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Differences in the obesity screening ability of 19 anthropometric parameters in young Japanese females: Comparisons of direct measurements, conventional and novel indices

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Abstract

Aim: The present study aimed to examine the usefulness of anthropometric parameters for obesity screening in young Japanese females by assessing their associations with indicators of adiposity obtained from a dual energy x-ray absorptiometry (DXA). **Methods:** Screening ability of 19 anthropometric parameters was examined using a total of 50 young Japanese females who completed detailed anthropometry and a whole-body DXA scan. Anthropometric parameters were categorized into 1) measured variables, 2) conventional indices, and 3) novel indices and their correlations with body fat variables obtained from DXA were investigated. Using a percentage body fat (%BF) of 30.0% as a cut-off point of obesity, the Area Under the Curve (AUC) was observed from the Receiver Operating Characteristics (ROC) analysis and cut-off points of anthropometric parameters were determined. **Results:** While body mass correlated highly with total fat tissue mass in this sample (r = 0.847), body mass index (BMI) and waist circumference (WC) correlated most strongly with trunk fat and android fat tissues respectively (r = 0.820 and 0.865). However, all body composition variables were correlated with the sum of eight skinfolds (Sum8SF) if %BF was used (r ranged 0.672 – 0.834). Among anthropometric parameters examined, Σ8SF showed highest AUC for $\%BF_{Total}$, $\%BF_{Gynoid}$ and $\%BF_{IAAT}$ while Σ2SF and abdominal circumference (AbC) showed highest AUC for $\%BF_{Trunk}$ and $\%BF_{Android}$ respectively. **Conclusion:** Directly measured variables and conventional indices showed moderate to strong correlations with results from DXA. However, the sum of skinfolds, particularly Sum8SF, showed stronger correlations and superior screening ability for obesity. Although many novel indices have been utilized to screen obesity and metabolic abnormalities, observed results indicated that these indices may not necessarily better than measured values or conventional indices. Further investigations to confirm proposed cut-off points are warranted.

Keywords: Anthropometry, Indices, Obesity screening, Japanese, Young females, DXA.

Resumen

Objetivo: El presente estudio tuvo como objetivo examinar la utilidad de los parámetros antropométricos para el cribado de la obesidad en mujeres jóvenes japonesas mediante la evaluación de sus asociaciones con indicadores de adiposidad obtenidos de una absorciometría de rayos X de energía dual (DXA). **Métodos:** Se examinó la capacidad de detección de 19 parámetros antropométricos utilizando un total de 50 jóvenes japonesas que completaron antropometría detallada y una exploración DXA de cuerpo entero. Los parámetros antropométricos se categorizaron en 1) variables medidas, 2) índices convencionales y 3) índices novedosos y se investigaron sus correlaciones con las variables de grasa corporal obtenidas de DXA. Utilizando un porcentaje de grasa corporal (% GC) del 30% como punto de corte de la obesidad, se observó el área bajo la curva (AUC) a partir del análisis de las características operativas del receptor (ROC) y se determinaron los puntos de corte de los parámetros antropométricos. **Resultados:** Si bien la masa corporal se correlacionó altamente con la masa de tejido graso total en esta muestra (r = 0,847), el índice de masa corporal (IMC) y la circunferencia de la cintura (CC) se correlacionaron más fuertemente con la grasa del tronco y los tejidos grasos androides, respectivamente (r = 0,820 y 0,865). Sin embargo, todas las variables de composición corporal se correlacionaron con la suma de ocho pliegues cutáneos (Sum8SF) si se utilizó% BF (r varió 0,672 - 0,834). Entre los parámetros antropométricos examinados, Σ8SF mostró el AUC más alto para% BFTotal,% BFGynoid y% BFIAAT, mientras que Σ2SF y la circunferencia abdominal (AbC) mostraron el AUC más alto para% BFTrunk y% BFAndroid respectivamente. **Conclusión**: Las variables medidas directamente y los índices convencionales mostraron correlaciones de moderadas a fuertes con los resultados de la DXA. Sin embargo, la suma de los pliegues cutáneos, en particular Sum8SF, mostró correlaciones más fuertes y una capacidad de detección superior para la obesidad. Aunque se han utilizado muchos índices nuevos para detectar la obesidad y las anomalías metabólicas, los resultados observados indicaron que estos índices pueden no ser necesariamente mejores que los valores medidos o los índices convencionales. Se justifican más investigaciones para confirmar los puntos de corte propuestos.

Palabras Clave: Antropometría, Índices, Cribado De Obesidad, Japonés, Mujeres Jóvenes, DXA.

Introducción

Obesity is defined as a condition with excessive accumulation of body fat that may impair health (World Health Organization 1997). Obese individuals, particularly those with excessive accumulation of visceral and ectopic fat are known to have increased risks of metabolic abnormalities including hypertension, hyperglycaemia, hyperlipidaemia that subsequently increase risks of cardio- and celebro-vascular diseases, type II diabetes mellitus and some forms of cancers. (Basen-Engquist and Chang 2011, McMorrow et al.2015, Saponaro et al.2015, Ross et al. 2020). While obesity has been estimated to continue increasing around the globe (NCD Risk Factor Collaboration (NCD-RisC) 2016), obesity and related health problems are considered to cause adverse impacts to individuals as well as to development of countries and the global economy (Specchia et al. 2015, Okunogbe et al. 2021). Therefore, a reduction in obesity has been an important global public health challenge.

Early screening and prevention strategies are key components to minimize the influence of obesity and related health problems. Since development of obesity-related diseases are not only associated with total amount of fat accumulation but also its distribution, an emphasis has been put on screening individuals with a greater health risk (The Examination Committee of Criteria for 'Obesity Disease' in Japan 2002). For this purpose, anthropometric parameters (i.e. measured variables and indices calculated from measured variables) are a common tool to screen obesity and related health conditions. Many anthropometric parameters such as body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR), and waist-to-height ratio (WHtR) have cut-off points that indicate obesity and risk of metabolic abnormalities (World Health Organization 1997, Ashwell and Hsieh 2005, International Diabetes Federation 2006, World Health Organization 2011). In addition, a number of other circumferences (e.g. neck and arm) have been examined for their usefulness to screen overweight and obesity in both adults and adolescents (Ferretti Rde et al. 2015, Chaput et al. 2016). In recent years, more complex indices such as the conicity index (C-Index), the body roundness index (BRI), the body adiposity index (BAI), and a body shape index (ABSI) have also been proposed (Valdez et al., 1993, Bergman et al. 2011, Krakauer and Krakauer 2012, Thomas et al. 2013).

These anthropometric parameters are, however, not equally useful to all individuals and groups as relationships between metabolic abnormalities and body composition as well as relationships between body composition and anthropometric parameters vary between race/ethnicity, age, and sex (WHO expert consultation 2004, Huxley et al. 2010, Hu et al. 2020, Ross et al. 2020). As a result, investigation of the usefulness of anthropometric parameters of interest and appropriateness of existing cut-off points for the population of the focus will become important. In addition, compared with studies focused on relationship between body composition and common anthropometric indices (e.g. BMI, WC, and WHtR), studies investigated skinfolds and novel anthropometric parameters comprehensively in Asia are scarce (Kagawa et al. 2008b, Kagawa et al. 2010, Yamborisut et al., 2012, Liu et al. 2020). The present study therefore aimed to examine the usefulness of anthropometric parameters in young Japanese females by assessing their association with indicators of adiposity obtained from a dual energy x-ray absorptiometry (DXA).

Material and Methods

Participants

Japanese female university students (aged between 18 and 30 years) enrolled in the School of Applied Nutrition were invited to participate in the study. Individuals with 1) genetic and chronic illnesses, 2) currently under prescribed medications that may influence body composition, 3) excessive level of radiation exposure during the past year, 4) presence of any metallic plates or bolt in the body, and 5) likelihood of being pregnant were excluded from the study. Potential participants were given verbal and written explanation on the study, including its rationale, aim, methods, associated risks, voluntary nature of their participation, their right to withdraw from the study without adverse consequences, and confidentiality of the data. Participants who agreed to join the study signed a written informed consent prior to commence assessments. Participants received an incentive of ¥2,000 upon successful completion of all assessments. The study was approved by the Human Research Ethics Committee of Kagawa Nutrition University prior to commence of recruitment process (approval number: 254).

Anthropometry

Participants underwent detailed anthropometric assessments including four basic measurements (stature, body mass, arm span, and demi-arm span), eight skinfolds, 14 circumferences, nine lengths and nine breadths. In the present study, anthropometric variables required to calculate anthropometric parameters were analyzed (i.e., Stature, body mass, eight skinfolds, seven circumferences [neck, arm, wrist, waist, abdominal, hip, mid-thigh]). All measurements except abdominal circumference were conducted according to the standard protocol of the International Society for the Advancement of Kinanthropometry (ISAK) (Stewart et al. 2012). Abdominal circumference was measured at the level of the umbilicus based on the protocol to assess metabolic syndrome in Japan (Japanese Society for the Study of Obesity 2016). Stature was measured using a stadiometer to the nearest 0.1 cm and body mass was measured using a single-frequency bioelectrical impedance analysis (SFBIA) device (Karadascan HBF-361, Omron Corp., Japan) to the nearest 0.1 kg. Skinfolds were measured using a Harpenden skinfold caliper (British Indicators Ltd., England) and measured to the nearest 0.1 mm whereas circumferences were measured using a steel tape measure (W606PM, Lufkin, the United States) to the nearest 0.1 cm. All participants were instructed to wear light clothes with no socks and shoes and measured by a Level three anthropometrist accredited by ISAK. An intra-tester technical errors of measurement (TEM) of all analyzed variables were within an internationally acceptable standard of ≤ 10% for skinfolds and ≤ 2% for the rest of the measurement sites (Gore et al.1996, Wang et al. 2000).

In the present study, a total of 19 anthropometric parameters were investigated. Parameters were divided into three categories of 1) parameters from direct measurements (body mass, six circumferences [neck, arm, waist, abdominal, hip, and mid-thigh], sum of two skinfolds [Σ2SF] and sum of eight skinfolds [Σ8SF]), 2) conventional indices (BMI, WHR, WHtR, AHtR, and Waist-to-Height Index [WHI]), and 3) novel indices with complex equations (Body Roundness Index [BRI], Body Adiposity Index [BAI], Conicity Index [C-Index], Waist-to-Hip-to-Height Ratio [WHHR], and A Body Shape Index [ABSI]). Definitions and equations for each anthropometric parameter were described in Table 1.

Body composition assessment

A whole-body scan was conducted on participants using a dual energy x-ray absorptiometry (DXA: Lunar iDXA with enCORE 2011, version 13.60.033, GE Medical Systems Lunar, Madison, WI, USA). Participants were instructed to remove all jewelries and metals prior to the measurement and positioned supine on a DXA bed by a trained operator. Scanned images were divided into body regions according to the manufacture's instruction and lean mass, fat mass, bone mineral content and bone mineral density of total body as well as different regions were determined. In addition, regional percentage body fat (%BF) of total body ($\%BF_{Total}$) was calculated using an equation fat tissue/(fat tissue + lean tissue + bone tissue) x 100. Along with $\%BF_{Total}$, %BF of the trunk ($\%BF_{Trunk}$), the android ($\%BF_{Android}$), the gynoid and ($\%BF_{Gynoid}$) regions were determined. Furthermore, based on a previous study that indicated association with the intra-abdominal adipose tissue (IAAT), %BF of specific region of interest (ROI) from the bottom of ribs to the top of iliac crest ($\%BF_{IAAT}$) was determined (Hill et al. 2007).

Statistical Analysis

Of 68 female students recruited, 51 participants completed both anthropometry and whole-body DXA scan and one participant was excluded due to an embedded bolt in the body, resulting in 50 participants for analysis. Normality of data was examined using the Shapiro–Wilk test. Variables were expressed in both mean and standard deviation as well as median and percentiles. Pearson correlation coefficients were calculated to assess relationship between anthropometric parameters and absolute and percentage fat values obtained from DXA. The receiver operating characteristics (ROC) analysis was conducted and the area under the curve (AUC) with sensitivity and specificity for each anthropometric parameter were determined. Based on past studies that suggest 30% ≤ as a cut-off point for obesity for adult women (Huenemann et al., 1966, Wilmore et al., 1986, Bray, 1993), optimal cut-off points of anthropometric parameters for each %BF variable (i.e. $\%BF_{Total}$, $\%BF_{Trunk}$, $\%BF_{Android}$, $\%BF_{Gynoid}$, and $\%BF_{IAAT}$) were determined using the Index of Union (IU: defined as (|Sensitivity – AUC| + |Specificity – AUC|)) (Unal, 2017). All statistical analysis was conducted using SPSS statistical package (version 27.0, IBM, Tokyo) and significance level of 5% was applied unless otherwise stated.

Table 1. Definitions and equations of anthropometric indices used in the study

Categories	Indices	Definitions/equations	References
Direct measurements	Body mass (kg) [BM]	The force the matter exerts in a standard gravitational field.	(Stewart et al., 2012)
	Neck circumference (cm) [NC]	The circumference of the neck immediately superior to the thyroid cartilage, and perpendicular to the long axis of the neck.	(Stewart et al., 2012)
	Arm circumference (cm) [AC]	The circumference of the arm at the level of the Mid-acromiale-radiale site, perpendicular to the long axis of the arm.	(Stewart et al., 2012)
	Waist circumference (cm) [WC]	The circumference of the abdomen at its narrowest point between the lower costal (10th rib) border and the top of the iliac crest, perpendicular to the long axis of the trunk.	(Stewart et al., 2012)
	Abdominal circumference (cm) [AbC]	The circumference of the abdomen at the level of umbilicus, perpendicular to the long axis of the trunk.	(Japanese Society for the Study of Obesity, 2016)
	Hip circumference (cm) [HC]	The circumference of the buttocks at the level of their greatest posterior protuberance, perpendicular to the long axis of the trunk.	(Stewart et al., 2012)
	Mid-thigh circumference (cm) [MTC]	The circumference of the thigh measured at the level of the Mid-trochanterion-tibiale laterale site, perpendicular to its long axis.	(Stewart et al., 2012)
	Sum of 2 skinfolds (mm) [Sum2SF]	Sum2SF = Triceps + Subscapular	(Nagamine and Suzuki, 1964)
	Sum of 8 skinfolds (mm) [Sum8SF]	Sum8SF = Triceps + Subscapular + Biceps + Iliac crest + Supraspinale + Abdominal + Front thigh + Medial calf	(Kagawa et al., 2007)
Conventional Indices	Body mass index (kg/m^2) [BMI]	BMI = Body mass (kg) / Stature $(m)^2$	(World Health Organization, 1997)
	Waist-to-Hip Ratio [WHR]	WHR = WC (cm) / HC (cm)	(World Health Organization, 2011)
	Waist-to-Height Ratio [WHtR]	WHtR = WC (cm) / Stature (cm)	(Ashwell and Hsieh, 2005)
	Abdominal-to-Height Ratio [AHtR]	AHtR = AbC (cm) / Stature (cm)	(Kagawa et al., 2008a)
	Waist-to-Height Index [WHI]	WHI = WC (cm) / (Stature $[m]^2$)	(Kaneko et al., 2014)
Novel Indices	Body Roundness Index [BRI]	BRI = 364.2 - 365.5 x (1 - (WC [cm] / $(2 \times \pi)^2$) / ((0.5 x Stature $[cm])^2)^{0.5}$)	(Thomas et al., 2013)
	Body Adiposity Index ($cm/m^{1.5}$) [BAI]	BAI = HC (cm) / (Stature $[m]^{1.5}$) – 18	(Bergman et al., 2011)
	Conicity Index [C-Index]	C-Index = WC (m) / (0.109 x $\sqrt{}$[Body mass (kg) / Stature (m)])	(Valdez et al., 1993)
	Waist-to-Hip-to-Height Ratio [WHHR]	WHHR = WC (m) / (HC [m] x Stature [m])	(Rosenblad et al., 2011)
	A Body Shape Index ($m^{11/6}$ $kg^{-2/3}$) [ABSI]	ABSI = WC (m) / ($BMI^{2/3}$ x Stature $[m]^{0.5}$)	(Krakauer and Krakauer, 2012)

Results

Average age, stature, and body mass of participants were 19.4 ± 1.5 years old, 159.3 ± 5.2 cm, and 52.3 ± 5.8 kg respectively (Table 2). A whole-body DXA scan revealed that participants had approximately 35 kg of lean mass and 15 kg of fat mass. When expressed in percentages, participants had an average $\%BF_{Total}$ of 27.4 ± 4.8% on average. However, a proportion of fat accumulation was different between the region of interest and $\%BF_{Gynoid}$ was higher than the other regions examined ($\%BF_{Trunk}$: 27.4 ± 6.1%, $\%BF_{Android}$: 29.7 ± 8.0%, $\%BF_{Gynoid}$, 38.0 ± 4.2%, $\%BF_{IAAT}$: 23.0 ± 6.5%).

Table 2. Demographics and body composition of participants (n = 50)

Variables	Mean (Standard deviation)	Median (Interquartile range)
Age (years)♯	19.4 (1.5)	19.0 (18.0, 21.0)
Stature (cm)	159.3 (5.2)	159.3 (154.9, 162.9)
Body mass (kg)	52.3 (5.8)	51.8 (48.3, 56.2)
Lean mass (g)	35158.8 (3025.4)	34993.5 (32807.8, 36694.0)
Fat mass (g) ♯	14674.1 (3887.9)	13907.5 (11520.5, 17549.8)
Bone mineral content (g)	2329.4 (315.2)	2348.5 (2123.1, 2551.5)
Bone mineral density (g/cm^2)	1.15 (0.07)	1.16 (1.10, 1.19)
$\%BF_{Total}$ (%)	27.8 (4.8)	27.2 (23.7, 32.2)
$\%BF_{Trunk}$ (%)♯	27.4 (6.1)	26.5 (22.9, 30.9)
$\%BF_{Android}$ (%)	29.7 (8.0)	29.1 (24.1, 33.9)
$\%BF_{Gynoid}$ (%)	38.0 (4.2)	37.7 (35.7, 41.5)
$\%BF_{IAAT}$ (%)♯	23.0 (6.5)	21.7 (18.8, 27.1)

♯ Significant at the 0.05 level for the Shapiro-Wilk normality test.

A total of 19 anthropometric parameters were examined for their usefulness as an obesity screening tool. Table 3 shows results of anthropometric parameters. Their correlations with results from DXA which expressed in tissue mass and percentages were shown in Table 4. When total and regional tissue masses were used as indicators of adiposity (Table 4a), body mass was found to be the best anthropometric parameter for total and gynoid fat tissues (r = 0.847 and r = 0.864 respectively, *p*<0.01). On the other hand, trunk fat tissue was most strongly correlated with BMI (r = 0.820, *p*<0.01), followed by arm circumference (r = 0.811, p<0.01) and Sum8SF (r = 0.806, p<0.01). Waist circumference (WC) was the best parameter for fat accumulations of the android region (r = 0.865, *p*<0.01) and also for the IAAT (r = 0.776, *p*<0.01).

Table 3. Anthropometric parameters of the participants (n = 50)

Categories	Variables	Mean ± SD	Median (Interquartile range)
Measured variables	Neck (cm) ♯	31.1± (1.7)	30.9 (30.3, 31.8)
	Arm (cm)	26.1 ±(2.3)	26.0 (24.4, 27.3)
	Waist (cm) ♯	66.4 ±(4.2)	65.6 (63.6, 68.5)
	Abdominal (cm) ♯	73.4 ±(6.1)	72.3 (69.9, 77.1)
	Hip (cm)	92.0 ±(4.2)	91.1 (89.0, 95.7)
	Mid-thigh (cm)	48.1 ±(3.4)	47.6 (45.9, 50.2)
	Σ2SF (mm) ♯	29.5 ±(7.6)	28.3 (24.1, 34.5)
	Σ8SF (mm)	120.3 ±(31.1)	113.6 (97.8, 144.0)
Conventional Indices	BMI (kg/m^2)	20.6 ±(2.1)	20.8 (19.0, 21.7)
	WHR♯	0.72 ±(0.03)	0.72 (0.70, 0.74)
	WHtR♯	0.42 ±(0.03)	0.41 (0.40, 0.43)
	AHtR♯	0.46 ±(0.04)	0.45 (0.44, 0.48)
	WHI	26.3 ±(2.4)	26.1 (24.6, 27.5)
Novel Indices	BRI♯	6.4 ±(0.6)	6.4 (6.0, 6.6)
	BAI ($cm/m^{1.5}$)	27.9 ±(2.6)	28.0 (25.7, 29.8)
	C-Index♯	1.06 ±(0.04)	1.05 (1.04, 1.09)
	WHHR	0.45 ±(0.03)	0.45 (0.44, 0.47)
	ABSI ($m^{11/6}\ kg^{-2/3}$)	0.072 ±(0.003)	0.071 (0.070, 0.073)

♯ Significant at the 0.05 level for the Shapiro-Wilk normality test.

Table 4. Correlations between anthropometric indices and body composition parameters in (a) absolute values

Categories	Variables	Total Fat	Trunk Fat	Android Fat	Gynoid Fat	IAAT Fat
Measured Variables	BM	0.847**	0.804**	0.737**	0.864**	0.622**
	NC	0.277	0.284*	0.300*	0.310*	0.278
	AC	0.826**	0.811**	0.788**	0.790**	0.734**
	WC	0.779**	0.805**	0.865**	0.649**	0.776**
	AbC	0.749**	0.803**	0.850**	0.609**	0.742**
	HC	0.797**	0.712**	0.639**	0.859**	0.550**
	MTC	0.774**	0.713**	0.652**	0.819**	0.574**
	Σ2SF	0.782**	0.752**	0.753**	0.674**	0.723**
	Σ8SF	0.828**	0.806**	0.817**	0.698**	0.764**
Conventional Indices	BMI	0.840**	0.820**	0.806**	0.802**	0.742**
	WHR	0.282*	0.398**	0.546**	0.049	0.522**
	WHtR	0.616**	0.652**	0.748**	0.469**	0.707**
	AHtR	0.678**	0.742**	0.821**	0.509**	0.755**
	WHI	0.452**	0.492**	0.595**	0.306*	0.601**
Novel Indices	BRI	0.633**	0.655**	0.745**	0.455**	0.706**
	BAI	0.535**	0.498**	0.516**	0.515**	0.522**
	C-Index	0.143	0.231	0.400**	-0.072	0.375**
	WHHR	0.138	0.235	0.388**	-0.070	0.414**
	ABSI	-0.224	-0.130	0.040	-0.417**	0.041

(b) percentages

Categories	Variables	$\%BF_{Total}$	$\%BF_{Trunk}$	$\%BF_{Android}$	$\%BF_{Gynoid}$	$\%BF_{IAAT}$
Measured Variables	BM	0.633**	0.647**	0.594**	0.491**	0.582**
	NC	0.176	0.198	0.210	0.148	0.219
	AC	0.723**	0.729**	0.701**	0.574**	0.671**
	WC	0.675**	0.718**	0.733**	0.469**	0.746**
	AbC	0.644**	0.721**	0.745**	0.477**	0.741**
	HC	0.616**	0.583**	0.528**	0.502**	0.524**
	MTC	0.625**	0.606**	0.555**	0.512**	0.530**
	Σ2SF	0.789**	0.743**	0.731**	0.660**	0.721**
	Σ8SF	0.834**	0.804**	0.808**	0.672**	0.787**
Conventional Indices	BMI	0.738**	0.736**	0.711**	0.600**	0.712**
	WHR	0.320*	0.412**	0.488**	0.159	0.502**
	WHtR	0.611**	0.631**	0.670**	0.453**	0.687**
	AHtR	0.655**	0.717**	0.760**	0.500**	0.762**
	WHI	0.520**	0.526**	0.573**	0.400**	0.596**
Novel Indices	BRI	0.631**	0.654**	0.690**	0.464**	0.711**
	BAI	0.564**	0.510**	0.510**	0.500**	0.524**
	C-Index	0.189	0.253	0.339*	0.026	0.372**
	WHHR	0.263	0.308*	0.390**	0.162	0.414**
	ABSI	-0.140	-0.076	0.019	-0.241	0.050

BM: Body mass, NC: Neck circumference, AC: Arm circumference, WC: Waist circumference, AbC: Abdominal circumference, HC: Hip circumference, MTC: Mid-thigh circumference, Sum2SF: Sum of two skinfolds, Sum8SF: Sum of eight skinfolds, BMI: Body Mass Index, WHR: Waist-to-Hip Ratio, WHtR: Waist-to-Height Ratio, AHtR: Abdominal-to-Height Ratio, WHI: Waist-to-Height Index, BRI: Body Roundness Index, BAI: Body Adiposity Index, C-index: Conicity Index, WHHR: Waist-to-Hip-to-Height Ratio, ABSI: A Body Shape Index, $\%BF_{Total}$: Total percentage body fat, $\%BF_{Trunk}$: Trunk percentage body fat, $\%BF_{Android}$: Android percentage body fat, $\%BF_{Gynoid}$: Gynoid %BF, $\%BF_{IAAT}$: Percentage body fat for the intra-abdominal adipose tissue region, ROI: Region of Interest.
* Significant at the 0.05 level.
** Significant at the 0.01 level.

Compared with conventional indices (i.e. BMI, WHR, WHtR, AHtR, and WHI), correlations of novel indices were lower and both C-Index and WHHR showed weak to moderate correlations with the android fat tissues and IAAT. In the case of ABSI, a negative correlation with the gynoid fat tissue was observed. When percentage values were used (Table 4b), Sum8SF was found to be the anthropometric parameter that most strongly correlated with all variables obtained from DXA (r ranged between 0.672 and 0.834, *p*<0.01). Other direct measurements except neck circumference (NC) and conventional indices except WHR showed weak to moderate correlations. Novel indices also showed weak to moderate correlations with DXA results but ABSI did not significantly correlate with any of DXA results.

Table 5. Area under curve, sensitivity, specificity, and cut-off points using the Index of Union for different percentage body fat parameters

%BF parameters		$\%BF_{Total}$				$\%BF_{Trunk}$				$\%BF_{Android}$			
Categories	Variables	AUC	Sen	Spe	Cut-off	AUC	Sen	Spe	Cut-off	AUC	Sen	Spe	Cut-off
Measured Variables	BM	0.815 (0.682, 0.949)	0.786	0.778	53.00	0.817 (0.677, 0.957)	0.769	0.811	53.50	0.779 (0.644, 0.911)	0.818	0.750	51.80
	NC	0.698 (0.527, 0.870)	0.714	0.778	31.40	0.734 (0.564, 0.903)	0.769	0.784	31.40	0.607 (0.445, 0.769)	0.591	0.679	31.15
	AC	0.858 (0.750, 0.966)	0.786	0.778	26.55	0.878 (0.775, 0.982)	0.769	0.811	26.65	0.783 (0.659, 0.908)	0.818	0.607	25.55
	WC	0.854 (0.733, 0.976)	0.786	0.750	66.55	0.831 (0.699, 0.962)	0.692	0.811	67.30	0.854 (0.746, 0.962)	0.773	0.821	66.10
	AbC	0.856 (0.730, 0.983)	0.786	0.806	74.30	0.833 (0.696, 0.969)	0.769	0.811	74.55	0.907 (0.825, 0.990)	0.818	0.857	72.80
	HC	0.815 (0.675, 0.956)	0.786	0.778	92.70	0.809 (0.662, 0.956)	0.846	0.757	92.45	0.718 (0.568, 0.867)	0.682	0.821	92.45
	MTC	0.767 (0.612, 0.922)	0.786	0.694	48.15	0.770 (0.607, 0.934)	0.692	0.838	49.65	0.718 (0.575, 0.862)	0.818	0.571	46.85
	Sum2SF	0.950 (0.895, 1.006)	0.786	0.861	32.70	0.954 (0.901, 1.008)	0.846	0.838	32.30	0.881 (0.787, 0.976)	0.773	0.821	29.75
	Sum8SF	0.954 (0.902, 1.007)	0.786	0.861	140.35	0.952 (0.898, 1.007)	0.846	0.838	140.25	0.883 (0.791, 0.975)	0.773	0.821	116.75
Conventional Indices	BMI	0.858 (0.740, 0.975)	0.786	0.778	21.05	0.859 (0.742, 0.976)	0.769	0.757	21.05	0.782 (0.656, 0.907)	0.727	0.679	20.75
	WHR	0.703 (0.518, 0.888)	0.643	0.750	0.725	0.682 (0.487, 0.877)	0.615	0.730	0.725	0.782 (0.656, 0.907)	0.591	0.821	0.725
	WHtR	0.797 (0.648, 0.945)	0.786	0.667	0.415	0.771 (0.613, 0.9304)	0.769	0.649	0.415	0.808 (0.680, 0.937)	0.773	0.786	0.415
	AHtR	0.872 (0.757, 0.987)	0.714	0.778	0.465	0.848 (0.723, 0.974)	0.692	0.838	0.475	0.903 (0.821, 0.986)	0.818	0.821	0.455
	WHI	0.800 (0.651, 0.948)	0.786	0.722	26.27	0.780 (0.620, 0.939)	0.769	0.703	26.27	0.753 (0.613, 0.893)	0.773	0.643	25.61
Novel Indices	BRI	0.819 (0.681, 0.958)	0.786	0.722	6.52	0.794 (0.645, 0.943)	0.769	0.703	6.52	0.821 (0.698, 0.945)	0.818	0.750	6.358
	BAI	0.812 (0.681, 0.958)	0.786	0.694	28.58	0.792 (0.653, 0.931)	0.769	0.676	28.58	0.701 (0.544, 0.859)	0.682	0.750	28.58
	C-Index	0.671 (0.478, 0.863)	0.643	0.778	1.077	0.638 (0.439, 0.838)	0.615	0.757	1.077	0.701 (0.543, 0.860)	0.591	0.821	1.071
	WHHR	0.675 (0.486, 0.864)	0.571	0.806	0.467	0.653 (0.453, 0.853)	0.538	0.811	0.469	0.706 (0.549, 0.863)	0.591	0.821	0.463
	ABSI	0.552 (0.357, 0.746)	0.571	0.694	0.0722	0.511 (0.315, 0.708)	0.538	0.676	0.0722	0.584 (0.416, 0.753)	0.545	0.750	0.0722

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%BF parameters		$\%BF_{Gynoid}$				$\%BF_{IAAT}$			
Categories	Variables	AUC	Sen	Spe	Cut-off	AUC	Sen	Spe	Cut-off
Measured Variables	BM	0.771 (0.642, 0.900)	0.708	1.000	48.95	0.888 (0.795, 0.985)	0.800	0.825	54.80
	NC	0.609 (0.446, 0.772)	0.521	1.000	30.85	0.800 (0.655, 0.945)	0.800	0.825	31.55
	AC	0.854 (0.727, 0.981)	0.771	1.000	24.45	0.908 (0.823, 0.992)	0.800	0.825	26.85
	WC	0.594 (0.244, 0.944)	0.813	0.500	63.35	0.929 (0.855, 1.003)	0.800	0.825	67.55
	AbC	0.693 (0.366, 1.020)	0.813	0.500	69.30	0.909 (0.805, 1.012)	0.800	0.875	77.00
	HC	0.667 (0.487, 0.847)	0.750	0.500	89.15	0.853 (0.747, 0.958)	0.800	0.825	94.20
	MTC	0.859 (0.698, 1.021)	0.750	1.000	46.00	0.829 (0.688, 0.969)	0.800	0.825	49.65
	ΣSum2SF	0.938 (0.853, 1.022)	0.813	1.000	23.80	0.949 (0.887, 1.010)	0.800	0.875	34.25
	ΣSum8SF	0.958 (0.898, 1.018)	0.813	1.000	92.35	0.970 (0.924, 1.016)	0.900	0.825	140.35
Conventional Indices	BMI	0.818 (0.603, 1.033)	0.667	1.000	19.65	0.915 (0.830, 1.000)	0.800	0.825	21.35
	WHR	0.427 (0.173, 0.681)	0.500	0.500	0.715	0.781 (0.622, 0.940)	0.700	0.725	0.725
	WHtR	0.620 (0.440, 0.799)	0.479	1.000	0.415	0.841 (0.675, 1.007)	0.700	0.775	0.425
	AHtR	0.792 (0.642, 0.941)	0.833	0.500	0.435	0.905 (0.805, 1.005)	0.800	0.825	0.475
	WHI	0.688 (0.555, 0.820)	0.667	1.000	25.36	0.828 (0.649, 1.006)	0.800	0.750	26.50
Novel Indices	BRI	0.646 (0.490, 0.802)	0.583	1.000	6.298	0.855 (0.695, 1.015)	0.800	0.775	6.565
	BAI	0.719 (0.562, 0.876)	0.792	0.500	25.38	0.800 (0.645, 0.955)	0.700	0.825	29.41
	C-Index	0.344 (-0.139, 0.827)	0.688	0.500	1.043	0.733 (0.553, 0.912)	0.800	0.650	1.057
	WHHR	0.542 (0.399, 0.684)	0.521	1.000	0.453	0.720 (0.519, 0.921)	0.600	0.825	0.471
	ABSI	0.271 (-0.114, 0.656)	0.542	0.500	0.0708	0.570 (0.381, 0.759)	0.600	0.675	0.0722

AUC: Area Under the Curve, Se: Sensitivity, Spe: Specificity, BM: Body mass, NC: Neck circumference, AC: Arm circumference, WC: Waist circumference, AbC: Abdominal circumference, HC: Hip circumference, MTC: Mid-thigh circumference, Sum2SF: Sum of two skinfolds, Sum8SF: Sum of eight skinfolds, BMI: Body Mass Index, WHR: Waist-to-Hip Ratio, WHtR: Waist-to-Height Ratio, AHtR: Abdominal-to-Height Ratio, WHI: Waist-to-Height Index, BRI: Body Roundness Index, BAI: Body Adiposity Index, C-index: Conicity Index, WHHR: Waist-to-Hip-to-Height Ratio, ABSI: A Body Shape Index, $\%BF_{Total}$: Total percentage body fat, $\%BF_{Trunk}$: Trunk percentage body fat, $\%BF_{Android}$: Android percentage body fat, $\%BF_{Gynoid}$: Gynoid %BF, $\%BF_{IAAT}$: Percentage body fat for the intra-abdominal adipose tissue region, ROI: Region of Interest.

From the ROC analysis, Sum8SF showed the greatest AUC for $\%BF_{Total}$ (0.954 [95%CI: 0.902, 1.007]), $\%BF_{Gynoid}$ (0.958 [95%CI: 0.898, 1.018]), and also for $\%BF_{IAAT}$ (0.970 [95%CI: 0.924, 1.016]) (Table 5). Estimated cut-off point for $\%BF_{Total}$ and $\%BF_{IAAT}$ that indicate %BF ≥ 30.0% was 140.4 mm while the cut-off point for $\%BF_{Gynoid}$ was 92.4 mm. Anthropometric parameters that showed the greatest AUC for $\%BF_{Trunk}$ was Sum2SF (0.954 [95%CI: 0.901, 1.008]) and its cut-off point was 32.3 mm. On the other hand, the highest AUC for $\%BF_{Android}$ was observed from abdominal circumference (AbC) (0.907 [95%CI: 0.898, 1.018]) and its cut-off points was 72.8 cm. Among conventional indices, the greatest AUC was observed either from BMI or AHtR (BMI: AUC ranged between 0.782 [95%CI: 0.656, 0.907] to 0.915 [95%CI: 0.830, 1.000], AHtR: AUC ranged between 0.792 [95%CI: 0.642, 0.941] to 0.905 [95%CI: 0.805, 1.005]. Apart from $\%BF_{Android}$, the AUC obtained from these indices at each %BF variable were greater than that observed from WC and AbC which showed stronger correlations. Their cut-off points ranged from 19.7 kg/m^2 to 21.4 kg/m^2 for BMI and 0.44 to 0.48 for AHtR respectively. Observed AUC from novel indices were lower than directly measured variables and conventional indices and either BRI or BAI showed the highest AUC (BRI: AUC ranged between 0.646 [95%CI: 0.490, 0.802] to 0.855 [95%CI: 0.695, 1.015], BAI: AUC ranged between 0.701 [95%CI: 0.544, 0.859] to 0.812 [95%CI: 0.681, 0.958]. Cut-off points for BRI and BAI ranged from 6.3 to 6.5 and from 25.4 cm/m$^{1.5}$ to 29.4 cm/m$^{1.5}$ respectively.

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Discussion

Anthropometry is a cost-effective, non-invasive, simple and convenient technique that has been utilized for assessments of growth, nutritional status, disease and metabolic risks. To date, a wide range of anthropometric parameters have been proposed as useful screening tools for obesity and metabolic abnormalities. Among anthropometric parameters examined, common indices such as BMI, WC, and AbC showed moderate to strong correlations with DXA results. Although r values vary by correlations with fat tissue mass or percentages, BMI was generally higher in correlations than WC and AbC except for the android region. This may indicate that BMI reflects overall adiposity while WC and AbC reflect abdominal fat accumulation, which partially support current screening process being practiced around the world (World Health Organization 1997, The Examination Committee of Criteria for 'Obesity Disease' in Japan 2002, International Diabetes Federation 2006). However, AUC showed that AHtR was higher than WC and AbC in most cases, suggesting better screening ability of AHtR over WC or AbC. The observed differences may partially due to using %BF values to determine AUC as correlations of WC and AbC with %BF variables were lower than those obtained from fat tissue mass. While WC and AbC have been commonly applied to determine metabolic risks internationally (International Diabetes Federation, 2006, Ross et al., 2020), application of AHtR may be a better option if screening is based on %BF. Cut-off points proposed from BMI and AHtR ranged from 19.7 kg/m^2 to 21.4 kg/m^2 and 0.44 to 0.48 respectively, depending on the region of focus. While these values were lower than internationally recognized cut-off points (World Health Organization 1997, Ashwell and Hsieh 2005), cut-off points for %BF_{Total} was consistent to previous study obtained from Japanese females (BMI: 21.1 kg/m^2 vs 21.9 kg/m^2, AHtR: 0.47 vs 0.49) (Kagawa et al. 2006, Kagawa et al., 2008b). This may reflect index-%BF relationships specific to this population and therefore validity of proposed cut-off values than the universal cut-off points proposed for all people.

Although the study indicated the usefulness of BMI and AHtR, it is important to acknowledge limitations of these indices. BMI is only an index of “heaviness” and unable to distinguish body composition of individuals even with the use of a population-specific cut-off point. For AHtR, definition of “waist” or “abdominal” circumference will become an issue. In the present study, AHtR and WHtR were treated separately as measurement sites of WC and AbC were different. However, it is common to treat AbC as one way of measuring “waist” (International Diabetes Federation 2006) as different definitions for WC exist (World Health Organization 2011, Stewart et al. 2012). The present study showed that WC and AbC as well as related indices have different correlations with body fat and hence cause differences in usefulness as obesity screening tools depending on the definition used. Since “waist” is a common measurement site as well as an important site to identify abdominal, especially a visceral fat accumulation. In the present study, seven out of 10 indices categorized either as “conventional” or “novel” indices used WC in their calculation. Despite the possibility of AHtR or WHtR as useful screening tool for obesity, it is important to understand the impacts of technical factors on the screening ability of anthropometric parameters. In the case of waist-related indices, it is important to first identify the definition of “waist” that yields optimum screening ability of the parameter, and standardize both definition and measurement protocols of “waist” in order to allow comparisons between studies.

Alternative to BMI and AHtR, this study showed the usefulness of the sum of skinfolds. Σ8SF was found to be the best anthropometric parameter to identify excessive fat accumulations of the whole-body (%BF_{Total}) as well as two body regions (%BF_{Gynoid}, and %BF_{IAAT}) while Σ2SF was found to be the best parameter to screen fat accumulation of the trunk region (%BF_{Trunk}). Σ2SF and Σ8SF were both highly corelated with fat tissues than WHR and WHtR and highly correlated with %BF than body mass, BMI, WHtR, WHR, and WC, which were partially consistent to a study by Boeke and colleagues (2013). Also the Σ2SF cut-off point established from the study was very close to previously reported cut-off points for the comparable population (32.7 mm vs 35.0 mm) (Kagawa et al. 2010), suggesting its validity. While the number of studies that apply sum of skinfolds for obesity screening is limited compared to those using BMI, WHtR and WC, findings from the present study emphasize usefulness of skinfolds in obesity screening and frequent application should be considered.

In recent years, AC has been proposed as a potential parameter for obesity (Chaput et al. 2016). Although its screening ability for android fat and IAAT was not as high as AHtR or AbC, AC showed high AUC for %BF_{Total} and %BF_{Trunk}, following sum of skinfolds. Considering its simplicity and easiness compared with skinfolds, AC has potential to assess obesity risk especially at a situation where weighing scale (or stadiometer) is not available.

Compared with directly measured anthropometric variables and conventional indices, novel indices (i.e. BRI, BAI, C-Index, WHHR and ABSI) showed weaker correlations with results from DXA. Compared with a study of similar sample size, correlation of BRI was stronger while BAI and ABSI were comparable although ABSI negatively correlated in the current study (Yang et al. 2020). From these results, despite being proposed as better screening tools, novel indices may be no more useful for obesity screening than directly measured or conventional indices.

Conclusion

The present study aimed to investigate the usefulness of existing anthropometric parameters for obesity screening in young Japanese females. Results confirmed usefulness of BMI, WC, AbC and also AHtR but also showed the better screening ability of skinfolds. On the other hand, novel indices including BRI, BAI, C-Index, WHHR and ABSI were found to be weakly correlated with results obtained from DXA and had poor screening abilities. Although many novel indices have been utilized to screen obesity and metabolic abnormalities, observed results indicated that these indices may not necessarily be better than measured values or conventional indices. In order to screen at-risk individuals accurately and promote lifestyle modification, it is important to select appropriate anthropometric parameters for the target population and also for fat accumulation of particular region of the focus.

This was the first study to investigate a wide range of anthropometric parameters for their usefulness for obesity screening comprehensively. Results may be useful when considering appropriate anthropometric parameters to assess obesity status among young Japanese females whose "masked" obesity (i.e. obese individuals with normal body mass) is common and ordinary screening approach may be missed. However, it is important to acknowledge the limitations of the present study. The study was conducted on a relatively small sample of young Japanese females. To generalize the results, the study needs to be replicated using a larger sample size including a wider age range. In addition, the present study determined cut-off points of each anthropometric parameter using the Index of Union (UI), was a new approach proposed as a superior to previously known methods such as the Youden Index and the Concordance Probability method (Unal 2017). Since previous studies that proposed cut-off points of anthropometric parameters used different analysis techniques, future research to confirm the findings are warranted.

References

Ashwell M. Hsieh S. D. (2005). Six reasons why the waist-to-height ratio is a rapid and effective global indicator for health risks of obesity and how its use could simplify the international public health message on obesity. *International Journal of Food Science and Nutrition,* 56(5): 303-307.

Basen-Engquist K. Chang M. (2011). Obesity and cancer risk: recent review and evidence. *Current Oncology Reports,* 13(1)**:** 71-76.

Bergman R. N., Stefanovski D., Buchanan, T. A., Sumner A. E., Reynolds J. C., Sebring N. G., Xiang A. H. Watanabe R. M. (2011). A better index of body adiposity. *Obesity (Silver Spring),* 19(5)**:** 1083-1089.

Boeke C. E., Oken E., Kleinman K. P., Rifas-Shiman S. L., Taveras E. M., Gillman, M. W. (2013). Correlations among adiposity measures in school-aged children. *BMC Pediatrics,* 13**:** 99.

Bray G. A. (1993). Fat distribution and body weight. *Obesity Research,* 1(3)**:** 203-205.

Chaput J. P., Katzmarzyk P. T., Barn es J. D., Fogelholm M., Hu G., Kuriyan R., Kurpad A., Lambert E. V., Maher C., Maia J., Matsudo V., Olds T., Onywera V., Sarmiento O. L., Standage M., Tudor-Locke C., Zhao P., Tremblay M. S., ISCOLE Research Group (2016). Mid-upper arm circumference as a screening tool for identifying children with obesity: a 12-country study. *Pediatric Obesity*.

Ferretti Rde L., Cintra Ide P., Passos M. A., de Moraes Ferrari, G. L., Fisberg, M. (2015). Elevated neck circumference and associated factors in adolescents. *BMC Public Health [Electronic resource],* 15: 208.

Gore C., Norton K., Olds T., Whittingham N., Birchall K., Clough M., Dickerson B., Downie L. (1996). Accreditation in anthropometry: an Australian model. In Norton, K. & Olds, T. (Eds.) *Anthropometrica. University of New South Wales Press*. Sydney.

Hill A. M., LaForgia J., Coates A. M., Buckley J. D., Howe P. R. C. (2007). Estimating abdominal adipose tissue with DXA and anthropometry. *Obesity,* 15(2)**:** 504-510.

Hu L., Hu G., Huang X., Zhou W., You C., Li J., Li P., Wu Y., Wu Q., Wang Z., Gao R., Bao H., Cheng X. (2020). Different adiposity indices and their associations with hypertension among Chinese population from Jiangxi province. *BMC Cardiovascular Disorders,* **20** (1)**:** 115.

Huenemann R. L., Hampton M. C., Shapiro L. R. Behnke A. R. (1966). Adolescent food practices associated with obesity. *Federation Proceedings,* 25 (4): 4-10.

Huxley R., Mendi S., Zheleznyakov E., Reddy S., Chan J. (2010). Body mass index, waist circumference and waist:hip ratio as predictors of cardiovascular risk--a review of the literature. *European Journal of Clinical Nutrition,* 64(1)**:** 16-22.

International Diabetes Federation (2006). The IDF consensus worldwide definition of the metabolic syndrome. Brussels.

Japanese Society for the Study of Obesity (2016). Guidelines for the management of obesity disease 2016. Life Science Publisher, Tokyo, Japan.

Kagawa M., Byrne N. M., Hills A. P. (2008a). Comparison of body fat estimation using waist to height ratio (WHtR) using different "waist" measurements in Australian adults. *British Journal of Nutrition,* 100(5)**:** 1135-1141.

Kagawa M., Kuroiwa C., Uenishi K., Mori M., Hills A. P., Binns C. W. (2007). New percentage body fat prediction equations for Japanese females. *Journal of Physiological Anthropology,* 26 (1)**:** 23-29.

Kagawa M., Tahara Y., Byrne N. M., Moji K., Tsunawake, N., Hills A. P. (2008b). Are Japanese obesity criteria useful for screening at risk Japanese? Consideration from anthropometric indices-percentage body fat relationships. *Asia Pacific Journal of Public Health,* 20 (Suppl)**:** 102-110.

Kagawa M., Uenishi K., Kuroiwa C., Mori M., Binns C. W. (2006). Is the BMI cut-off level for Japanese females for obesity set too high? - A consideration from body composition perspective. *Asia Pacific Journal of Clinical Nutrition,* 15 (4)**:** 502-507.

Kagawa M., Uenishi K., Mori M., Uchida H., Kerr D. A., Binns C. W., Hills A. P. (2010). Obesity screening for young Japanese males and females using skin fold measurements: the classification revisited. *Asia Pacific Journal of Clinical Nutrition,* 19 (2)**:** 289-293.

Kaneko R., Nakazaki N., Tagawa T., Ohishi C., Kusayanagi S., Kim M., Baba T., Ogawa, M., Sato, Y. (2014). A new index of abdominal obesity which effectively predicts risk of colon tumor development in female Japanese. *Asian Pacific Journal of Cancer Prevention,* 15 (2)**:** 1005-1010.

Krakauer N. Y., Krakauer J. C. (2012). A new body shape index predicts mortality hazard independently of body mass index. *PLoS One,* **7** (7)**:** e39504.

Liu, J. Fan D., Wang X., Yin F. (2020). Association of two novel adiposity indicators with visceral fat area in type 2 diabetic patients: Novel adiposity indexes for type 2 diabetes. *Medicine (Baltimore),* 99 (19)**:** e20046.

McMorrow A. M., Connaughton R. M., Lithander F. E., Roche H. M. (2015). Adipose tissue dysregulation and metabolic consequences in childhood and adolescent obesity: potential impact of dietary fat quality. *Proceedings of Nutrition Society,* 74 (1)**,** 67-82.

Nagamine S., Suzuki, S. (1964). Anthropometry and body composition of Japanese among men and women. *Human Biology,* 36**:** 8-15.

NCD Risk Factor Collaboration (NCD-RisC) (2016). Trends in adult body-mass index in 200 countries from 1975 to 2014: a pooled analysis of 1698 population-based measurement studies with 19·2 million participants. *Lancet,* **387** (10026)**,** 1377-1396.

Okunogbe A., Nugent R., Spencer G., Ralston J., Wilding J. (2021). Economic impacts of overweight and obesity: current and future estimates for eight countries. *BMJ Global Health,* 6:e006351. doi:10.1136/bmjgh-2021-006351

Rosenblad A., NLeppert J., Nilsson G. (2011). The waist-hip-height-ratio (WHHR): an improvement of the waist-hip-ratio for predicting all-cause mortality. *Journal of Diabetes,* 3 (s1): 231.

Ross R., Neeland I. J., Yamashita S., Shai I., Seidell J., Magni P., Santos R. D., Arsenault, B. Cuevas A., Hu F. B., Griffin B. A., Zambon A., Barter P., Fruchart J. C., Eckel R. H., Matsuzawa Y., Despres J. P. (2020). Waist circumference as a vital sign in clinical practice: a Consensus Statement from the IAS and ICCR Working Group on Visceral Obesity. *Nature Reviews Endocrinolog,* 16 (3)**:** 177-189.

Saponaro C., Gaggini M., Carli, F., Gastaldelli, A. (2015). The Subtle Balance between Lipolysis and Lipogenesis: A Critical Point in Metabolic Homeostasis. *Nutrients,* 7 (11)**:** 9453-9474.

Specchia M. L., Veneziano M. A., Cadeddu C., Ferriero A. M., Mancuso A., Ianuale C., Parente P., Capri S., Ricciardi W. (2015). Economic impact of adult obesity on health systems: a systematic review. *European Journal of Public Health,* 25 (2): 255-262.

Stewart A., Marfell-Jones M., Olds, T., de Ridder, H. (2012) International standards for anthropometric assessment (2011). ISAK: Lower Hutt,, New Zealand.

The Examination Committee of Criteria for 'Obesity Disease' in Japan (2002) New criteria for 'obesity disease' in Japan. *Circulation Journal,* 66 (11)**:** 987-992.

Thomas D. M., Bredlau C., Bosy-Westphal A., Mueller M., Shen W., Gallagher D., Maeda Y., McDougall A., Peterson C. M., Ravussin E., Heymsfield S. B. (2013). Relationships between body roundness with body fat and visceral adipose tissue emerging from a new geometrical model. *Obesity (Silver Spring),* 21 (11)**:**2264-2271.

Unal I., (2017). Defining an Optimal Cut-Point Value in ROC Analysis: An Alternative Approach. *Computational and Mathematical Methods in Medicine,* 2017: 1-14, Article ID3762651|https://doi.org/10.1155/2017/3762651

Valdez R., Seidell J. C., Ahn Y. I., Weiss K. M. (1993). A new index of abdominal adiposity as an indicator of risk for cardiovascular disease. A cross-population study. *International Journal of Obesity and Related Metabolic Disorders,* 17 (2)**:** 77-82.

Wang J., Thornton J. C., Kolesnik, S., Pierson Jr, R. N. (2000). Anthropometry in body composition. An overview. *Annals of New York Academy of Science,* 904**:**317-326.

WHO expert consultation (2004). Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. *Lancet,* 363 (10)**:** 157-163.

Wilmore J. H., Buskirk E. R., DiGirolamo M., Lohman, T. G. (1986). Body composition-a round table-. *The Physician and Sportsmedicine,* 14 (3)**:** 144-162.

World Health Organization (1997). Obesity: Preventing and managing the global epidemic. *WHO/NUT/NCD/98.1*. Geneva.

World Health Organization (2011). Waist circumference and waist-hip ratio: Report of a WHO Expert Consultation Geneva.

Yamborisut U., Sakamoto N., Visetchart, P., Tontisirin, K. (2012). Central body fat distribution indices in Thai preschool children. *Open Journal of Pediatrics,* 2 (1)**,** 47-52.

Yang H. I., Cho W., Ahn K. Y., Shin S. C., Kim J. H., Yoo S., Park Y. I., Lee E. Y., Lee D. H., Spence J. C., Jeon J. Y., (2020). A new anthropometric index to predict percent body fat in young adults. *Public Health Nutrition,* 23 (9)**:** 1507-1514.

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Conflict of Interest

The author declares no conflict of interest with respect to the research, authorship, and/or publication of this article.

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