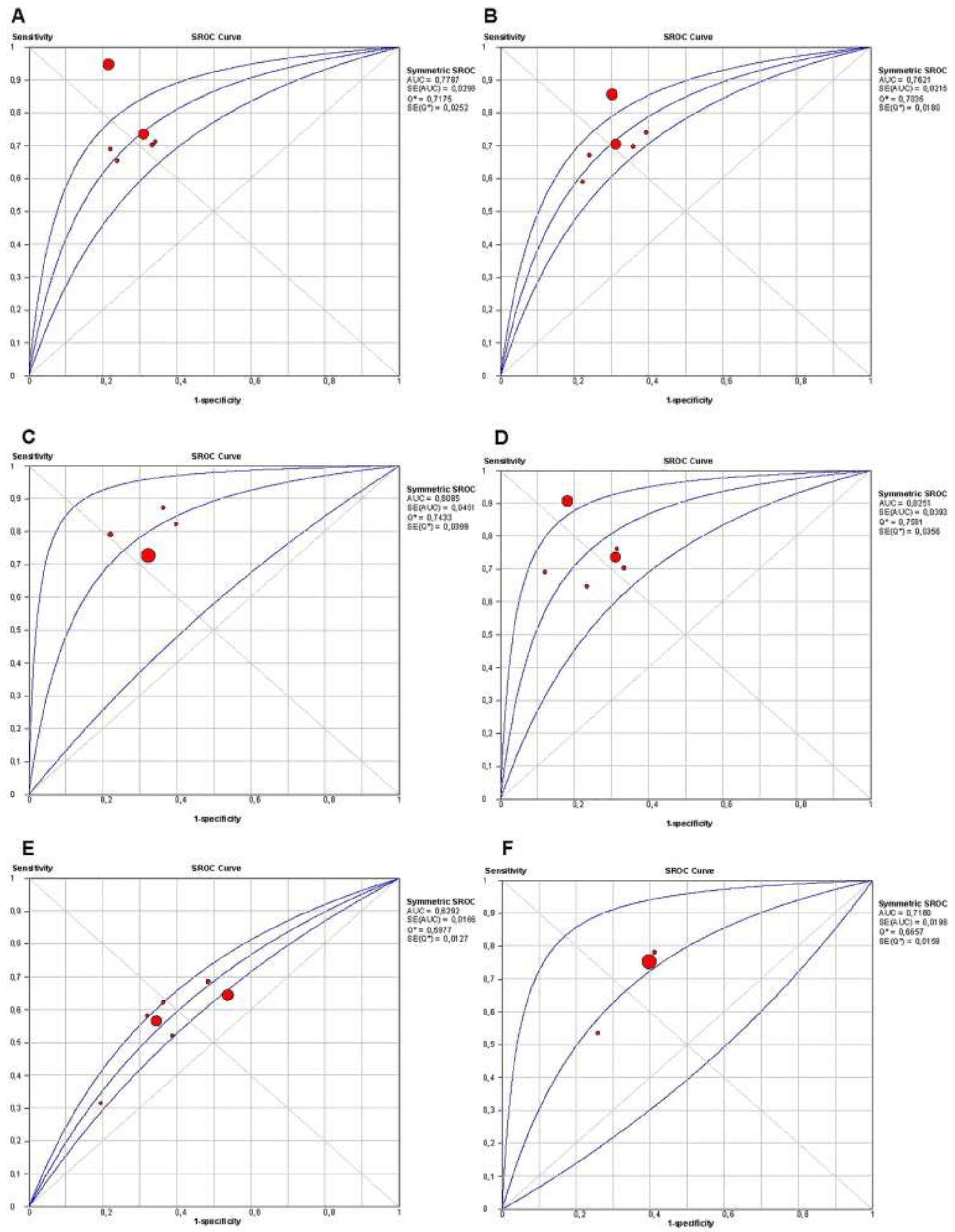

FIGURE 4 Estimated pooled AUC-SROC in women for BRI (a), BMI (B), WC (C), WHtR (D), ABSI (E) and BAI (F). ABSI, body shape index; AUC, area under curve; SROC; summary receiver operating characteristic curve; BAI, body adiposity index; BMI, body mass index; BRI, body roundness index; SE, standard error; WC, waist circumference; WHtR, waist-to-height ratio

were statistically non-significantly higher that WHtR. In addition, pooled AUC-SROCs for WHtR were lower than WC for women, men and all subjects, but differences were not statistically significant. Similar results were found for pooled ORs, except for uncategorized pooled ORs for WC, which were inferior to pooled ORs for BRI. The meta-analyses mentioned above[27,81] did not calculate pooled ORs.

The anthropometric measure cut-off points derived from non-Asian populations are not applicable to Asians.[82] Ethnicity is an important modifier in the association between simple anthropometric measures and cardiovascular risk factors, which applies to both men and women.[83] The idea that ethnicity alters the relationship between anthropometric indices and cardiovascular risk factors has been more widely studied with findings that in populations of Chinese origin, raised levels of cardiovascular risk factors occur at lower BMI and WC values than in European populations.[84–86] Currently, there are no studies comparing BRI values among ethnically different populations. In this meta-analysis, the non-Chinese population pooled AUCs for all anthropometric measurements were better predictors of MetS that for the Chinese population.

Although BRI was not superior to WC and WHtR for determining the presence of MetS, there were no significant differences in the pooled AUCs, ORs or AUC-SROCs for predicting MetS, suggesting that BRI could be used as an alternative obesity measurement in assessing MetS. As Thomas et al.[35] pointed out, the advantages of BRI exceed BMI and WRH because BRI can improve the predictive power of body fat and visceral adipose tissue thus better reflecting health status as a function of the body. The relationship between visceral adipose tissue and MetS is well known.[87] In contrast to the meta-

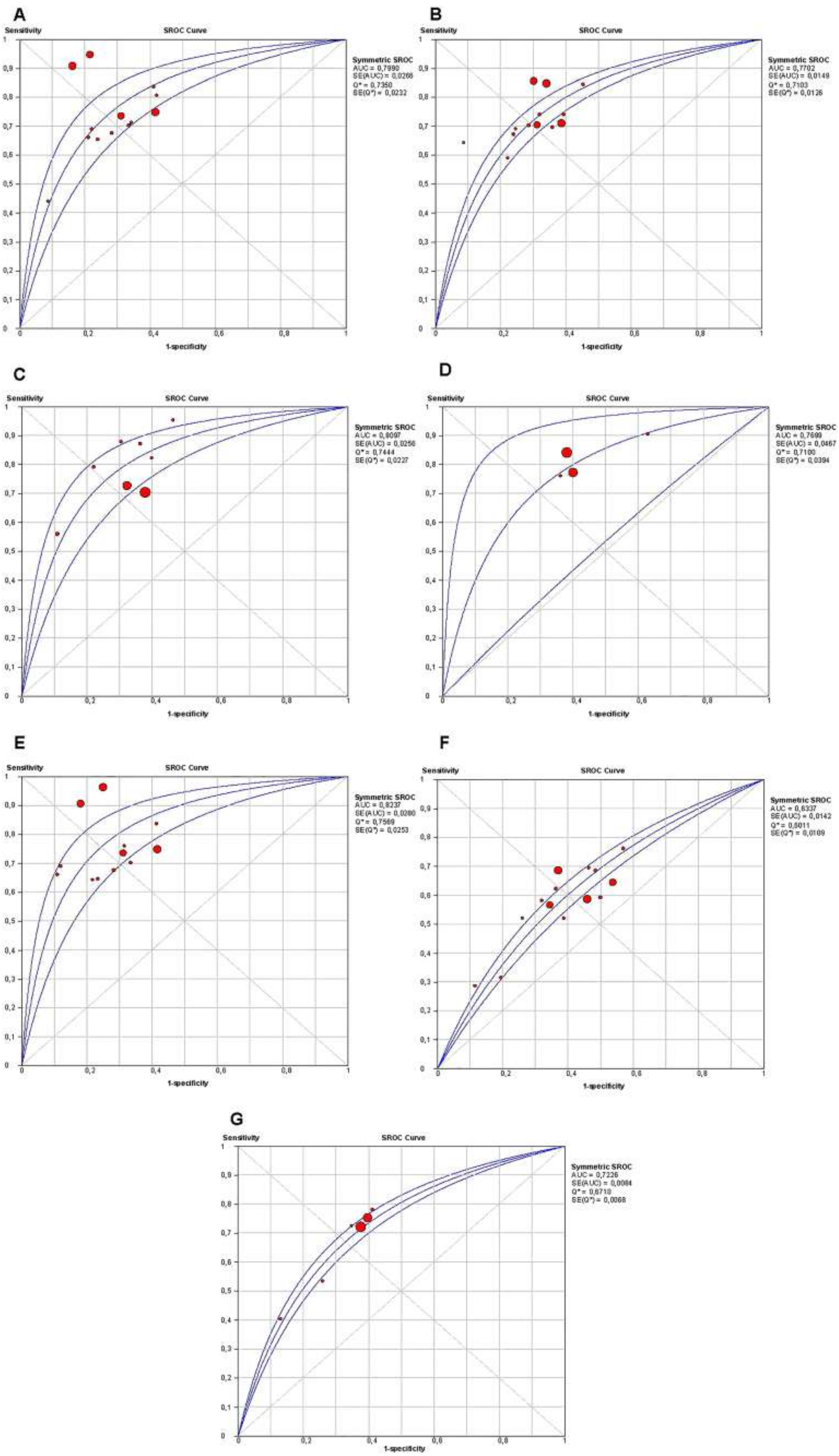

FIGURE 5 Estimated pooled AUC-SROC in total population for BRI (a), BMI (B), WC (C), WHR (D), WHtR (E), ABSI (F) and BAI (G). AUC, area under curve; SROC; summary receiver operating characteristic curve; BAI, body adiposity index; BMI, body mass index; BRI, body roundness index; SE, standard error; WC, waist circumference; WHC, waist-to-hip ratio; WHtR, waist-to-height ratio

TABLE 5 Pooled odds ratios of included studies

		BRI			BMI			WC			WHR			WHtR		
		N	OR (95%CI)	I^2	*N*	OR (95%CI)	I^2	*N*	OR (95%CI)	I^2	*N*	OR (95%CI)	I^2	*N*	OR (95%CI)	I^2
Women	Tertiles (T3)	2[&]	2.92 (2.01–4.25)	0%	-	-	-	-	-	-	-	-	-	-	-	-
	Quartiles (Q4)	2[&]	2.83 (1.02–7.83)	97%	2[&]	2.42 (0.44–13.23)	98%	2[&]	3.83 (2.35–6.22)	81%	2[&]	1.45 (0.27–7.89)	98%	-	-	-
	Uncategorized	3[$]	2.46 (1.94–3.12)	92%	3[$]	2.19 (1.31–3.66)	100%	2[$]	1.58 (0.79–3.17)	100%	-	-	-	2[$]	3.06 (1.75–5.34)	93%
		2[#]	2.77 (1.28–5.98)	96%	2[#]	2.22 (0.66–7.40)	98%	-	-	-	-	-	-	-	-	-
Men	Quartiles (Q4)	2[&]	3.95 (1.07–9.40)	95%	2[&]	3.45 (0.48–24.66)	97%	2[&]	5.43 (2.26–13.03)	85%	2[&]	2.08 (0.34–12.83)	96%	-	-	-
													-	-		
	Uncategorized	3[$]	3.23 (1.99–5.27)	96%	3[$]	2.66 (1.61–4.40)	99%	2[$]	1.66 (0.81–3.41)	1050%	-	-	-	2[$]	3.78 (1.59–8.97)	98%
		2[#]	3.80 (1.58–9.15)	96%	2[#]	2.86 (0.68–12.03)	99%	-	-	-	-	-	-	-	-	-
Total	Quartiles (Q4)	5[&]	4.98 (2.31–10.74)	97%	5[&]	3.92 (1.80–8.53)	97%	5[&]	6.39 (3.48–11.73)	94%	4[&]	1.78 (0.78–4.05)	97%	3[&]	8.76 (4.69–16.35)	93%
	Uncategorized	6[$]	2.70 (2.36–3.09)	94%	6[$]	2.41 (1.74–3.33)	100%	4[$]	1.62 (1.08–2.44)	100%	-	-	-	4[$]	3.09 (2.64–3.61)	95%
		4[#]	3.24 (1.89–5.54)	96%	4[#]	2.46 (1.62–3.74)	99%	-	-	-	-	-	-	-	-	-

		ABSI			BAI		
		N	OR (95%CI)	I^2	*N*	OR (95%CI)	I^2
Women	Tertiles (T3)	-	-	-	-	-	-
	Quartiles (Q4)	2[&]	1.45 (0.95–2.22)	34%	-	-	-
	Uncategorized	3[$]	1.23 (1.07–1.41)[†††]	95%	-	-	-
		2[#]	1.37 (0.82–2.28)	93%			
Men	Quartiles (Q4)	2[&]	1.64 (1.35–1.98)	0%	-	-	-
	Uncategorized	3[$]	1.23 (0.97–1.56)[†††]	94%	-	-	-
		2[#]	1.26 (0.77–2.08)[†]	95%			
Total	Quartiles (Q4)	5[&]	1.79 (1.33–2.40)[†]	73%	-	-	-
	Uncategorized	6[$]	1.21 (1.10–1.34)[†††]	94%	-	-	-
		4[#]	1.20 (1.06–1.35)[†††]	92%			

Abbreviations: ABSI, body shape index; BMI, body mass index; BRI, body roundness index; CI, confidence interval; IDF, International Diabetes Federation; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

[&]Chinese population;

[#]Non Chinese population;

[$]Chinese and non Chinese population. Differences between BRI and BMI, WC, WHR or WHtR:

[†]$p < 0.05$,

[††]$p < 0.01$,

[†††]$p < 0.001$.

analyses of Ashwell M et al.[27] and Lo et al.[81] we did not assess the discriminatory power of anthropometric measurements in distinguishing cardiometabolic risk factors (hypertension, diabetes, dyslipidaemia or CVD). We found that there were few published studies to be able to perform a quality meta-analysis.

This review has several limitations. First, the criterion for identifying MetS involved WC measurement, which may lead to bias despite the high AUC values. In the present review, the definition provided by the IDF is more commonly adopted (five studies), defining elevated WC as a necessary condition for MetS.[88] Other guidelines to identify MetS, including NCEP ATP-III,[4] IDF harmonized[89] and Chinese Diabetes Society[90] criteria, define central obesity as one of the criteria instead of a necessary condition. On the other hand, we used the inverse variance method for pooling the AUCs for each study, and this approach is not the most appropriate for meta-analysis of diagnostic accuracy studies. Actually, the most recommended and rigorous approaches are the SROC model, hierarchical SROC model and bivariate random effects meta-analysis of sensitivities and specificities.[58,91,92] To solve this inconvenient issue, we constructed SROC curves through studies that reported sensitivity and specificity values. Although using hierarchical summary receiver operating characteristic (HSROC) or bivariate random effects models has been advocated,[93] the results provided by these methods are very similar to those obtained by Moses' SROC model.[94] Another limitation is that some studies included in the meta-analysis did not report the AUC/OR of BMI, WC, WHR, WHtR, ABSI or BAI, and the resulting pooled AUCs/ORs did not include the same number of studies for BRI as for the rest of the anthropometric indices. Therefore, comparison bias could be present. A similar issue exists for AUC-SROCs. Finally, this study only included articles written in English or Spanish. Some eligible studies written in other languages might have been missed.

The main strength of the present meta-analysis consists in quantifying the performance of BRI in screening MetS and comparing it with other common and novel anthropometric measures (BMI, WC, WHR, WHtR, ABSI, and BAI). It is the first meta-analysis of the discriminatory power of BRI, highlighting that most of the included studies were published in 2019 (70%).

5 | CONCLUSION

This systematic review and meta-analysis is the first to show that BRI is a good predictor of MetS in both sexes in populations of various nationalities and ethnic groups. WC and WHtR offer the best performance when screening MetS, but no significant differences were found with BRI. In contrast, BRI was superior to BMI, WHR, ABSI and BAI in predicting MetS. Finally, pooled ORs showed that increased BRI is associated with increased MetS risk. Further studies should investigate the prospective relationship between BRI and adverse health outcomes in all age groups.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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