

Article

Optimum Cut-Off Points of Conventional and Novel Anthropometric Indices for Obesity Screening in Young Japanese Females: A Pilot Study

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Abstract

Background: Conventional anthropometric indices such as body mass index (BMI), waist circumference (WC), and waist-to-height ratio (WHtR) are widely used for obesity screening; however, their accuracy may be limited in young Japanese women, who often exhibit higher percentage body fat (%BF) at lower BMI values. This pilot study examined the relationships between DXA-derived %BF and anthropometric indices and evaluated their ability to identify excess adiposity. **Methods:** A cross-sectional study was conducted among 78 Japanese female university students aged 18–28 years. Whole-body composition was assessed using dual-energy X-ray absorptiometry (DXA), and excess adiposity was defined as %BF $\geq$ 30%. Receiver operating characteristic analyses were performed to evaluate the discriminatory ability of anthropometric indices and identify exploratory optimal cut-off values. **Results:** Participants had a median BMI of 20.3 kg/m² and a mean %BF of 32.3 $\pm$ 5.4%. Conventional BMI, WC, and WHtR thresholds showed very low sensitivity for detecting excess adiposity despite perfect specificity. ROC analyses identified substantially lower optimal cut-off values, yielding sensitivities of approximately 70–80%, specificities of 58–75%, and AUC values of 0.76–0.78. Among novel anthropometric indices, body roundness index (BRI) demonstrated the strongest discriminatory ability. **Conclusions:** Conventional anthropometric thresholds may underestimate DXA-defined excess adiposity in young Japanese female university students. This exploratory pilot study identified lower candidate cut-off values and suggested that BRI may serve as a useful adjunctive anthropometric index for identifying excess adiposity in this population. These findings should be interpreted cautiously and require validation in larger and more diverse populations before clinical application.



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This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.**Keywords:** obesity screening; percentage body fat; dual energy X-ray absorptiometry; body mass index; body roundness index; normal-weight obesity; Japanese females

1. Introduction

Obesity is defined as an excess or abnormal accumulation of body fat that may impair health [1]. Body composition is therefore considered an important component to screen and diagnose the obesity status of individuals. Body composition can be estimated using a

range of techniques, including densitometry, hydrometry, bioelectrical impedance analysis (BIA), and dual energy X-ray absorptiometry (DXA). Among the available techniques, DXA is widely regarded as a reference method for body composition assessment because of its high accuracy, precision, and reproducibility compared with many field techniques that require population-specific prediction equations [2]. Despite its advantages, DXA is not practical for routine screening or large-scale epidemiological studies because of its cost, limited accessibility, and requirement for specialized equipment. In addition, although the radiation exposure from a single whole-body DXA scan is very low, its use should be justified in research involving healthy participants [3].

As alternatives to body composition assessment techniques, a number of anthropometric indices have been used as practical proxies for screening and diagnosis of obesity. Anthropometric indices are simple, cost- and time-effective, and efficient tools to screen and diagnose a large number of populations. While body mass index (BMI) has been frequently utilized for this purpose based on the World Health Organization (WHO) recommendation [1], other indices such as waist circumference (WC), waist-to-hip ratio (WHR), and waist-to-height ratio (WHtR) have also been adopted to determine a likelihood of an excessive fat accumulation around the trunk region as a visceral fat [4,5]. A recently proposed new definition of obesity stated that obesity will be diagnosed using either BMI, WC or WHtR if detailed body composition assessment techniques are not available [6–8].

Although BMI, WC, WHR, and WHtR are practical surrogate measures of adiposity and are associated with obesity-related health outcomes at the population level, they do not directly assess body composition (i.e., fat mass [FM] and fat-free mass [FFM]) and provide limited information regarding adipose tissue distribution, particularly subcutaneous adipose tissue (SAT) and visceral adipose tissue (VAT) [9–12]. Therefore, these anthropometric indices may misclassify obesity and fat accumulation patterns at an individual level. In addition, it is well documented that relationships between body composition and anthropometric indices vary between ethnic groups [13,14]. Previous studies reported that Asian people are likely to have a greater amount of percentage body fat (%BF) at a given BMI and WC compared to Caucasian people [7,15]. Based on these observations, several organizations recommend ethnic-specific cut-off points for obesity screening and diagnosis because the relationships between BMI, waist circumference, percentage body fat, and cardiometabolic risk differ across ethnic groups [16–18].

Similar to other Asian populations, Japanese people also exhibit higher %BF at lower BMI values. Due to this %BF–BMI relationship, a substantial proportion of young Japanese females may have an excessive level of adiposity despite having normal or even low BMI—conditions known as “normal weight obesity (NWtO)”. In Japan, this phenotype is also commonly referred to as masked obesity (MO). Meanwhile, ethnic differences in the %BF–BMI relationship have been reported among young Japanese women, who may exhibit excess body fat despite having a normal BMI [17]. Although these individuals are frequently overlooked during routine obesity screening, accumulating evidence suggests that NWtO is associated with adverse metabolic profiles, including insulin resistance, dyslipidemia, metabolic syndrome, and increased cardiovascular risk despite normal body weight [19]. Consequently, identifying individuals with excess adiposity despite normal BMI has become an increasingly important public health concern.

Furthermore, there is a complete scarcity of studies that explored relationships between DXA-derived body fat percentage and novel anthropometric indices that have been emerging in recent years, including body roundness index (BRI), conicity index (CI), and body shape index (BSI) in this population. As these indices consider body geometry and proportionality in the assessment of adiposity [20–22], they may offer theoretical advantages over BMI. However, their ability to accurately reflect adiposity and their comparative

diagnostic performance for young Japanese females remain unknown. The present study therefore aimed to examine the relationship between %BF derived from DXA and a range of conventional and novel anthropometric indices in young Japanese females. The study also sought to evaluate the diagnostic performance of these indices and to identify exploratory cut-off values for detecting excess adiposity within this study population.

2. Materials and Methods

Study Design and Participants: A cross-sectional study was conducted between December 2024 and February 2025. Female university students were recruited through classroom visits, flyers and posters displayed on campus notice boards, email announcements, LINE groups, and word-of-mouth referrals. Inclusion criteria included Japanese females aged 18–28 years who were not engaged in regular athletic training or specialized dietary programs. Participants were excluded if they were non-Japanese and outside of the age range, were pregnant or lactating, or diagnosed as having metabolic or chronic conditions affecting body composition (e.g., endocrine or thyroid disorders) and were also taking prescription medication that may alter body composition.

All participants received written and verbal explanations of the study procedures, including the DXA examination, and provided written informed consent prior to participation. Because DXA involves exposure to a very low dose of ionizing radiation (approximately 4 μ Sv) [23,24]. The study protocol conformed to the Declaration of Helsinki and was approved by the Human Research Ethics Committee of the affiliating institution (Approval No. 544).

Body composition assessment: Body composition was assessed using whole-body scanning with DXA (Horizon Wi, Hologic Inc., Marlborough, MA, USA). From the scan, total and segmental body composition, including fat mass, lean mass, and bone mineral content, were estimated. Scans were performed after conducting a daily calibration procedure, and all scans were made by the same trained DXA operator according to the manufacturer's guidelines. All participants were instructed to void before the measurement and remove all jewelry and metallic items when changing into a standardized examination gown. Participants were instructed to lie on the DXA bed in supine position and remain still during the scan. A vast majority of the participants underwent a single scan that takes approximately 10 min to minimize radiation exposure.

Anthropometry: Stature was measured using a stadiometer (BH-100, Tanita Corp., Tokyo, Japan), and body mass was assessed using a multi-frequency BIA device (MC-980 Plus, Tanita Corp., Tokyo, Japan). Waist circumference (WC) was measured using a flexible steel tape measure (W606PM, Apex Tool Group LLC, Apex, NC, USA). All measurements were conducted according to the protocol by the International Society for the Advancement of Kinanthropometry (ISAK) [25]. From anthropometry, BMI, WHtR, BRI, CI, and BSI were calculated.

All measurements were performed by a single trained researcher under standardized conditions. Measurements were obtained in duplicate, and a third measurement was taken if discrepancies exceeded predefined limits (0.6 cm for height and WC and 0.6 kg for body mass). The final value was calculated as the mean of the two closest measurements. Intra-tester relative technical errors of measurement (%TEMs) were below the acceptable threshold of 1% [26,27].

Statistical Analysis: Descriptive statistics were used to summarize participant characteristics. Normality was assessed using the Shapiro–Wilk test. Data are presented as mean $\pm$ standard deviation (SD) for normally distributed variables and median (interquartile range [IQR]) for non-normally distributed variables. Excess adiposity was defined as DXA-derived %BF $\geq$ 30%, consistent with previous studies involving young adult women

and widely adopted thresholds for defining excess adiposity using DXA [28,29]. Although Asian-specific body fat thresholds remain under investigation, a %BF cut-off point of 30% has been utilized in the previous literature [30]. The diagnostic performance of conventional anthropometric indices (BMI, WC, and WHtR) was evaluated using established cut-off points, whereas the discriminatory ability of BMI, WC, WHtR, BRI, CI, and BSI to identify excess adiposity was assessed using receiver operating characteristic (ROC) curve analysis with DXA-derived %BF as the reference.

Discriminative ability was assessed using ROC curve analysis by calculating the area under the curve (AUC) with corresponding 95% confidence intervals (CIs). Exploratory optimal cut-off values were identified using both the Youden Index and the Index of Union (IU). The Youden Index identifies the cut-off that maximizes the combined sensitivity and specificity, whereas the IU selects the cut-off that simultaneously minimizes the difference between sensitivity, specificity [31], and AUC, thereby providing an alternative measure of overall diagnostic performance. Both approaches were used to evaluate the robustness of the identified candidate thresholds. Diagnostic performance metrics, including sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV), were calculated for both conventional and optimized thresholds. Net reclassification improvement (NRI) analysis was performed to evaluate classification improvement.

All statistical analyses were conducted using IBM SPSS Statistics for Windows, version 26.0 (IBM Japan, Tokyo, Japan) with a significance level of 5%.

This study was designed as an exploratory pilot investigation to evaluate the diagnostic performance of anthropometric indices against DXA-derived body fat percentage in a specific population. Given the exploratory nature of this study, no formal a priori sample size calculation was performed.

3. Results

A total of 78 Japanese female university students aged 18–28 years were included in the analysis. Participant characteristics are summarized in Table 1. The median age was 20 years (IQR: 19–21). Mean stature was 159.5 ± 4.7 cm, median body mass was 51.5 kg (IQR: 46.0–56.2 kg), and median BMI was 20.3 kg/m^2 . Median WC was 67.6 cm (IQR: 57.5–84.5 cm), mean WHtR was 0.44 ± 0.03 , and mean DXA-derived %BF was $32.3 \pm 5.4\%$.

Table 1. Descriptive characteristics of participants (n = 78).

Variables	Mean $\pm$ SD/Median (IQR)
Age (years)	20.0 (19–21)
Stature (cm)	159.5 ± 4.7
Body mass (kg)	51.5 (46.0–56.2)
BMI (kg/m^2)	20.3 (19.0–22.4)
WC (cm)	67.6 (57.5–84.5)
WHtR	0.44 ± 0.03
%BF (%)	32.3 ± 5.4
BRI	2.1 ± 0.6
CI	1.09 ± 0.04
BSI	0.072 ± 0.003

BMI (body mass index); WC (waist circumference); WHtR (waist-to-height ratio); %BF (percentage body fat); BRI (body roundness index); CI (conicity index); BSI (body shape index).

The diagnostic performance of internationally recommended cut-off values for BMI, WC, and WHtR in detecting excess adiposity (%BF $\geq 30\%$) is presented in Table 2. The BMI cut-off of 25.0 kg/m^2 yielded a sensitivity of 7.4% and a specificity of 100.0%. The corresponding sensitivity and specificity values for WC and WHtR are also shown in Table 2. Youden indices ranged from 0.00 to 0.07.

Table 2. Diagnostic accuracy of conventional cut-off values for detecting excess %BF $\geq 30\%$.

Index	Conventional Cut-Off	Sens (%)	Spec (%)	PPV (%)	NPV (%)	Youden Index
BMI	25 kg/m ²	7.4	100.0	100.0	32.4	0.07
WC	85.5 cm *	0.0	100.0	100.0	30.8	0.00
WHtR	0.50	3.7	100.0	100.0	31.6	0.04

* No participant exceeded the conventional Japanese waist circumference criterion used in this study. Therefore, the highest observed waist circumference (85.5 cm) represented the maximum evaluable threshold; BMI (body mass index); WC (waist circumference); WHtR (waist-to-height ratio); Sens (sensitivity); Spec (specificity); PPV (positive predictive value); NPV (negative predictive value).

The %BF values corresponding to conventional anthropometric thresholds for BMI, WC, and WHtR were estimated to facilitate comparison with the DXA-derived excess adiposity criterion (%BF $\geq 30\%$) (Table 3). The BMI cut-off of 25.0 kg/m² corresponded to an estimated %BF of approximately 38.0%, whereas the conventional WC and WHtR cut-off points corresponded to %BF values of approximately 40.0% and 39.0%, respectively. The estimated percentage body fat values corresponding to conventional BMI, WC, and WHtR thresholds are presented in Table 3 to facilitate comparison with the DXA-derived criterion. The highest observed WC was 85.5 cm, which was therefore used as the maximum evaluable threshold for analysis.

Table 3. Estimated %BF cut-offs based on conventional cut-off values of BMI, WC and WHtR.

Index	Cut-Off Point	Estimated %BF Cut-Off	Sens (%)	Spec (%)	Youden Index	AUC
BMI	25 kg/m ²	38%	12	65	0.07	0.54
WC	85.5 cm *	40%	5	100	0.05	0.52
WHtR	0.50	39%	7	100	0.07	0.53

* No participant exceeded the conventional Japanese waist circumference criterion used in this study. Therefore, the highest observed waist circumference (85.5 cm) represented the maximum evaluable threshold. BMI (body mass index); WC (waist circumference); WHtR (waist-to-height ratio); Sens (sensitivity); Spec (specificity); PPV (positive predictive value); NPV (negative predictive value); AUC (Area under the curve).

ROC curve analyses identified exploratory candidate cut-off values for BMI, WC, and WHtR within this study population (Table 4). Candidate BMI cut-off values ranged from 19.5 to 19.6 kg/m², yielding sensitivities of 72.2% and specificities between 70.8% and 75.0%. Candidate WC cut-off values ranged from 65.5 to 65.7 cm, while the candidate WHtR cut-off was 0.42. The corresponding AUC values ranged from 0.76 to 0.78, indicating acceptable discriminatory performance against DXA-derived excess adiposity. Because conventional anthropometric thresholds demonstrated poor sensitivity for detecting DXA-defined excess adiposity, ROC curve analyses were subsequently performed to explore candidate thresholds with improved discriminatory performance. The candidate cut-off values identified using the Youden Index and the IU were highly comparable, with only minor differences in sensitivity and specificity across the evaluated anthropometric indices.

Novel anthropometric indices with no universal cut-off points were also evaluated using ROC analysis (Table 5). The exploratory BRI cut-off that reflects an excessive level of adiposity in this study population was 1.76, yielding a sensitivity of 79.6%, specificity of 58.3%, and a Youden Index of 0.379. The exploratory CI cut-off was 1.06, yielding a sensitivity of 90.7%, specificity of 45.8%, and a Youden Index of 0.365. The exploratory BSI cut-off was 0.069, yielding a sensitivity of 87.0%, specificity of 20.8%, and a Youden Index of 0.078. The corresponding AUC values were 0.779, 0.673, and 0.502, respectively.

Table 4. ROC-derived exploratory candidate cut-off values for BMI, WC and WHtR from the ROC analyses.

Index	Criteria Cut-Off	Cut-Off	Sens (%)	Spec (%)	PPV (%)	NPV (%)	AUC
BMI	IU	19.5 kg/m ²	72.2	70.8	84.7	53.2	0.76
	Youden	19.6 kg/m ²	72.2	75.0	86.7	54.5	
WC	IU	65.7 cm	72.2	70.8	84.7	53.2	0.78
	Youden	65.5 cm	74.1	70.8	85.1	54.8	
WHtR	IU	0.42	70.4	70.8	84.4	51.5	0.77
	Youden	0.42	72.2	75.0	86.7	54.5	

BMI (body mass index); WC (waist circumference); WHtR (waist-to-height ratio); Sens (sensitivity); Spec (specificity); PPV (positive predictive value); NPV (negative predictive value); IU (index of union); AUC (Area under curve).

Table 5. Diagnostic performance of BRI, CI and BSI.

Index	Cut-Off	Sens (%)	Spec (%)	Youden Index	AUC (95% CI)
BRI	1.76	79.6	58.3	0.379	0.779 (0.666–0.891)
CI	1.06	90.7	45.8	0.365	0.673 (0.540–0.805)
BSI	0.069	87.0	20.8	0.078	0.502 (0.360–0.644)

BRI (body roundness index); CI (conicity index); BSI (body shape index); Sens (sensitivity); Spec (specificity); AUC (Area under the curve).

4. Discussion

The present study identified a marked discrepancy between conventional anthropometric classifications and DXA-derived adiposity among young Japanese female university students. Although participants exhibited relatively low body mass and BMI values, the mean DXA-derived %BF exceeded 30%, suggesting a substantial prevalence of NWtO within this study population. These findings are consistent with previous studies demonstrating that Japanese individuals tend to possess higher body fat percentages at lower BMI values than Western populations [32,33]. Furthermore, previous investigations in Japanese populations have reported that conventional obesity screening criteria may inadequately identify individuals with elevated adiposity [33]. Collectively, these findings support previous evidence that reliance on conventional anthropometric thresholds alone may underestimate excess adiposity in young Japanese women.

ROC analyses identified lower candidate anthropometric thresholds for detecting DXA-defined excess adiposity than currently recommended international thresholds. Similar observations have been reported in previous studies involving Japanese populations [33,34], supporting the notion that conventional anthropometric cut-off values may not adequately reflect body fatness in this population [35,36]. Although differences between the present findings and previous reports may reflect variations in study characteristics, body composition assessment methods, or participant demographics, the current study was not designed to investigate temporal changes in lifestyle or body composition. Therefore, any influence of secular changes in physical activity or dietary patterns remains speculative and should be examined in future research.

The clinical importance of these findings lies in the identification of individuals with NWtO, who may remain undetected when obesity screening relies solely on BMI. Despite having a normal body weight, individuals with NWtO have been reported to exhibit adverse metabolic characteristics, including insulin resistance, dyslipidemia, systemic inflammation, metabolic syndrome, and increased cardiovascular risk compared with metabolically healthy individuals of similar BMI [37–39]. Consequently, improving the

identification of excess adiposity in this population may facilitate earlier lifestyle interventions and more comprehensive cardiometabolic risk assessment.

In addition to conventional anthropometric indices, the present study explored the performance of several novel anthropometric indices. Among the evaluated indices, BRI warrants further investigation as a complementary anthropometric measure because it demonstrated the highest discriminatory ability within this exploratory study. Although both BRI and CI incorporate aspects of body shape and central adiposity, they differ mathematically in how waist circumference and stature are integrated. BRI was developed to approximate body roundness and body fatness and has been shown to correlate strongly with total and visceral adiposity, whereas CI primarily reflects body shape relative to body mass and may be less sensitive to variations in %BF among relatively lean young females. Consequently, BRI may better capture subtle variations in adiposity within populations characterized by a high prevalence of NWtO. In contrast, BSI demonstrated limited utility in the present study. One possible explanation is the difference in the protocol for WC measurement. The original BSI model was developed using WC measured according to the protocol adopted in the source population, whereas the present study measured WC at the narrowest point between the costal border and the iliac crest. Variations in WC measurement sites are known to affect derived anthropometric indices [21] and may partially explain the reduced performance of BSI observed in this study. Nevertheless, the superior performance of BRI observed in this exploratory study should be confirmed in larger independent cohorts before recommending its broader application.

Collectively, the present findings provide preliminary evidence that conventional anthropometric thresholds may underestimate DXA-defined excess adiposity among young Japanese female university students. Within this exploratory study population, lower candidate thresholds demonstrated improved discrimination of excess adiposity, while BRI showed the strongest overall performance among the evaluated novel indices. However, these findings should not be interpreted as recommendations to replace existing anthropometric criteria. Rather, they highlight the need for larger validation studies to determine whether alternative thresholds improve obesity screening and prediction of cardiometabolic risk in Japanese populations.

Several limitations of the present study should be acknowledged. First, this study was designed as an exploratory pilot investigation and included a relatively small sample of young Japanese female university students recruited from a single institution. Consequently, the ROC-derived candidate cut-off values may be sample-dependent and should not be generalized beyond the study population without external validation. Second, although DXA is widely accepted as a reference method for body composition assessment, the present study evaluated agreement with DXA-derived %BF rather than associations with cardiometabolic outcomes. Therefore, the clinical utility of the candidate anthropometric thresholds for predicting future disease risk remains unknown. Future studies incorporating metabolic biomarkers and longitudinal follow-up are required to determine whether these thresholds improve prediction of obesity-related health outcomes. Third, although information on individual dietary intake, physical activity patterns, and metabolic biomarkers was collected, these variables were not incorporated into the present analyses. As these factors may influence body fat accumulation and adiposity distribution, future analyses should examine their potential contribution to the observed discrepancy between anthropometric indices and DXA-derived %BF. Consequently, the hypothesis that secular lifestyle changes contributed to the observed findings could not be evaluated. Future investigations involving larger multi-center cohorts, external validation, and longitudinal assessment of cardiometabolic outcomes are required before these candidate thresholds can be considered for broader clinical or public health application.

5. Conclusions

The present study demonstrated that conventional anthropometric cut-off points substantially underestimate excess adiposity in young Japanese women when DXA-derived %BF is used as the reference standard. ROC analyses identified lower optimal cut-off values for BMI, WC, and WHtR than currently recommended international thresholds, resulting in improved sensitivity and overall diagnostic performance. Among the novel anthropometric indices evaluated, BRI showed the strongest discriminatory ability, whereas CI demonstrated moderate utility and BSI provided limited diagnostic value. These findings suggest that population-specific anthropometric thresholds, together with the incorporation of BRI, may improve the identification of excess adiposity and normal-weight obesity in young Japanese women. Further studies involving larger and more diverse populations are warranted to confirm the proposed cut-off values and their applicability in clinical and public health settings.

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Informed Consent Statement: Informed consent was obtained from all participants involved in the study.

Data Availability Statement: The data presented in this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy and ethical restrictions.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

%BF	Percentage Body Fat
AUC	Area Under the Curve
BIA	Bioelectrical Impedance Analysis
BMI	Body Mass Index
BRI	Body Roundness Index
BSI	Body Shape Index
CI	Conicity Index
DXA	Dual-Energy X-ray Absorptiometry
FFM	Fat-Free Mass

FM	Fat Mass
IQR	Interquartile Range
ISAK	International Society for the Advancement of Kinanthropometry
IU	Index of Union
MO	Masked Obesity
NPV	Negative Predictive Value
NRI	Net Reclassification Improvement
NWtO	Normal-Weight Obesity
PPV	Positive Predictive Value
ROC	Receiver Operating Characteristic
SAT	Subcutaneous Adipose Tissue
SD	Standard Deviation
VAT	Visceral Adipose Tissue
WC	Waist Circumference
WHR	Waist-to-Hip Ratio
WHtR	Waist-to-Height Ratio
WHO	World Health Organization
95% CI	95% Confidence Interval

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