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Compatibility of different methods for the measurement of visceral fat in different body mass index strata

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PURPOSE
Obesity, particularly visceral obesity, is associated with increased risk of cardiovascular morbidity and mortality. Therefore, cardiovascular risk should be determined by evaluating visceral fat tissue not only in obese individuals but also in non-obese individuals. We aimed to evaluate the comparison of visceral fat tissue measurement methods with computed tomography (CT).

MATERIALS AND METHODS
One hundred four participants, 19 to 58 years of age (21 males, 83 females) were enrolled in this study. Participants underwent anthropometric evaluation, bioelectrical impedance analysis (BIA), ultrasonography (US), and CT examinations on the same day.

RESULTS
The mean body mass index (BMI) was 31.2 ± 8.7 kg/m^2 (73 individuals [70.2%] had BMI ≥30, and 31 individuals [29.8%] had BMI <30). The non-obese group (BMI <30) that showed the best correlation coefficient values were for visceral fat area (VFA) by BIA in all participants, males and women (r = 0.902, $P < 0.001$; r = 0.994, $P < 0.001$; r = 0.645, $P = 0.01$, respectively); in case of BMI ≥30 the best correlation coefficient values were for VFA by BIA (r = 0.774, $P < 0.001$) for all participants, and visceral fat thickness by US for males (r = 0.851, $P < 0.001$), and BMI (r = 0.786, $P < 0.001$) for females. Using multiple stepwise regression analysis, the methods best reflecting VFA by CT were as follows: In subjects with BMI <25, BIA correlated best with CT measures of VFA; while in subjects with BMI >30 waist-to-hip ratio showed the best correlation with CT measures of VFA. The method best reflecting VFA by CT was visceral thickness by US in males; and the method best reflecting VFA by CT in females was visceral thickness by US,BMI and waist circumference.

CONCLUSION
Anthropometric measurements and visceral fat tissue measurement methods such as US and BIA exhibit differences with respect to compliance with CT results in visceral fat tissue measurements by gender and BMI levels.

Key words: • *obesity* • *visceral fat* • *measurement*

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Obesity is an important risk factor for diabetes mellitus, hypertension, hyperlipidemia, and cardiovascular disease (1); and is a strong predictor of increased morbidity and mortality (1, 2). Visceral adipose tissue accumulation, through increased fatty acid production, may be involved in the genesis of insulin resistance, creating a milieu for the development of these diseases (3, 4).

Anthropometric measurements are often used as indirect measurements of visceral fat. Most widely used are waist circumference (WC) and waist-to-hip ratio (WHR). These measurement methods cannot differentiate between visceral fat tissue and subcutaneous fat tissue, but because their correlation with visceral fat tissue is quite good, they are often used as markers of visceral fat (5, 6). However, many trials have reported that such correlation was not applicable for all ages and BMI levels (7). The decreasing correlation is thought to reflect problems in anthropometric measurements in these populations, as these methods are subject to considerable between-examiner and within-examiner variation (5).

Computed tomography (CT) has been considered the most accurate and reproducible technique of abdominal fat assessment (8). However, CT scans are costly and time-consuming and expose patients to ionizing radiation. Because of these limitations, a variety of alternative methods to assess fat distribution and estimate intra-abdominal fat deposition have been developed (5). Magnetic resonance imaging (MRI) yielded excellent concordance with CT without radiation exposure but was more expensive than CT (9). Ultrasonography (US) may be another alternative to CT for estimation of visceral fat tissue (10). Bioelectrical impedance analysis (BIA) measures visceral fat tissue using bipolar or tetrapolar electrodes on the legs and sometimes on the arms (11). Bioelectrical impedance analysis may be a good alternative because it does not expose the patient to radiation and is not time consuming. However, several body-composition characteristics, such as hydration and edema, may affect the validity of the interpretation of impedance measurements, particularly in morbidly obese patients; thus use of BIA is still controversial (11).

Although anthropometric methods are frequently used today, they are inadequate for predicting cardiovascular risk increase, particularly in non-obese individuals. Therefore, search for convenience in clinical practice, low cost, and appropriate visceral fat tissue measurement methods are ongoing. This study aimed to compare methods for assessment of abdominal fat distribution, particularly visceral fat deposition, in different body mass index strata as alternatives to CT.

Materials and methods

Study design and subjects

One hundred four healthy volunteers, 19 to 58 years of age (21 males, 83 females) were enrolled in this study. Exclusion criteria were pregnan-

cy, disease leading to fluid/electrolyte imbalance, and use of pharmaceuticals affecting water/salt balance. The study protocol was approved by the ethics committee of our hospital, and all volunteers gave written informed consent. Participants underwent anthropometric evaluation, BIA, and abdominal US and CT examinations on the same day, following an overnight fast.

Anthropometric measurements

Anthropometric measurements included weight, height, and waist and hip circumferences. Body mass index was calculated by dividing body weight (in kilograms) by the square of the height (m^2). Waist circumference was measured in standing position at the midpoint between the lateral iliac crest and the lowest rib. Hip circumference was measured at the level of the major trochanter. Waist-to-hip ratio (WHR) was also calculated. The intraexaminer coefficient of variation was 3.6%.

Radiological examinations

To assess the reliability and reproducibility of US, CT, and BIA measurements, the first 30 participants were selected consecutively. These measurements were repeated at the same time after one day by the same investigators. Within 95% confidence limits, intraclass correlation coefficients were 99.8 (99.6–99.9) for US, 97.4 (94.6–98.7) for CT, and 99.8 (99.6–99.9) for BIA. This assessment showed reliability and reproducibility of our measurements.

Ultrasonography

All US examinations were performed by the same radiologist with the patient in supine position after an overnight fast using a 3.75 MHz probe located 1 cm from the umbilicus (Toshiba Aplio Ultrasound Imaging System, Japan). Subcutaneous fat was measured as the distance (cm) between the skin and external surface of the rectus abdominis muscle, and visceral fat was measured as the distance between the internal surface of rectus abdominis muscle and the anterior wall of the aorta (12). The intra-examination coefficient of variation (within-subject variation from measurement to measurement) for US was 1%.

CT

CT was performed with a Toshiba Aquilion 2005 multislice (16 detector row) device. A single axial tomographic slice was obtained at the L4–L5 level using 120 kV 300 mA, 0.5 s gantry rotation time. Cross-sectional abdominal contour was estimated by delineating the skin manually with a graph pen through the muscular structures and vertebral corpora. The area between –50 HU and –250 HU pixels was calculated automatically by the CT software. Subcutaneous fat tissue area was calculated by subtracting the visceral fat tissue area inside the abdominal wall from the total fat tissue area inside the line that was drawn on the skin of the abdomen (13, 14). All CT examinations were performed by the same investigator. The intraexamination coefficient of variation was 2% for CT.

Bioelectrical impedance analysis

Intra-abdominal fat area was estimated by a multifrequency bioelectrical impedance analysis (BIA) device (X-scan body composition analyzer, Jawon Medical, Korea) with tetrapolar electrodes. Subject age and sex data were entered into the BIA machine. BIA measured impedance by a tetrapolar method, consisting of four electrodes separated by a power supply electrode and a measurement electrode. BIA was performed between both hands and feet (ankle) with the patient standing upright. Both hands were held at a 45 degree angle away from the body. X-scan uses 1 kHz, 5 kHz, 50 kHz, 250 kHz, 550 kHz, and 1000 kHz frequencies to analyze intra/extracellular fluid value and water. The participants did not perform any strenuous exercise for 4 hours before the measurement. The intraexamination coefficient of variation for BIA was 2.2%. All BIA measurements were performed by the same investigator. The device automatically calculated visceral fat area (VFA)

Statistical analysis

The data were analyzed with SPSS for Windows 11.5. Shapiro-Wilk test was used to test the normality of distribution for continuous variables; data are expressed as mean ± standard deviation (min-max). The Mann-Whitney U test was used to determine if differences in continuous variables between gender groups were statistically significant. The comparability and agreement levels between CT and BIA visceral fat measurements were performed by Bland-Altman method. Also, coefficients of variation (CV) of CT and BIA measurements were calculated for repeatability of findings. Intra-class correlation coefficients and 95% confidence intervals were calculated for evaluation of intra-examiner reliability in CT and BIA measurements. Degree of association between continuous variables was calculated by the Spearman *rho* correlation coefficient. Multiple linear stepwise regression analyses were then conducted to identify the most effective predictive methods for visceral fat, as determined by CT. The coefficient of determination for each meaningful independent variable was calculated and also defined as a percentage. A P value less than 0.05 was considered statistically significant.

Results

The mean age of the trial population was 37.3 ± 9.1 years (19–58 years); there were 21 males (20.2%) and 83 females (79.8%). Mean BMI was 31.2 ± 8.7 kg/m^2 (for 73 individuals [70.2%] BMI ≥30, for 31 individuals [29.8%] BMI <30). Mean WC was 94.3 ± 19.2 cm, and mean WHR was 0.84 ± 0.09. Visceral fat measurements by US, BIA, and CT were 7.3 ± 2.1 cm, 129.6 ± 83 cm^2; and 134 ± 82 cm^2, respectively (Table 1).

The anthropometric parameters and visceral fat tissue measurements of the female and male subjects are shown in Table 2. Parameters were similar between genders; only WHR measurements were higher in males than in females ($P < 0.001$).

Among all participants, the measurements methods best correlating with VFA by CT were BIA (r = 0.870, $P < 0.001$), WC (r = 0.861, $P < 0.001$), BMI (r = 0.843, $P < 0.001$), and visceral fat thickness by US (r = 0.823, $P < 0.001$), respectively. The methods with the best correlation coefficients in males were visceral fat thickness by US, BMI, and WC (r = 0.896, $P < 0.001$; r = 869, $P < 0.001$; r = 0.840, $P < 0.001$, respectively). The methods with the best correlation coefficients in females were BMI, VFA by BIA, and WC (r = 0.885, $P < 0.001$; r = 0.879, $P < 0.001$; r = 0.867, $P < 0.001$, respectively) (Table 3).

When the participants were assessed in two categories as obese and non-obese, the non-obese group (BMI <30) showed the best correlation coefficient values were for VFA by BIA in all participants, males and females (r = 0.902,

Table 1. Anthropometric and visceral fat measurements of the participants

	Healthy volunteers (n = 104)	Range
Age (years)	37.3±9.1	19–58
BMI (kg/m^2)	31.2±8.7	18.3–52.8
WC (cm)	94.3±19.2	62–147
WHR	0.84±0.09	0.61–1.3
Visceral fat thickness by US (cm)	7.3±2.1	1.8–15.7
VFA by BIA (cm^2)	129.6±83.0	21.0–364.0
VFA by CT (cm^2)	134.8±82.1	17.6–344.2

BIA, bioelectric impedance analysis; BMI, body mass index; CT, computed tomography; US, ultrasonography; VFA, visceral fat area; WC, waist circumference; WHR, waist/hip ratio.

Table 2. Anthropometric and visceral fat measurements of the males and females

	Males (n = 21)	Females (n = 83)	*P*
Age (years)	36.4±7.8 (23–50)	37.4±9.4 (19–58)	0.721
BMI (kg/m^2)	28.2±6.7 (18.3–44.0)	31.2±9.0 (18.5–52.8)	0.110
WC (cm)	97.0±17.5 (72.0–134.0)	93.7±19.6 (62.0–147.0)	0.420
WHR	0.90±0.08 (0.75–1.06)	0.82±0.08 (0.67–1.13)	<0.001
Visceral fat thickness by US (cm)	7.4±2.0 (4.3–12.0)	7.2±2.2 (1.8–15.7)	0.659
VFA by BIA (cm^2)	136.2±83.6 (33.0–364.0)	127.9±83.3 (21.0–331.0)	0.600
VFA by CT (cm^2)	149.7±85.9 (35.0–344.2)	131.0±81.3 (17.6–340.5)	0.386

BIA, bioelectric impedance analysis; BMI, body mass index; CT, computed tomography; US, ultrasonography; VFA, visceral fat area; WC, waist circumference; WHR, waist/hip ratio.

Table 3. Correlation of age, anthropometric values and measurement methods with VFA by CT values

	All participants (n = 104)		Males (n = 21)		Females (n = 83)	
	R	*P*	r	*P*	r	*P*
Age	0.351	<0.001	0.145	<0.001	0.404	<0.001
BMI	0.843	<0.001	0.869	<0.001	0.885	<0.001
WC	0.861	<0.001	0.840	<0.001	0.867	<0.001
WHR	0.624	<0.001	0.739	<0.001	0.612	<0.001
Visceral fat thickness by US (cm)	0.823	<0.001	0.896	<0.001	0.809	<0.001
VFA by BIA (cm^2)	0.870	<0.001	0.839	<0.001	0.879	<0.001

BIA, bioelectric impedance analysis; BMI, body mass index; CT, computed tomography; US, ultrasonography; VFA, visceral fat area; WC, waist circumference; WHR, waist/hip ratio.

$P < 0.001$; r = 0.994, $P < 0.001$; r = 0.645, $P = 0.01$, respectively); in case of BMI ≥30, the best correlation efficient values were for VFA by BIA (r = 0.774, $P < 0.001$) for all participants, and visceral fat thickness by US for males (r = 0.851, $P < 0.001$), and BMI (r = 0.786, $P < 0.001$) for females (Table 4).

The Bland-Altman method for comparison between VFA observed by CT and VFA estimated by BIA showed a mean bias of –5.3 ± 42.1 cm^2, meaning that VFA measured by BIA was 5.3 cm^2 lower than VFA measured by CT. To determine if the concordance between CT-determined VFA and BIA-determined VFA was affected by BMI, participants were divided into four groups (BMI <25, BMI: 25–29.9, BMI: 30–34.9, and BMI ≥35). BIA and CT visceral fat tissue measurements were found to be concordant with the Bland-Altman method in all groups (Table 5). Visceral fat tissue measured by BIA was lower than visceral fat tissue measured by CT in participants with BMI <25, "BMI, 25–29.9", and "BMI, 30–34.9" by a bias of –9.1 ± 17.0, –4.4 ± 30.4, and –30.9 ± 54.6, respectively. But in participants with BMI ≥35, BIA-determined VFA was higher than CT values by a bias of 9.7 ± 52.3 (Table 5). Investigating the compliance of BIA with CT in females and males using the Bland Altman method, VFA by BIA in females was higher than CT values by a bias of 3.21±40.45, while VFA by BIA was higher than CT values by a bias of 13.47 ± 48.17 in males.

Multiple linear stepwise regression analyses (Table 6) performed on all cases without stratification into BMI groups revealed that the methods best reflecting VFA by CT were VFA by BIA, visceral thickness by US, and WHR (75.5%, 5.6%, and 1.9% of the VFA by CT change could be explained by BIA, US, and WHR, respectively).

Investigation by stratification by BMI revealed the following: in subjects with BMI <25, the method best reflecting VFA by CT was VFA by BIA (coefficient of determination was 80.8%); in case of 25–29.9, visceral thickness by US (coefficient of determination was 30.6%); in the range of 30–34.9, WHR (coefficient of determination was 70.8%); and in case of BMI >35, VFA by BIA, visceral thickness by US (coefficient of determination of VFA by BIA and visceral thickness by US were 41.4% and 12.0%, respectively). Assess-

Table 4. Correlations of age, anthropometric values and visceral fat tissue measurement methods with VFA by CT in obese and non-obese individuals

	BMI <30						BMI ≥30					
	All		Males		Females		All		Males		Females	
Variables	r	*P*	r	*P*	r	*P*	r	*P*	r	*P*	r	*P*
Age	0.238	NS	0.162	NS	0.295	NS	0.381	0.001	0.238	NS	0.434	0.01
BMI	0.569	0.001	0.838	0.09	0.571	0.04	0.731	<0.001	0.820	0.001	0.786	<0.001
WC	0.649	<0.001	0.755	0.03	0.381	NS	0.761	<0.001	0.770	0.02	0.761	<0.001
WHR	0.361	0.04	0.180	NS	0.180	NS	0.436	<0.001	0.769	0.02	0.388	0.002
Visceral fat thickness by US (cm)	0.500	0.004	0.862	0.006	0.243	NS	0.745	<0.001	0.851	<0.001	0.727	<0.001
VFA by BIA (cm^2)	0.902	<0.001	0.994	<0.001	0.645	0.01	0.774	<0.001	0.736	0.004	0.783	<0.001

BIA, bioelectric impedance analysis; BMI, body mass index; CT, computed tomography; NS, not significant; US, ultrasonography; VFA, visceral fat area; WC, waist circumference; WHR, waist/hip ratio.

Table 5. The agreement levels for visceral fat measurements by BIA and CT

					Confidence limit for bias	
Measurement	BMI	n	Bias	SD	Bias –1.96 SD	Bias +1.96 SD
BIA-CT [a]	All participants	104	–5.3	42.1	–87.75	77.19
	<25	31	–9.1	17.0	–42.37	24.20
	25.0-29.9	23	–4.4	30.4	–63.91	55.09
	30.0-34.9	16	–30.9	54.6	–137.88	76.12
	≥35	34	9.7	52.3	–92.82	112.12
	Male	21	13.47	48.17	80.95	107.90
	Female	83	3.21	40.45	76.07	82.49

[a] Visceral fat tissue measured by BIA was lower than visceral fat tissue measured by CT in patients with BMI<25, BMI 25-29.9 and BMI 30-34.9. But, in patients with BMI≥35 BIA-determined VFA was higher than CT values. The mean difference between CT and BIA visceral fat measurements was -5.28 when all patients were analyzed.

Table 6. Demonstration of the levels of predicting the VFA with CT change using visceral fat measurement methods via multiple linear stepwise regression analyses

			Non-standardized	Standardized		95% confidence interval for B	
Groups	Models	Variables	coefficients	coefficients	*P*	Lower bound	Upper bound
All	Overall	BIA	0.516	0.521	<0.001	0.376	0.655
		US	12.415	0.321	<0.001	7.084	17.745
		BMI	3.833	0.424	0.003	1.317	6.350
		WHR	163.812	0.172	<0.001	67.967	259.656
	BMI <25	BIA	1.421	0.902	<0.001	1.163	1.679
	BMI 25.0–29.9	US	16.826	0.581	0.004	6.127	27.525
	BMI 30.0–34.9	WHR	576.287	0.853	<0.001	374.055	778.520
	BMI ≥35.0	BIA	0.518	0.463	0.002	0.210	0.827
		US	12.783	0.411	0.005	4.224	21.341
Males	Overall	US	38.688	0.896	<0.001	29.490	47.885
	BMI <25	BIA	1.630	0.959	<0.001	1.150	2.109
	BMI 25.0–29.9	US	23.639	0.931	0.007	10.779	36.498
Females	Overall	BMI	3.833	0.424	0.003	1.317	6.350
		US	7.119	0.190	0.022	1.034	13.204
		WC	1.172	0.283	0.026	0.147	2.196
	BMI <25	BIA	1.171	0.645	<0.001	0.542	1.800
	BMI 30.0–34.9	WHR	657.568	0.784	0.003	290.279	1024.857
	BMI ≥35.0	BIA	0.484	0.424	0.007	0.142	0.826
		US	12.460	0.422	0.007	3.612	21.309

BIA, bioelectrical impedance analysis; BMI, body mass index; US, ultrasonography; WC, waist circumference; WHR, waist to hip ratio.

ment of males revealed that the method best reflecting the VFA by CT was visceral thickness by US (coefficient of determination was 79.3%). Assessment of females revealed the order of methods as follows: BMI, visceral thickness by US, and WC (coefficient of determination of BMI, visceral thickness by US and WC were 78.1%, 1%, and 1%, respectively).

Discussion

Our trial showed that VFA results obtained by VFA by BIA, visceral thickness by US, and WHR most accurately reflected VFA by CT; however visceral fat tissue measurement methods exhibited differences in correlation with VFA by CT results at different BMI levels. In addition, correlation of other VFA measurements with VFA by CT exhibited differences by gender.

Obesity is not just a problem of excess weight; it also significantly increases morbidity and mortality. Many reports have revealed the significance of VFA in obesity associated with hyperlipidemia and hypertension (4, 15). It is reported that people with >100 cm^2 CT-determined VFA, which is called visceral obesity, have higher rates of diabetes mellitus and coronary artery disease (16).

Body mass index is the most common method for estimating body fat, and several epidemiological studies have reinforced its role in the prediction of morbidity and mortality (2, 17). In addition, BMI together with WC and WHR are anthropometric parameters commonly used for the prediction of intra-abdominal fat deposition. While methods such as BMI and anthropometric parameters can predict the amount of visceral adipose tissue, they become inadequate as BMI increases (10, 16, 18). Our results suggest that BMI is helpful for estimation visceral fat tissue (for all participants, males and females, r = 0.843, $P < 0.001$, r = 0.869, $P < 0.001$, and r = 0.885, $P < 0.001$ respectively). Investigating obese and non-obese individuals separately, the method exhibiting the best correlation was BMI, particularly in obese females (r = 0.786, $P < 0.001$). Again in females, linear stepwise regression analyses revealed that it was the best method explaining the VFA by CT change (total variances explained by the variable). However based on assessment by BMI strata, concordance with BMI CT results were lost. Body mass index includes not only the visceral fat tissue, but the total body fat. Therefore, lack of concordance with CT results that directly measure visceral fat tissue only and not total body fat amount is an expected result.

Waist circumference and WHR have been the most commonly used anthropometric parameters for abdominal obesity. Convenience and cost-effectiveness of these methods have resulted in their inclusion in several guidelines for determining cardiovascular risk, particularly for metabolic syndrome. On the other hand, these methods are limited by potential variations by individual operators and the fact that WHR does not alter with weight loss, reducing its use in follow-up. Moreover, some authors have shown that WC correlated better with subcutaneous fat rather than VFA (19). In our study, WC was among the methods that best correlated with VFA by CT in males and females when assessed separately, and in all subjects (r = 0.861, $P < 0.001$; r = 0.840, $P < 0.001$; and r = 0.867, $P < 0.001$). In obese individuals, correlation was sustained with WC VFA by CT, while no correlation was noted in case of non-obese females (Table 4). Contrary to our results, a previous study found a significant correlation between WC and VFA normal weight females, whereas in obese females no positive correlations were found between anthropometric measurements and CT indices of visceral fat distribution (7). While WC is a method descriptive of the total variances in females explained by the variable VFA by CT when assessed using multiple linear stepwise regression analyses, the method lost its consistency when the subjects were evaluated by BMI groups, and no consistency was noted for males (Table 6). When there was correlation between VFA by CT and WC among all participants, they were divided into two groups as obese and non-obese; then the correlation between WC and VFA by CT among non-obese females disappeared. Regression analysis revealed no statistically significant relationship between WC and VFA by CT when participants were divided into 4 groups in terms of BMI values. Reduced compliance of WC in BMI segments with VFA by CT was reflected the inability of WC to differentiate visceral and subcutaneous fat tissue.

In our study, WHR correlated with VFA by CT in all participants, males and females (r = 0.624, $P < 0.001$; r = 0.739, $P < 0.001$; and r = 0.612, $P < 0.001$, respectively). WHR sustained its correlation with VFA by CT in obese individuals, whereas no correlation was observed in non-obese individuals (Table 4). In contrast to our results, it has been reported that significant correlations between WHR and VFA by CT were found in normal weight males, but decreased correlation was noted for obese males (7). When assessed using multiple linear stepwise regression analyses, there was compatibility between WHR and VFA by CT in "BMI, 30–35" groups of all participants and females, while no compatibility was observed for males. Male type obesity (android) shows a dominant visceral and upper thoracic distribution of adipose tissue; whereas in the feminine (gynecoid) type, adipose tissue is found predominantly in the lower part of the body (hips and thighs). Therefore, an increase in WHR is a stronger indicator of abdominal obesity in females than males. Thus, higher consistency of WHR and VFA by CT findings in females was associated with a loss of sensitivity with WHR weight increases in males.

Ultrasonography has proved to be a suitable noninvasive and reliable tool for quantifying abdominal fat and has been found to be as useful as CT in evaluating abdominal fat (10, 12, 20–24). In studies evaluating visceral adipose tissue with ultrasonography, area or thickness was measured and measurements of both VFA and visceral fat thickness by US were demonstrated to be consistent with VFA by CT measurements (10, 12, 21–24). In our study, US-determined visceral adipose thickness was also shown to be correlated with VFA measurements by CT (for all participants, and for males: r = 0.823, $P < 0.001$; r = 0.896, $P < 0.001$, respectively). A multiple linear stepwise regression analyses assessment without categorizing the subjects by BMI groups, visceral thickness by US was among the best methods to reflect VFA by CT. However, when the subjects were grouped by BMI, visceral thickness by US showed highest consistency with VFA by CT with BMIs of 25–29.9 and >35. When the subjects were assessed by gender, visceral thickness by US was among the methods that best

reflected VFA by CT in both males and females. When the participants were separated by BMI, some BMI segments showed very good consistency, while consistency of visceral thickness by US with VFA by CT disappeared in others; this reflected the fact that the number of patients in segments were not equal and adequate, which was a limitation of our study.

Bioelectrical impedance analysis is a commonly used method for estimating body composition based on assessing total body water (TBW) and fat-free mass but is limited in its ability to distinguish the distribution of TBW into its intracellular and extracellular compartments. Body weight is also measured in the leg-to-leg pressure contact BIA; in addition to providing information on fat mass, multi-frequency BIA (frequencies up to 300 kHz) may have an added advantage over SF-BIA (50 kHz) for evaluating leg skeletal muscle (25, 26). Martinolli et al. reported that multi-frequency BIA seems to be a more accurate method than single frequency BIA for estimating the TBW compartment of healthy and obese adults (27). The advantages of BIA include its portability and ease of use, relatively low cost, minimal participant participation required, and safety (although not recommended for participants with pacemakers). Validity of BIA is also influenced by sex, age, disease state, race/ ethnicity (28), and level of fatness (TBW and extracellular water are greater in obese individuals than normal-weight individuals) (29). Multiple linear stepwise regression analyses not categorizing subjects by BMI showed that VFA by BIA was one of the methods that best reflected VFA by CT. However, when subjects were grouped by BMI, VFA by BIA demonstrated best consistency with VFA by CT for BMIs <25 and >35. When all participants were analyzed, BIA measured visceral fat tissue 5.28 cm^2 less than CT. While BIA underestimated VFA in participants with BMI <35, it overestimated VFA in participants with BMI >35, consistent with previous reports (30, 31). These findings may be reflect relatively increased amount of total body water and relatively increased extracellular water, which may result in an underestimation of the percentage of body fat and an overestimation of fat free mass in morbid obesity (9). This discrepancy may also be due to posture of the participants during BIA measurement. In our study, BIA was performed in participants in the standing position. Nagai et al. showed that VFA by using tetrapolar with 100 kHz BIA method was correlated with CT with patients in the supine position (31).

The most significant limitation of our trial was the small number of participants, particularly non-obese individuals (BMI <30). Assignment of equal number of patients to BMI strata to enable comparison between methods in males and females would give clearer results. The other limitation in our study is that we measured visceral thickness (cm) by US; although visceral thickness (cm) has been used for evaluating visceral adipose tissue by US in many previous trials, we believe that VFA (cm^2) measurement by US would be more appropriate for detection of US and CT compatibility.

In conclusion, our data showed that although exhibiting different grades of compliance between gender and BMI levels, visceral fat tissue evaluation methods such as anthropometric measurements and US and BIA yield consistent results. However, none of the investigational methods in our trial exhibited compliance at a level to replace CT despite high costs, exposure to ionizing radiation, and difficulty of administration.

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