Novel anthropometric parameters to define obesity and obesity-related disease in adults: a systematic review

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Context: *Obesity is defined as an abnormal or excessive accumulation of body fat. Traditionally, it has been assessed using a wide range of anthropometric, biochemical, and radiological measurements, with each having its advantages and disadvantages.* ***Objective:*** *A systematic review of the literature was conducted to identify novel anthropometric measurements of obesity in adults.* ***Data Sources:*** *Using a combination of MeSH terms, the PubMed database was searched.* ***Data Extraction:*** *The current systematic review was conducted in accordance with the PRISMA guidelines. The data extracted from each study were (1) details of the study, (2) anthropometric parameter(s) evaluated, (3) study methods, (4) objectives of the study and/or comparisons, and (5) main findings/conclusions of the study.* ***Data Analysis:*** *The search yielded 2472 articles, of which 66 studies were deemed eligible to be included. The literature search identified 25 novel anthropometric parameters. Data on novel anthropometric parameters were derived from 26 countries. Majority were descriptive cross-sectional studies (n = 43), while 22 were cohort studies. Age range of the study populations was 17–103 years, while sample size varied from 45 to 384 612.* ***Conclusions:*** *The novel anthropometric parameters identified in the present study showed variable correlation with obesity and/or related metabolic risk factors. Some parameters involved complex calculations, while others were derived from traditional anthropometric measurements. Further research is required in order to determine the accuracy and precision.*

INTRODUCTION

Obesity is defined as an abnormal or excessive accumulation of body fat that may impair health.[1] Obesity and its precursor, overweight, are common problems in developed countries and becoming increasingly problematic in developing countries.[2] Over the past 3 decades, the worldwide prevalence of obesity has more than doubled, and in 2014, an estimated 39% of the world's adult population aged over 18 years were overweight and 13% were obese.[1] Excess body fat has been shown to be deleterious for multiple organ systems, through thrombogenic, atherogenic, oncogenic, hemodynamic, and neurohumoral mechanisms.[3–7] Obesity is the central and causal component in the pathogenesis of numerous diseases, including type 2 diabetes mellitus (T2DM), cardiovascular disease, and several cancers.[8] However, obesity is preventable and early identification plays a

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key role in the likelihood of overcoming the condition and associated metabolic complications.

Traditionally, overweight and obesity have been assessed on the basis of an excess of body weight, most commonly relative to height, with the assumption that excess body fat is recognized to be present at higher levels of body weight. However, many bigger (heavier) individuals may be classified as overweight (or obese) based on high levels of muscularity – that is, even in the absence of excess adiposity and/or associated metabolic risks.[9] In short, body weight is not a measure of body composition and does not differentiate between the major components of body composition: fat mass and fat-free mass. The amount of body fat in different regions of the body also varies considerably between individuals and is a major factor in determining health risk. Many studies have demonstrated that central adiposity is associated with greater risk of metabolic complications.[10–12] In the absence of consensus regarding the optimal gold standard technique to assess body fat in vivo, numerous proxy techniques have been used to estimate both body fat and its distribution. A wide range of anthropometric, biochemical, and radiological measurement approaches have been adopted. For example, the deuterium dilution technique is an example of a reference method used to assess total body water and subsequently estimate total fat mass based on a 2-compartment model.[13] Magnetic resonance imaging and computed tomography are considered gold standard approaches for determining subcutaneous abdominal adipose tissue and intra-abdominal adipose tissue.[14] However, such biochemical and radiological approaches cannot be routinely used in clinical and primary care settings to assess adiposity. Accordingly, various anthropometric measurements have been employed to assess overweight and obesity within a clinical setting.

The body mass index (BMI), a ratio between stature and body weight, is the most widely used anthropometric measure to define obesity in adults.[15–17] Despite the derivation of ethnic-specific cutoffs, for example lower cutoffs for Asians, the use of BMI still leads to high false-positive rates.[15] Importantly, BMI does not distinguish between body fat and lean mass and therefore overestimates fatness among those who are muscular.[16,18,19] Other widely used anthropometric indices of central obesity are waist circumference (WC), waist to hip ratio (WHR), and waist to height ratio (WHtR).[20,21] Each index confers both advantages and disadvantages, and presently no anthropometric measurement for central adiposity satisfies the criteria of being accurate, precise, accessible, and widely acceptable.[22] Accordingly, the scientific literature has repeatedly referenced the need for future studies to determine more precise, simple, and cost-effective measures for assessing obesity.[15,16] The current systematic review was conducted in accordance with the PRISMA guidelines (Table S1 in the Supporting Information online) and aims to systematically evaluate the literature, and identify, compare, and contrast novel anthropometric measures to assess overweight and obesity in adults.

METHODS

A systematic review of published studies reporting novel anthropometric tools to define obesity among adults was undertaken in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[23]

Search strategy

A comprehensive literature search was conducted in a stepwise process for studies published before December 31, 2017. During the first stage, the PubMed database was searched using the following MeSH (medical subject heading) terms: "obesity," "overweight," and "adiposity," and combined with the following MeSH subheadings: "body weight and measures/diagnosis," "body weight and measures/methods," "anthropometry/diagnosis," and "anthropometry/methods." Search limits were species ("humans"), language ("English"), publication type ("journal articles"), and age ("19+ yr"). In the second stage, the total hits obtained from searching the database were screened for suitability by reading the article "title" and "abstract." Subsequently, the filtered articles were further screened by reading the individual manuscripts, and those not satisfying inclusion criteria (described below) were excluded. This search process was conducted independently by 2 reviewers (P.R. and R.J.) and the final group of articles to be included in the review was determined through an iterative consensus process. The search strategy is summarized in Figure 1.

Inclusion and exclusion criteria

A study was considered eligible for data extraction if it described 1 or more novel anthropometric tools to define obesity in adults (age $\geq$18 y). Studies evaluating already well-established measures of obesity, such as BMI, WC, WHR, and WHtR, were excluded. In addition, conference proceedings, editorials, opinions/commentaries, and book chapters/book reviews were excluded.

Data extraction and analysis

Data were extracted from the included studies by one reviewer (Y.M.) using a standardized form and checked

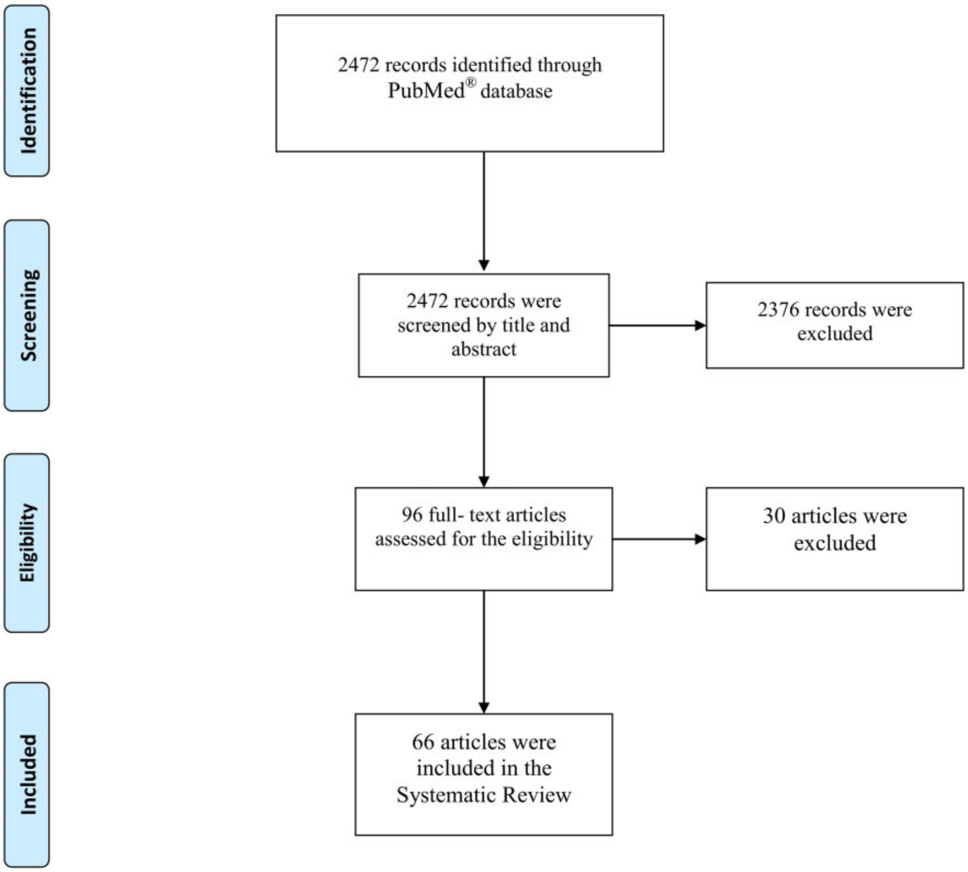

Figure 1 **Flow diagram of the literature search process.**

for accuracy by a second reviewer (S.W.). The data extracted from each study were (1) details of the study (lead author, country), (2) anthropometric parameter(s) evaluated in the study and its details (definition, cutoff, etc.), (3) study methods (sample size, male:female ratio, age group, study design), (4) objectives of the study and/or comparisons, and (5) main findings/conclusions of the study. Any discrepancies in the data extracted in this manner were rechecked and resolved by discussion, while a third reviewer (R.J.) was also involved where necessary. Data not presented in the published manuscript were obtained by contacting the corresponding author, or where possible calculated from the available data. When there were several studies describing the same anthropometric index, only the study with the largest sample and incorporating both males and females was selected. Studies involving novel anthropometric parameters are described in Table 1.[12,24–42]

Furthermore, when a single study reported several anthropometric indices, only details pertaining to the novel anthropometric parameters described in the study were included. In addition, where possible the first article that proposed a particular index was also identified via retrospective search of citation, with differences in the original concept and present index being highlighted.

RESULTS

Literature search and study characteristics

The literature search yielded 2472 articles, and the title and abstract of these papers were screened for relevance. Full-text copies were obtained for 96 articles and after reading, 66 studies were deemed eligible to be included in the final analysis. A summary of the search strategy is presented in Figure 1. Data on novel anthropometric parameters were derived from 26 countries (Australia, Brazil, Bulgaria, China, Colombia, Denmark, Finland, India, Iran, Italy, Japan, Malaysia, Netherland, Nigeria, Norway, Republic of Korea, Mexico, Portugal, Saudi Arabia, Singapore, Spain, Sri Lanka, Sweden, Turkey, UK, and USA). The majority were descriptive cross-sectional studies (n = 43, 65.2%), while 22 (33.3%) were cohort studies. Age range of the study populations was 17–103 years, while sample size varied from 45 to 384 612. The literature search identified 25 novel

1. Abdominal Circumference – hip ratio (AbCHR)
2. Arm Fat Area (AFA)
3. A Body Shape Index (ABSI), A Body Shape Index – Z Score (ABSIz) and Log transformed A Body Shape Index (LBSIZ)
4. Anthropometric Risk Index (ARI)
5. Abdominal Volume Index (AVI)
6. Body Adiposity Index (BAI)
7. Body Roundness Index (BRI)
8. Conicity Index (C-Index)
9. Clinica Universidad de Navarra-Body Adiposity Estimator (CUN-BAE)
10. Hip Index (HI)
11. Height Wrist Ratio (HtWrR)
12. Mid-Calf Circumference (MCC) and Mid-Thigh Circumference (MTC)
13. Neck Circumference (NC)
14. Ponderal Index (PI)
15. Sagittal Abdominal Diameter (SAD)
16. Sagittal Abdominal Diameter to Height Ratio (SADHtR)
17. Surface Based Body Shape Index (SBSI)
18. Thigh circumference (TC)
19. Waist Circumference to Hip Circumference to Height Ratio (WHHtR)
20. Waist Circumference to Thigh Circumference Ratio (WTR)
21. Waist to Height Index (WHI)
22. Xiphisternum to Umbilicus Distance (XUD)

Figure 2 **List of the novel anthropometric parameters identified in this review.**

anthropometric parameters, all of which are listed in Figure 2. For each of the novel anthropometric parameters, the study that described the parameter in the largest cohort of participants was included in Table 1,[12,24–42] with a description of the relevant study and the anthropometric parameter. Each parameter is described in detail in the following section.

Indices based on a single anthropometric measurement

Mid-calf circumference and mid-thigh circumference. The mid-calf circumference is defined as the maximum girth of the calf[25] and correlates strongly with magnetic resonance imaging (MRI)-measured total adipose tissue mass and total adipose tissue fat mass.[25] Mid-thigh circumference was measured at the midpoint between the inguinal crease and the proximal border of the patella,[25] and correlated strongly with MRI-measured total adipose tissue mass and total adipose tissue fat mass.[25] However, it is important to acknowledge that although mid-calf circumference is defined as the maximal girth of the calf, the point of measurement may not be the mid-calf.

Neck circumference. In a study conducted by Assyov et al,[43] neck circumference (NC) was measured between the mid-cervical spine and mid-anterior neck just below the laryngeal prominence among adults with severe obesity (BMI > 30 kg/m^2). They concluded that NC was more effective than WC at distinguishing T2DM (area under the curve [AUC] = 0.758), insulin resistance (AUC = 0.757), metabolic syndrome (Met S; AUC = 0.724), and hypertension (AUC = 0.763) in those with severe obesity. NC was used by Akin et al[44] to investigate the relationship between overactive bladder in women with MetS, with a high NC associated with an overactive bladder (AUC = 0.73). A large NC (measured just above the cricoid cartilage and perpendicular to the long axis of the neck) has also been associated with cardiovascular risk factors (odds ratio [OR]: 1.1–2.6) in older people[45] and with metabolic factors such as pre-diabetes (OR: 1.18–1.26).[46] According to Ozkaya and Tunckale,[47] there was a significant correlation between NC and obesity ($r = 0.24$–0.68), as defined by traditional anthropometric parameters. NC has also shown positive correlations with WC, BMI, and MetS in Chinese individuals with T2DM.[48] The authors defined NC cutoffs for overweight (males ≥38 cm, females ≥35 cm) and MetS (males ≥39 cm, females ≥35 cm). In another Chinese study, NC was significantly associated with cardiometabolic risk factors and independently contributed to the prediction of cardiometabolic risks (OR: 1.29–1.44) beyond the classical anthropometric indices.[42] However, Chagas et al[27] concluded that NC in patients undergoing coronary angiography for

Table 1 **Novel anthropometric parameters**

Author [Ref]; Country	Indices	Study population (study design; sample size;male:female ratio; age group)	Measurement (method; cutoff)	Comparison/objective	Findings
Abulmeaty et al[24] Saudi Arabia	HtWrR	Descriptive cross-sectional; n = 390; 167:223; 18–50 y	**HtWrR** = Ht (cm) / WC (cm) Cutoff: NR	To investigate the prediction of long-term cardiometabolic risk using anthropometric parameters	HtWrRdid not discriminate the risk in either sex
Al-Gindan et al[25] USA	MCC; MTC	Case-control cases: n = 416 (194: 222) 18–88 y Controls: n = 204 (94:110) 18–86 y	**MCC** – maximum girth of calf **MTC** – measured at the midpoint between the inguinal crease and the proximal border of the patella Cutoff: NR	To validate new anthropometric equations to estimate MRI-measured TATM/ TATFM/total body fat and compare these with existing prediction equations using older methods	New anthropometric measurement–based equations correlated better with MRI-measured TATM and TATFM than existing equations
Carlsson et al[26] Sweden	SAD; SADHR	Longitudinal cohort study; n = 3741; 1751:1990; 60 y	**SAD =** distance between table and the top of the body at the level of the iliac crest **SADHR**= SAD (cm) / Ht (cm) Cutoff: NR	To compare anthropometric measures (BMI, WHR, WC, SAD, WHHtR, WHtR, and SADHR) in their ability to predict ischemic CVD	BMI, WC, and WHtR were weaker predictors than SAD and SADHR in predicting ischemic CVD
Chagas et al[27] Brazil	AbCHR	Descriptive cross-sectional study; n = 337; 213:124; 23–89 y	**AbCHR** = AbC (cm) / HC (cm) AbC measured 1 cm above the iliac crest Cutoff: NR	To evaluate the association of different anthropometric parameters with the coronary atherosclerotic burden	AbCHR was not an independent risk factor for coronary atherosclerotic burden
Chang et al[28] China	BRI	Descriptive cross-sectional study; n = 11 345; 5253:6092; $\geq$ 35 y	**BRI** = 364.2–365.5 $\times$ (1– $[WC/2\pi]^2$ / $[0.5 \times Ht]^2$) Cutoff: 0.66 (male) and 0.67 (female)	To assess the capacity of BRI to identify subjects with T2DM and determine whether it is superior to BMI, WC, and WHtR	BRI was not superior to BMI, WC, or WHtR for predicting the presence of T2DM
Chung et al[29] Korea	ABSI; $LBSI_Z$	Cohort study; n = 54 893; 23 769: 31 124; 20–103 y	**ABSI** = WC (m) / ($BMI^{2/3} \times Ht^{1/2}$) **LBSI** = log(ABSI) **$LBSI_Z$** = (LBSI–LBSI[mean])/LBSI (SD) Cutoff: ABSI = 0.68; $LBSI_Z$ = 1.32 (male) and 1.86 (female)	To assess sensitivity of ABSI and $LBSI_Z$ based on BF% and its ability to predict hypertension and impaired health-related quality of life	$LBSI_Z$ is a measure of abdominal obesity that can predict hypertension and impaired health-related quality of life, and was more generalizable than ABSI
Fu et al[30] China	BAI	Descriptive cross-sectional study; n = 4868; 2323:2545; 18–96 y	**BAI** = (HC [cm] / Ht $[cm]^{1.5}$) − 18 Cutoff: (for $\geq$1 cardiometabolic abnormality): BAI = 26.39 (male) and 31.29 (female)	To correlate new anthropometric indices and cardiometabolic abnormalities	BAI was significantly associated with cardiometabolic abnormalities

(continued)

Table 1 **Continued**

Author [Ref]; Country	Indices	Study population (study design; sample size;male:female ratio; age group)	Measurement (method; cutoff)	Comparison/objective	Findings
Haghighatdoost et al[31] Iran	CUN-BAE	Descriptive cross-sectional study; n = 9555; 4777:4778; Mean age 38.7±15.5 y	**CUN-BAE formula for BF%** = −44.988 + (0.503 × age) + (10.689 × sex) + (3.172 × BMI) − (0.026 × BMI2) + (0.181 × BMI × sex) − (0.02 × BMI × age) – (0.005 × BMI2 × sex) + (0.00021 × BMI2 × age) Cutoff: NR	To compare the predictive power of ABSI, BMI, WHtR, and CUN-BAE for MetS and cardiovascular disease risks	CUN-BAE was a good predictor of body fat percentage; however, it was not the best anthropometric predictor of cardiovascular risks
Jung et al[32] Korea	TC	Descriptive cross-sectional study; n = 315 628; 199 423:116 205 30–79 y	**TC:** measured immediately below the gluteal fold in left thigh Cutoff: NR	To study the association between TC and T2DM, in relation to age and BMI	Small TC was associated with T2DM, and this association was stronger among participants with a BMI <25 kg/m^2. TC is a possible T2DM marker in lean populations
Kaneko et al[33] Japan	WHI	Descriptive cross-sectional study; n = 695; 433:262; 45–74 y	**WHI** = WC (cm) / (Ht [m] × Ht [m]) Cutoff: ≥ 35	To determine the ability of WHI as an index of abdominal obesity to predict the risk of colon cancer in Japanese persons	WHI is an efficient predictor (more effective than WC and BMI) of risk of colon cancer in females
Katulanda et al[34] Sri Lanka	XUD	Descriptive cross-sectional study; n = 4485; 1772:2713; ≥18 y	**XUD:** distance between the lower border of xiphisternum and the center of umbilicus at the end of normal expiration; Cutoff: NR	Relationship between obesity-associated risk factors for CVD and XUD, WC, BMI, and WHR	XUD is significantly, but weakly, associated with obesity-associated risk factors for CVD, but the association was weaker than that of BMI, WC, and WHR with obesity-associated risk factors for CVD
Kommuri et al[35] USA	C-index	Longitudinal cohort study; n = 6814; 3213:3601; 45–84 y	**C-index** = WC (m) / (0.109 × ✓ [Wt (kg) / Ht (m)]) Cutoff: NR	To explore the association between various anthropometric measures and markers of subclinical atherosclerosis	C-index was associated with subclinical atherosclerosis compared to other measures. However, the association was weaker than other anthropometric parameters
Krakauer and Krakauer[36] USA	HI; ARI	Cohort study; n = 16 034; 7696:8338; Mean age 43 y	**HI** = HC of a given person normalized to a standard height and weight **ARI** = the sum of function values for each individual's combination of anthropometric index scores, denoting natural logarithm of the combined estimated hazard from 4 independent indices: HC, BMI, ABSI, and HI Cutoff: NR	To evaluate HI and ARI as predictors of mortality risk	HI and ARI were consistent predictors of mortality hazard

(continued)

Table 1 **Continued**

Author [Ref]; Country	Indices	Study population (study design; sample size;male:female ratio; age group)	Measurement (method; cutoff)	Comparison/objective	Findings
Li et al[37] USA	WTR	Descriptive cross- sectional study; n = 6277; 2994:3283; ≥20 y	**WTR** = WC (cm) / TC (cm) (TC = circumference of the mid-thigh, perpendicular to the long axis of the thigh) Cutoff: NR	To examine whether WTR performed better than WHtR, WHR, WC, and BMIin relation to T2DM among US adults	For the association with T2DM, WTR performed better than the other 4 indices in men, and WTR performed similarly to WHtR, WHR, and WC, but better than BMI, in women
Motamed et al[38] Iran	AVI	Descriptive cross- sectional study; n = 3201; 1826:1375; 40–79 y	**AVI**= (2 × WC2 + 0.7 [WC – HC^2]) / 1000 Cutoffs: NR	To determine the performance of WC, WHR, WHtR, C-index, and AVI to predict risk of 10-y CVD events	AVI had the lowest discriminatory accuracy to predict 10-y CV events, while C-index had the highest accuracy
Ononamadu et al[39] Nigeria	PI	Descriptive cross-sectional study; n=912; 436:476; 17–79 y	**PI** = Wt (kg) / $(Ht [cm])^3$ Cutoffs: hypertension and pre-hypertension: PI = 14.45, 13.69 (female); 16.38, 17.65 (male)	To compare anthropometric indices of obesity as correlates and potential predictors of risk of hypertension and pre-hypertension	BMI, WHtR, WC, and PI were the best predictors of hypertension risk, and BMI, WC, and PI of pre-hypertension risk
Rahman and Adjeroh[40] USA	SBSI	Longitudinal cohort study; n = 11 808; Sex: NR; 18–85 y	**SBSI** = $(Ht^{7/4} \times WC^{5/6})$ / (BSA × VTC) Cutoff: NR	To evaluate SBSI as a predictor of all-cause mortality	SBSI is generally linear with age and increases with increasing mortality, when compared with other popular anthropometric indices of body shape
Song et al[12] Finland	WHHR	Cohort study; n = 46 651; 24 686:21 965; 24–99 y	**WHHR** = WC (m) / (HC [m] × Ht [m]) Cutoffs: NR	To compare the ability of anthropometric indicators of obesity to predict CVD mortality	WHHtR was a stronger predictor of CVD mortality than BMI
Vogel et al[41] Brazil	AFA	Cohort study; n = 116; 72:44; 30–85 y	**AFA** = (AC * TSF/2) – $(3.14*[TSF]^2/4)$ Cutoffs: 90th percentile (obesity)	To evaluate the association between obesity indices and mortality among patients with ischemic heart failure	AFA did not predict survival among heart failure patients
Zhou et al[42] China	NC	Descriptive cross-sectional study; n = 4201; 2508:1693; 20–85 y	**NC** = measured with head erect and eyes facing forward, horizontally at the upper laryngeal bulge Cutoffs: males ≥37 cm, females ≥33 cm	To investigate whether NC independently contributes to the prediction of cardiometabolic risks over BMI, WC, and WHR in Chinese individuals	NC independently contributed to the prediction of cardiometabolic risks in Chinese individuals

AbC, abdominal circumference, AbCHR, abdominal circumference to hip ratio; ABSI, a body shape index; ABSIz, a body shape index z-score AC, arm circumference; AFA, arm fat area; AH, abdominal height; ARI, anthropometric risk index; AUC, area under the curve; AVI, abdominal volume index; BAI, body adiposity index; BF, body fat; BMI, body mass index; BRI, body roundness index; BSA, body surface area; C-index, conicity index; CUN-BAE, Clinica Universidad de Navarra-Body Adiposity Estimator; CV, cardiovascular; CVD, cardiovascular disease; F, female; HC, hip circumference; HCNC, height-corrected neck circumference; HI, hip index; Ht, height; HtWrR, height to wrist ratio; $LBSI_Z$, log-transformed body shape index; M, male; MAC, mid-arm circumference; MAMA, mid-arm muscular area; MCC, mid-calf circumference; MetS, metabolic syndrome; MRI, magnetic resonance imaging; MTC, mid-thigh circumference; NC, neck circumference; NR, not reported; OSA, obstructive sleep apnea; PCOS, polycystic ovarian syndrome; PI, ponderal index; SAD, sagittal abdominal diameter; SADHR, sagittal abdominal diameter to height ratio; SBSI, surface-based body shape index; TATFM, total adipose tissue fat mass; TATM, total adipose tissue mass; TC, thigh circumference; T2DM, type 2 diabetes mellitus; TSF, triceps skinfold thickness; VAT, visceral adipose tissue; VTC, vertical trunk circumference; WC, waist circumference; WHHR, waist circumference to hip circumference to height ratio; WHI, waist to height index; WHR, waist to hip ratio; WHtR, waist to height ratio; Wt, weight; WTR, waist circumference to thigh circumference ratio; XUD, xiphisternum to umbilicus distance.

suspected coronary artery disease was not an independent risk factor for atherosclerotic burden after multivariate analysis ($r = 0.09$). It is important to note that authors have used different sites in the assessment of NC, which may have influenced the final results.

Sagittal abdominal diameter. The sagittal abdominal diameter (SAD) has been measured at different anatomical sites in various studies including umbilical level, highest abdominal diameter, the narrowest point between the last rib and iliac crest, and the midpoint between the iliac crests.[49] SAD measured at the midpoint between the iliac crests strongly correlated with cardiometabolic risk factors in elderly men ($r = 0.107$–0.480).[49] Dahlen et al[50] prospectively explored how SAD predicted subclinical organ damage in patients with T2DM, with SAD measured with the patients in the supine position with bent knees, at the highest point of the abdomen. Results showed that SAD predicted arterial stiffness over 4 years in patients with T2DM ($r = 0.184$). In a subsequent study, Dahlen et al[51] found that SAD was a good predictor of inflammation ($r = 0.29$–0.31) and subclinical organ damage ($r = 0.11$–0.21) in middle-aged patients with T2DM. Other studies have shown that SAD is a good predictor of central obesity among women ($r = 0.79$),[52] but there were no significant correlations between body composition as measured by SAD and lung function.[53] SAD $\geq$25 cm was a significant and independent risk factor (hazard ratio [HR]: 2.81) that predicted major cardiovascular events in patients with T2DM compared with WC (HR: 1.44).[54] These findings have also been verified in a cohort study involving adults older than 60 years followed up for 11 years.[55] An inverse relationship was found between short sleep duration and SAD among Swedish females (−0.46 cm/h),[56] and SAD accurately estimated accumulation of epicardial adipose tissue and cardiovascular risk in a study conducted among premenopausal Brazilian females (AUC: 0.81).[57]

Thigh circumference. A small thigh circumference (TC) has been associated with an increased risk of developing heart disease (TC < 56 cm in males and TC < 68 cm in women) or premature death (TC < 62 cm) in a prospective cohort study among males and females aged 35–65 years, followed up for 10.0–12.5 years.[58] A similar study among 2484 participants aged 50–75 years concluded that a larger TC was associated with a lower risk of T2DM in women, independent of BMI, age, and WC.[59] A large population study (n = 199 243) by Jung et al[32] also confirmed that a small TC was associated with T2DM (AUC: 0.795). The study further concluded that this association was stronger among participants with a BMI less than 25 kg/m^2, making TC a possible useful T2DM marker in lean populations. In all studies, the TC was measured immediately below the gluteal fold of the left leg, in contrast to the mid-thigh circumference measurement in previously discussed studies.

Xiphisternum to umbilicus distance. The xiphisternum to umbilicus distance (XUD) was first described by Katulanda et al,[34] who investigated the relationship between XUD and cardiovascular disease (CVD). XUD was defined as the distance between the lower border of the xiphisternum and the center of umbilicus at the end of normal expiration. The study concluded that XUD was significantly, but weakly (AUC for $\geq$2 cardiovascular risk factors: 0.62), associated with obesity-associated risk factors for CVD (AUC less than for BMI, WC, WHR). The authors also observed a significant correlation between XUD and BMI, WC, and WHR ($P < 0.001$).

Indices adjusted for height

Ponderal index. The ponderal index was originally described by Rohrer as a measure of intrauterine growth retardation in infants.[60] It is derived by dividing weight in kilograms by $(\text{height})^3$ in centimeters (Table 1).[12,24–42] Ononamadu et al[39] compared ponderal index and other indices as predictors of risk of hypertension and pre-hypertension in a cross-sectional study in Nigeria. PI (AUC: 0.52–0.68), together with BMI (AUC: 0.52–0.73) and WC (AUC: 0.51–0.61), were the best predictors of hypertension and pre-hypertension risk; however, a combination of indices in a regression model did not improve their performance as predictors.

Sagittal abdominal diameter to height ratio. The sagittal abdominal diameter to height ratio (SADHR) was used to predict ischemic CVD risk in an 11-year longitudinal cohort study comprising 3471 Swedish people[26] with SAD measured as the perpendicular distance between the table and top of the body at the level of the iliac crest in supine position, measured after normal expiration, using a ruler and spirit level. SADHR was a strong predictor of ischemic cardiovascular disease risk in the cohort. BMI (HR: 0.99–1.08), WC (HR: 0.99–1.07), and WHtR (HR: 1.04–1.12) were weaker predictors than SAD (HR: 1.05–1.16) and SADHR (HR: 1.10–1.19) in predicting ischemic CVD.

Waist circumference to hip circumference to height ratio. Waist circumference to hip circumference to height ratio (WHHR) was first described by Rosenblad et al[61] and is calculated as the ratio between WHR and height (Table 1).[12,24–42,61] A descriptive cross-sectional study involving 4868 Chinese adults showed a significant association between WHHR with cardiometabolic abnormalities (hypertension [AUC: 0.67–0.69], T2DM [AUC: 0.67], and dyslipidemia [AUC: 0.58–0.64]); however, other anthropometric parameters (BMI, WC, WHR, WHtR) showed a better association.[30] The authors recommended a cutoff WHHR value of 0.51 in males and 0.53 in females for the presence of 1 or more cardiometabolic abnormalities. Song et al[12] compared the ability of WHHR and other anthropometric indices to predict CVD mortality in a longitudinal cohort study (7.9 y) involving a population of 50 093 adults from 12 prospective studies conducted in 4 different European countries (Finland, Sweden, Turkey, and UK). This large population study revealed that WC (HR: 1.29–1.49), WHR (HR: 1.28–1.45), WHtR (HR: 1.35–1.52), and WHHR (HR: 1.37–1.45) were stronger predictors for CVD mortality than a body shape index (ABSI) (HR: 1.32–1.34) or BMI (HR: 1.19–1.37). Similar observations were reported in a study by Carlsson et al.[26,55] In a cohort of 3741 adults without CVD followed up for 11 years, WHHR (HR: 1.20) and WHR (HR: 1.14) were the best predictors of CVD in normal-weight women, and among overweight/obese individuals. WHHR was the strongest predictor after adjustments for CVD risk factors in men. A study conducted in a cohort of US adults showed that WHHR had a lower association and was an inferior discriminator of incident T2DM (HR: 1.26–1.61) among all race-sex groups, compared with BMI (HR: 1.56–1.76), WC (HR: 1.56–1.88), WHtR (HR: 1.57–1.86), and WHR (HR: 1.26–1.77).[62] All the above authors used the same measures to derive WHHR.

Waist to height index. Waist to height index is calculated using the WC divided by height squared (Table 1),[12,24–42] and was first described by Kaneko et al[33] in a cohort of Japanese patients who underwent colonoscopy. Waist to height index was an efficient predictor (OR: 1.32; $P < 0.05$) (more than WC and BMI) of risk of colonic cancer among the female patients.[33] The study recommended that women aged ≥55 years and/or with waist to height index ≥35 should undergo elective colonic endoscopy. All the above authors used the same calculation to derive waist to height index.

Indices adjusted for height and weight

Conicity index. Conicity index (C-index) is calculated according to WC, weight, and height (Table 1).[12,24–42] It was first described by Valdez[63] in 1991. This measurement has been used to investigate the prediction of long-term cardiometabolic risk among middle-aged males and females, and demonstrated good clinical discriminatory value for long-term cardiometabolic risk with an AUC of 0.817.[24] Another study evaluated the performance of C-index in discriminating high coronary risk in women[64] and showed that C-index was the indicator with highest discriminatory power in this cohort of women (AUC: 0.76). According to Chakraborty and Bose,[65] C-index showed no advantage over other adiposity measures in the prediction of hypertension among slum-dwelling Bengalee men in Kolkata. Chakraborty used 1.25 as the cutoff value for C-index. Similar findings were observed by Ononamadu et al,[39] who compared different anthropometric indices of obesity as correlates and potential predictors of risk of hypertension and pre-hypertension in a cross-sectional study. However, a high C-index has been found to be associated with a high risk of hypertension (OR: 4.3) among pre-university students.[66]

C-index has also been used to discriminate MetS in Brazilian women with polycystic ovarian syndrome.[67] The authors concluded that WC (AUC: 0.83) and WHtR (AUC: 0.82) were more effective than C-index (AUC: 0.74) at predicting MetS, with similar findings observed in a study among Chinese adults.[68] Kommuri et al[35] explored the associations between various anthropometric measures and markers of subclinical atherosclerosis in a longitudinal cohort study and concluded that C-index was a less consistent marker – in its association with various markers of subclinical atherosclerosis – than other anthropometric measures. However, another study showed that C-index (AUC: 0.67– 0.76) had the highest discriminatory accuracy to predict 10-year cardiovascular events compared with WC (AUC: 0.57–0.59), WHtR (AUC: 0.62–0.65), and abdominal volume index (AVI; AUC, 0.57–0.59).[38] C-index was a useful marker of inflammatory status, abdominal fat mass, and protein energy wasting in post-hemodialysis patients.[69] All the above authors used the same calculation to derive C-index.

Hip index. Hip index is defined as the hip circumference (HC) of a given person normalized to a standard height and weight (Table 1).[12,24–42] In analyses of data from the longitudinal cohort studies US National Health and Nutrition Examination Survey (NHANES) III and Atherosclerosis Risk in Communities Study (ARIC), involving 16 034 adults, Hip index was a consistent predictor of mortality hazard ("U"-shaped relationship); however, in both cohorts, BMI (HR: 1.06–1.11) and ABSI (HR: 1.16–1.26) were better nonlinear indicators of mortality hazard.[36] Furthermore, since hip index is calculated according to the standard height and weight of a population, it cannot be determined for populations from countries where national data are not available.

Indices to estimate percentage body fat

Body adiposity index. Body adiposity index (BAI) is an anthropometric parameter derived from HC and height (Table 1).[12,24–42] It was first described by Bergman et al[70] as a direct estimate of percentage adiposity. Belarmino et al[71] evaluated the performance of BAI in estimating body fat percentage (BF%) (measured by air displacement plethysmography) in severely obese Brazilian patients. BAI did not provide an accurate estimate of BF% in this study (level of agreement: 5.7%–16.0%) and has been reported to poorly predict body fat indices in obese women[72] and in athletes.[73] BAI (OR: 2.3) showed significant, but considerably lower, correlation than other adiposity measures (WHtR [OR: 4.0], BMI [OR: 3.3], WHR [OR: 4.2]) in the prediction of hypertension among slum-dwelling Bengalee men in Kolkata.[65] However, BMI (65%) and BAI (45%) were significant predictors of hypertension and subclinical organ damage in adult men in a prospective cohort study after 8 years of follow-up.[74] However, in a cross-sectional study, Ononamadu et al[39] showed that BAI correlates poorly with blood pressure ($r = 0.12$–0.18). Fu et al[30] found a significant correlation between BAI and cardiometabolic abnormalities (hypertension, T2DM, and dyslipidemia) in a descriptive cross-sectional study involving 4868 subjects. However, the association was weaker than traditional anthropometric parameters.[30,75] Similarly, BAI was not superior to traditional obesity indices for predicting MetS.[68,76] A study conducted by Garcia et al[77] found that BAI was a statistically significant predictor of cardiovascular risk (OR: 1.6–9.3) (criteria described by the National Cholesterol Education Program). In a prospective follow-up study of 7 years' duration, BAI was significantly associated with the presence of T2DM in men (OR: 1.9), but not in women (OR: 1.0).[78] However, BAI had lower associations and was an inferior discriminator of incident T2DM.[62] Furthermore, BAI was not a significant predictor of survival among ischemic heart failure patients.[41] All the above authors used the same calculation to derive BAI.

Body roundness index. Body roundness index (BRI), first described by Thomas et al,[79] is calculated according to the WC and height (Table 1)[12,24–42] and has been shown to slightly improve predictions of BF% and the percentage of visceral adipose tissue, compared with the traditional metrics of BMI, WC, or HC.[79] Chang et al[28] used BRI to identify participants with T2DM, and compared this index with traditional anthropometric indices. Although BRI (OR: 1.8–1.9) showed potential for use as an alternative obesity measure in the assessment of T2DM, it was not superior to BMI (OR: 1.6), WC (OR: 1.8–1.9), or WHtR (OR: 2.4–2.7) for predicting T2DM, in a rural Chinese population. BRI has also shown predictive value in MetS, especially among males.[68] However, the index was not superior to traditional obesity indices for predicting MetS.[76] Santos et al[73] compared BF% (bioelectrical impedance) with novel anthropometric measurements, including BRI, and found that these indices were poor predictors of BF% in athletes. All the above authors used the same calculation to derive BRI.

Clinica Universidad de Navarra-body adiposity estimator. The Clinica Universidad de Navarra-body adiposity estimator (CUN-BAE) formula is used to estimate BF% and is based on age, sex (where male = 0 and female = 1), and BMI (Table 1).[12,24–42,80] CUN-BAE which was first described by Gomez-Ambrosi et al,[81] has shown a very good correlation ($r = 0.89$, $P < 0.001$) with BF% (measured by air displacement plethysmography). A study conducted in Iran showed that CUN-BAE was a predictor for CVD risks and MetS (OR: 0.9–1.2); however it was not the best predictor of CVD risk in the Iranian population, compared with other traditional anthropometric parameters.[31] However, the Hordaland Health Study,[82] a prospective 6-year follow-up study in Norway, identified that CUN-BAE is more strongly associated with future risk of T2DM (4.3–5.4) and CVD (OR: 1.9–2.1) than with BMI (OR: 1.2–2.1) in an analysis stratified according to sex. A study conducted in Spain, to evaluate the relationship between CUN-BAE formula in comparison with BMI in the prediction of T2DM and hypertension, showed that the overall correlation between BMI and CUN-BAE was not good ($R^2 = 0.48$), but improved when age and gender were taken into account ($R^2 > 0.90$).[80] This study also concluded that CUN-BAE was a better predictor than BMI for hypertension and T2DM.[80] All the above authors used the same formula to calculate CUN-BAE.

Other indices

Abdominal circumference to hip ratio. Abdominal circumference to hip ratio (AbCHR) is defined as the ratio between the abdominal circumference and hip circumference. Chagas et al,[27] who first described the AbCHR, evaluated the association between AbCHR (and other standard anthropometric measurements) and coronary atherosclerosis burden (coronary angiography Friesinger score). In this study, abdominal circumference was measured 1 cm above the iliac crest and the maximum circumference between hips and buttocks was considered to be the hip circumference. In the above study, AbCHR was not an independent risk factor for coronary atherosclerotic burden ($r = 0.102$, $P = 0.061$). All the above authors used the same calculation to derive AbCHR.

Arm fat area. Arm fat area is calculated according to arm circumference and triceps skin fold thickness (Table 1).[12,24–42] According to Vogel et al,[41] arm fat area did not predict survival among ischemic heart failure patients. In this study, arm circumference and triceps skin fold thickness was measured at the midpoint between the acromion and the olecranon, with the arm extended down the side of the body and the palm of the hand facing the thigh. The above study utilized the same formula originally proposed by Gurney and Jelliffe[83] to calculate the arm fat area.

ABSI, ABSI z-score, and log-transformed ABSI z-score. ABSI is a recently introduced marker of abdominal adiposity derived from WC, BMI, and height (Table 1).[12,24–42] ABSI measures WC in relation to weight and height and thus can be a measure of abdominal obesity independent of weight, height, or BMI.[29] Studies have shown that ABSI could be used to define sarcopenia in overweight/obese individuals, where those with a lower ABSI ($r = -0.37$) have a significantly greater fat-free mass index.[84] However, ABSI poorly predicts body fat percentage in athletes ($R^2 = 0.22$).[73] According to Chang et al,[28] ABSI (OR: 1.51–1.55) was not superior to traditional anthropometric measurements (BMI [OR: 1.57], WC [OR: 1.79–1.90], and WHtR [OR: 2.40–2.67]) in predicting the presence of T2DM in a large cohort of Chinese adults (n = 11 345). The same conclusion was reached in another study conducted among adults from the USA.[62]

Furthermore, Fu et al[30] found no significant correlation between ABSI with cardiometabolic abnormalities (hypertension [OR: 0.07–0.08], T2DM [OR: 0.08], and dyslipidemia [OR: 0.07–0.08]) in a descriptive cross-sectional study involving 4868 participants. Another study including 9555 individuals from Iran also concluded that ABSI was a weak predictor of cardiovascular disease risks (hypertension [OR: 0.9–1.1], hyperglycemia [OR: 0.8–1.1], hypercholesterolemia [OR: 0.8–1.2]) and MetS (OR: 1.7–1.9).[31] These findings were confirmed by a study among Chinese adults, where ABSI did not show a predictive value for MetS for either sex.[68] However, a recent study among 6081 Caucasian adults, which tested the separate and joint contribution of ABSI and BMI to high triglyceride levels, low levels of high-density lipoprotein cholesterol, high blood pressure, and high fasting glucose and visceral abdominal fat thickness (by ultrasound), found that ABSI was independently associated with all outcomes.[85]

ABSI has been shown to be a weaker predictor of CVD mortality (HR: 1.32–1.34) than WC (HR: 1.29–1.49), WHR (HR: 1.28–1.45), WHtR (HR: 1.35–1.52), and WHHR (HR: 1.34–1.45).[12] However, US studies showed that all-cause mortality increases with increasing ABSI among US citizens.[36,40] These findings were also confirmed among a cohort of Australian adults.[86] The formula used by Krakauer and Krakauer,[87] who first proposed ABSI, was used in all of the above studies to derive ABSI.

To improve the predictive ability of ABSI, several authors have proposed the use of ABSI z-score and log-transformed ABSI z-score. ABSI z-score has also been used to evaluate all-cause mortality and found to be a consistent predictor of mortality hazard (HR: 1.13–1.18) compared to other measures of abdominal obesity such as BMI (HR: 1.00), WC (HR: 1.09), and WHtR (HR: 1.11).[88] Log-transformed ABSI z-score has been shown to be an independent predictor of hypertension (OR: 1.17–1.22), impaired health-related quality of life (OR: 1.11–1.27), and obesity (OR: 1.32–1.86).[29]

Anthropometric risk index. Anthropometric risk index, first defined by Krakauer and Krakauer, is the sum of function values for each individual's combination of anthropometric index scores, denoting the natural logarithm of the combined estimated hazard from the 4 independent indices HC, BMI, ABSI, and hip index (Table 1).[12,24–42] In analyses of data from the longitudinal cohort studies NHANES III and ARIC, involving 16 034 adults, anthropometric risk index was a consistent predictor of mortality hazard (HR: 1.43–1.46) and a substantially better predictor of mortality risk than any of the individual anthropometric indices tested.[36]

Abdominal volume index. Abdominal volume index (AVI) was first described by Guerrero-Romero and Rodríguez-Morán,[89] for the purpose of determining the obesity-associated risk of diabetes, where AVI is derived from WC and HC (Table 1).[12,24–42] The authors concluded that AVI is strongly related to impaired glucose tolerance (OR: 1.6) and T2DM (OR: 2.1),[89] with similar results observed in a cohort of Mexican women.[90] The same measurement was used by Abulmeaty et al[24] to investigate the prediction of long-term cardiometabolic risk (calculated using 5 different CVD risk scoring systems). The results showed that AVI was significantly positively correlated with long-term CVD risk scores in both men ($r = 0.229$) and women ($r = 0.345$). In another study, AVI (AUC: 0.58) was not as effective as the C-index (AUC: 0.67–0.739) as a predictor of 10-year cardiovascular events.[38] Another prospective cohort study, where the participants were followed up for 4.5 years for the development of MetS, both BMI (AUC:

0.73–0.75) and AVI (AUC: 0.79) were superior to the other anthropometric indices for predicting MetS in both men and women.[68] All the above-stated authors used the same calculation to derive AVI.

Height to wrist ratio. Height to wrist ratio is the ratio between height and wrist circumference (Table 1).[12,24–42] This measurement has been used to investigate the prediction of long-term cardiometabolic risk calculated using 5 different CVD risk scoring systems.[24] The study concluded that height to wrist ratio did not discriminate the risk in either sex, for any of the CVD risk scoring systems evaluated.

Surface-based body shape index. Surface-based body shape index is derived from height, WC, body surface area, and vertical trunk circumference (Table 1).[12,24–42] Rahman and Adjeroh,[40] who first described the surface-based body shape index, evaluated it as a predictor of all-cause mortality. They measured vertical trunk circumference using a tape from the shoulder, through the crotch, and back to the shoulder while the participant stands fully erect with the weight distributed equally on both feet and the arms hanging freely downwards. Body surface area was calculated as a product of $0.00949 \times$ weight (0.441) in kilograms $\times$ height (0.655) in meters. The study showed that the surface-based body shape index was generally linear with age, and increased with increasing mortality, and was more effective (HR: 2.3) than other popular anthropometric indices of body shape, including BMI (HR: 0.91), WC (HR: 1.3), and ABSI (HR: 2.3).

Waist circumference to thigh circumference ratio. Waist circumference to thigh circumference ratio (WTR) is defined as the ratio between WC and mid-TC (Table 1).[12,24–42] Duarte-Rojo et al[91] attempted to identify the predictive ability of WC, WHR, and WTR in relation to severe acute pancreatitis. Umbilical WC was the circumference at the level of the umbilicus, or above the iliac crests when displacement of the umbilicus was noticed. Findings suggested that WC, WHR, and WTR were all accurate predictors of severe acute pancreatitis. However, umbilical WC was the best predictor and the only variable retained in the multivariate analysis. In another study, WTR was associated (OR: 4.21–4.68) with the presence of peripheral vascular disease (defined as an ankle to brachial pressure index of <0.90 in at least one leg) in both males and females, and the association was much stronger than that with WC, especially in males (OR: 1.06–1.09).[92]

Several studies have evaluated the relationship between WTR and T2DM. Data analysis from the US NHANES III (1998–1994) showed that WTR (AUC: 0.83) performed better than 4 traditional indices in men (WHtR [AUC: 0.78], WHR [AUC: 0.79], WC [AUC: 0.76], and BMI [AUC: 0.72]). WTR (AUC: 0.80) performed similarly to WHtR (AUC: 0.80), WHR (AUC: 0.79), and WC (AUC: 0.78), but better than BMI (AUC: 0.73), in women for the association with T2DM.[37] Similar results were observed in a study conducted among a cohort of 1055 patients from North India, where out of several anthropometric measurements (including WC, HC, WHR), WTR ($r = 0.324$–0.377, $P < 0.01$) correlated significantly and positively with blood glucose (fasting, random, and postprandial) ($P < 0.001$), suggesting that it is the best predictor of T2DM.[93] The study recommended a WTR of 2.3 as a quick, noninvasive diagnostic tool for T2DM. WTR was originally proposed by Kahn et al,[94] who measured WC at the midpoint between iliac crest and lower ribs, while mid-TC was measured midway between lateral inguinal fold and mid-patella. Variations were noted in the study by Duarte-Rojo et al,[91] which used umbilical WC and upper TC to calculate WTR.

DISCUSSION

This is the first paper to systematically evaluate the literature in order to identify, compare, and contrast novel anthropometric approaches to assessing overweight and obesity in adults. Overweight and obesity are associated with an accumulation of body fat that may have a negative impact on health, with the latter generally defined as a body fat percentage of greater than 25% for men and greater than 32% for women. The 4-compartment analysis process is currently considered the "reference method" for body composition assessment[95] and incorporates independent measurement of bone mineral content, total body water, and body density to formulate a body fat prediction. However, it is neither practical nor feasible as a clinical measurement in most healthcare settings, as the process is both costly and time consuming. Hence, anthropometric parameters such as BMI, WC, HC, WHR, and WHtR are more typically used to define obesity in adults.[15–17,20,21] An ideal anthropometric measure for defining adiposity should be both simple and accurate.[22] Several novel anthropometric parameters identified in the present analysis, such as the BRI, ABSI, CUN-BAE formula, and C-index, used complex calculations to derive level of adiposity.[28,29,31,35] Furthermore, other anthropometric parameters relied upon several body measurements that were both complex and difficult to measure with precision. This lack of simplicity is likely to be a major barrier in the application of some of the novel anthropometric parameters cited, especially as a screening tool for overweight and obesity in primary and secondary healthcare settings.

Accuracy in the measurement of adiposity is another important characteristic of an ideal anthropometric parameter. The standard used to compare the novel anthropometric parameter varied in the studies included in the present analysis, with only a few studies using body fat percentage as the comparator.[25,31] As described earlier, the 4-compartment model is the ideal reference method for measuring body fat. However, most of the studies cited used single approaches such as Bioelectrical impedance analysis,[73] air displacement plethysmography,[71] and magnetic resonance imaging[25] to determine body fat, and used it as the reference method. Furthermore, most studies have only evaluated the relationship of body fat with the presence of cardiovascular/metabolic diseases such as T2DM, dyslipidemia, hypertension, and CVD,[28–30,32,34,37,39,42,55] and/or studied the relationship with cardiovascular/metabolic risks, by using scoring systems such as the Framingham risk scoring system and/or the American College of Cardiology and American Heart Association risk score.[24,38] Prospective follow-up for the outcomes and/or mortality were only evaluated in a few of the studies.[12,40,55,88] Similarly, few studies evaluated the relationship between the anthropometric measurement and arterial stiffness, inflammatory markers, and atherosclerotic burden, as assessed by angiography.[27,35] Hence, there is a need to further evaluate these novel anthropometric parameters to better understand their ability to predict body fat/adiposity, ideally as defined by the "gold standard" 4-compartment model. There is also a need for further prospective follow-up studies to understand the relationship of these anthropometric parameters with metabolic risk, cardiovascular/metabolic outcomes, and mortality.

The study populations included participants from 26 different countries, across 6 continents, with subjects from diverse sociodemographic and ethnic backgrounds. It is important to appreciate that obesity-associated adverse health outcomes vary among these different populations and ethnic groups. For example, south Asians have a higher cardiovascular disease risk than white Caucasians at a given BMI and WC value,[96–98] and this has led to the development of different ethnic/population specific cutoff values for BMI. Hence, although some of the novel anthropometric parameters have shown a positive relationship between risk factors and disease outcomes, the derived cutoffs may not be applicable across all populations and ethnic groups. In addition, a positive or negative association identified with any given anthropometric parameter may not be applicable to all populations. This limits their usage until further evaluation is undertaken and ethnic/population specific cutoff values are derived through future studies. Furthermore, although total adiposity is considered a risk factor for cardiovascular and metabolic disease, many studies have shown that fat distribution influences metabolism independent of the effects of total body fat stores.[99] The accumulation of fat in the abdominal area, particularly in the visceral fat compartment, seems to be associated with an increased risk of complications such as insulin resistance, T2DM, dyslipidemia, and atherosclerosis.[99] Furthermore, ectopic fat deposits around internal organs, and pericardial and peri-aortic tissues, for example, have also been shown to be associated with cardiovascular disease, cancer, and mortality in prospective follow-up studies.[100] Similarly, although abdominal visceral adipose tissue and abdominal subcutaneous adipose tissue are both associated with adverse cardiometabolic risk factors, the association is much stronger for visceral adipose tissue.[101] Hence, an ideal adiposity measure should also reflect body fat distribution. Most of the novel anthropometric parameters failed to distinguish fat distribution from body composition.

In addition to body fat percentage and fat distribution, recent studies have also identified the importance of muscle mass on cardiometabolic risk and mortality. A large population-based cohort study involving more than 11 000 adults in the USA showed that at a given level of BMI, those with low muscle mass had higher total body fat percentage and WC, were more likely to have T2DM, and had an increased risk of death.[102] The reduced survival for people with normal BMI, compared with survival in overweight persons, is possibly explained by loss of muscle mass in the former.[103] Few anthropometric parameters identified in the present review are also affected by muscle mass in addition to the fat content measured. For example, a low TC has been shown to be associated with an increased risk of developing heart disease or premature death, whereas a larger TC was associated with a lower risk of T2DM, independent of BMI, age, and WC.[58,59] Even analyses using direct measures of adiposity likely underestimate the risks of excess body fat as they fail to account for the increases in muscle mass that typically accompanies obesity.[102] These changes in muscle mass have an impact on mortality risk that is independent and in a direction opposite to the effect of increased body fat. Hence, muscle mass is also an important factor that needs to be considered in an anthropometric measure, in addition to identifying total adiposity and fat distribution.

This systematic review has several notable strengths, including being the first to critically review novel anthropometric parameters of adiposity and present the available evidence for each parameter for different populations. This makes it possible for future researchers to select the ideal parameter, based on the purpose of the study and the population involved. Furthermore, the identified gaps in the present knowledge will serve to guide future researchers. A potential limitation of the present analyses is the fact that the search was limited to a single database (PubMed); nevertheless, a large number of studies and different anthropometric parameters were identified. Furthermore, several novel anthropometric variables could not be compared with a direct measure of body fat, owing to a lack of published research on such parameters. Hence, an estimation of disease risk was employed – ie, for each of these parameters, their predictive value was estimated, rather than their accuracy as an indirect estimate of body composition.

CONCLUSION

In conclusion, the novel anthropometric parameters defining obesity identified in the present study showed variable correlation with obesity and/or related metabolic risk factors. Some of the parameters involved complex calculations, while others were derived from traditional anthropometric measurements. Owing to the absence of studies comparing most novel anthropometric parameters with direct measurements of body fat, further research is required in order to determine their accuracy and precision.

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Supporting Information

The following Supporting Information is available through the online version of this article at the publisher's website.

Table S1 **PRISMA checklist**

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