Original Article

Evaluation of a Leg-to-Leg Bioimpedance Device in the Estimation of Abdominal Visceral Fat for the Elderly – Comparison with CT

Cheng-Chyuan Lai a, Hsueh-Kuan Lu b, Li-Ming Chiang c, Jasson Chiang d, Kuen-Chang Hsiehe, Chung-Liang Lai e

a General Education Center, National Kaohsiung University of Hospitality and Tourism, Kaohsiung, Taiwan, b Sport Science Research Center, National Taiwan University of Sport, Taichung, Taiwan, c Department of Hotel Restaurant Tourism Management, East Stroudsburg University, PA, United States, d Department of Physical Education Sports Affairs, Chinese Culture University, Taipei, Taiwan, e Research Center, Charder Electronic Co., LTD., Taichung, Taiwan

1. Introduction

Obesity has begun to replace undernutrition and infectious disease in becoming the most significant contributor to ill health in the modern society around the globe. Obesity has become a serious problem as a result of the prevalence of cheap, processed food filled with a lot more sugar, salt, and saturated fat over time in developed countries1. Fat metabolism varies in different parts of the body. Existing research indicated that abdominal obesity was an important health index and had a positive relationship with indicators of metabolic syndrome, such as insulin resistance, hypertension, dyslipidemia, and pathoglycemia2.

The fat distributed around the abdominal skin adipose tissue considered abdominal subcutaneous fat, while the fat separating the organs considered visceral fat. Methods for estimating visceral fat, or the area of abdominal obesity, include anthropometric measurement, such as measuring the indicators of waist circumference, waist hip ratio (WHR), body mass index (BMI)3, and the Lange skinfold caliper4. These methods are rapid, simple and non-invasive and are often used in epidemiological studies, but they are limited for their low accuracy. To measure body and abdominal fat, the most prevalent methods recognized in the literature are CT and magnetic resonance imaging (MRI)5,6. Compared to the aforementioned methods for measuring body fat, bioelectrical impedance analysis (BIA) may obtain electrical impedance signals detected from our physiological tissues and organs. This technology offers advantages in that it is rapid, easy, low-cost and non-invasive7. Additionally, a number of agreements and studies on the safety, measurement standardization, bio-

Please cite this article in press as: Lai C-C, et al., Evaluation of a Leg-to-Leg Bioimpedance Device in the Estimation of Abdominal Visceral Fat for the Elderly — Comparison with CT, International Journal of Gerontology (2017), http://dx.doi.org/10.1016/j.ijge.2016.03.013
electricity-related variables, validity, clinical applications and restrictions of BIA have been published. Ryo et al applied bioelectrical impedance technology to measure the impedance of the cross-section of the waist, thereby estimating the abdominal visceral fat area (VFA). Browning et al performed assessments with the integrated results of both the waist circumference measurement and the abdominal VFA measured from the impedance of the cross-section of the waist. Shimomura et al used the height, weight, gender, age, and the impedance between the legs as estimation variables; this design is the same model as the standing leg-to-leg BIA for the estimation of abdominal visceral fat. Compared to the two previous estimations of VFA by BIA, the leg-to-leg BIA is more convenient and has also been widely applied in family health care. However, only a few studies are available on the validation of the method’s accuracy. The literature is scarce on the validation of the two previous estimations of VFA by BIA, the leg-to-leg BIA for the estimation of abdominal visceral fat. Compared to the method’s accuracy. The literature is scarce on the validation of the two previous estimations of VFA by BIA, the leg-to-leg BIA for the estimation of abdominal visceral fat.

Based on the above considerations, we assumed that the results of VFA measurements for the elderly in Taiwan’s Chinese by the leg-to-leg BIA and CT imaging would be similar, with a high correlation, no significant systematic deviation, and a small confidence interval. Therefore, the abdominal visceral fat of elderly individuals in Taiwan was measured using both the leg-to-leg BIA and CT imaging, and the results in groups of different genders and non-overweight and overweight individuals were compared to investigate whether the VFA measurement results were significantly different between the two methods.

2. Materials and methods

2.1. Study design and subjects

The subjects of this study were selected using a non-random purposive sampling method. Middle-aged and older adults in central Taiwan, 55 years of age or older and with good mobility skills, were recruited via posters. The subjects were required to complete a thorough health questionnaire, including personal information, physical characteristics, health status, and disease history. All participants with endocrine, nutritional and major chronic diseases, such as diabetes mellitus, cancer, kidney dysfunction, and liver diseases, were excluded from this study; after screening, 100 subjects were included. The study procedure was approved by the ethics committee of human trials at the Nantou Tsaotun Psychiatric Center (IRB-103035) and Ta-Li Jen-AI Hospital (IRB-97-02) and was implemented in the Taichung Hospital and Ta-Li Jen-Al Hospital of the Ministry of Health and Welfare.

2.2. Anthropometry

The body weight of the participants was measured using a Weight-Tronix (Scale Electronic Development, New York, USA) electronic scale. The height of the participants without shoes was measured using a stadiometer (Holtain, Crosswell, Wales, UK). The waist circumference (WC) was measured at a level parallel to the height of the navel, and the hip circumference (HC) was measured at the widest part of the hip using a standard measuring tape.

2.3. Four-plate standing bioelectrical impedance analyzer

A BC-305 (Tanita Corp, Tokyo, Japan) four-plate standing leg-to-leg BIA (hereinafter referred to as LBI A) was used in this study. Based on the built-in estimate equation and the height, sex, and age of the corresponding subject, the VFA at the lumbar level of L4-L5 of the subject could be estimated. With every 10 cm² as a level and with a level resolution of 0.5, the VFA values obtained are presented as VFA, LBI A, BIA. Before the actual measurement using LBI A, the VFA, LBI A was first measured for five participants with an interval of three days to evaluate the reliability of the LBI A measurement.

2.4. Computed tomography

A Somatom Sensation 64 CT system (Siemens Corp., Germany) with its operating software (software version syngo CT2005A) was used to perform a CT scan on the abdominal area. To scan the monolithic image in the middle of the lumbar L4-L5 vertebral area, each subject, wearing only a cotton hood, was asked to lay on the central CT scanning platform and lifted both arms straight over his/her head. Based on the procedures recommended by Yoshizumi et al. the abdominal visceral fat and the abdominal subcutaneous fat area were colored in the scanned image for the area calculation, wherein the threshold CT value of adipose tissue was (−260 ± 3) −(−10 ± 3) Hu. The abdominal cross-sectional area (ACSA), the abdominal VFA, and the abdominal subcutaneous fat area (SPA) at the lumbar level of L4-L5 of the subject obtained by CT scanning were represented as ACSA, VFA, and SPA, respectively. Before the actual CT scanning measurement, the CT scanning for the abdominal cross-sectional area at the lumbar L4-L5 level was first performed twice for five participants over a 3-day interval to analyze the reliability of the CT measurement.

2.5. Experimental procedures

Each experiment in this study was started at 2:00 p.m. daily. Before the test, the participants fasted for 4 h, with no intense exercise for 24 h and no consumption of alcohol or diuretics for one week. After the urine in the bladder was emptied before the test, the weight, height, waist circumference, hip circumference, bioelectrical impedance analysis and CT scanning measurements were sequentially collected. All measurements for each subject were completed within 2 h. The anthropometric measurement, CT scanning, and the operation of the bio-impedance measurement in this study were performed by research assistants and radiologists.

2.6. Statistical analysis

The data analysis in this study was performed using SPSS ver. 17 (SPSS Inc., Chicago, IL, USA). The results were presented as means ± SD. The correlation of VFA, LBI A and VFA, CT was described using Pearson’s product moment correlation, and their relationship was represented with a simple linear regression equation. The Bland-Altman method was used to describe the difference (bias ± SD) and the limit of agreement (95% confidence interval, bias ± 2 SD) of VFA, LBI A and VFA, CT. The difference between the two methods was compared using an independent samples t-test. Moreover, the participants were grouped according to gender and different levels of BMI, in which the group with BMI <25 kg/m² was defined as the non-overweight group and the group with BMI ≥25 kg/m² was defined as the overweight and obese group.

3. Results

In this study, a total of 100 subjects with an average age of 68.5 ± 8.5 years were included. The average BMIs were 25.1 ± 3.5 kg/m² for the male subjects and 23.7 ± 3.7 kg/m² for the female subjects. The subjects’ characteristics and measurement results are shown in Table 1. The calculated correlation coefficients of VFA, LBI A and VFA, CT for the male, female and total subjects were 0.565, 0.548, and 0.707 respectively in the non-overweight group; 0.600, 0.398, and 0.365 in the overweight group; and 0.540, 0.682, and 0.707 in the total group. The distribution of the VFA, CT and
Estimating Visceral Fat Area with BIA

Table 1
Descriptive characteristics of the subjects, divided by BMI group.

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<th>Male</th>
<th>Female</th>
<th>Total</th>
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<tbody>
<tr>
<td></td>
<td>BMI &lt; 25</td>
<td>BMI ≥ 25</td>
<td>Total</td>
</tr>
<tr>
<td>Age (years)</td>
<td>n = 24</td>
<td>n = 24</td>
<td>n = 48</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>22.4 ± 2.0</td>
<td>27.8 ± 2.2</td>
<td>25.1 ± 3.3</td>
</tr>
<tr>
<td>WHR</td>
<td>0.90 ± 0.02</td>
<td>0.95 ± 0.04</td>
<td>0.93 ± 0.04</td>
</tr>
<tr>
<td>ACSACT (cm²)</td>
<td>478.4 ± 85.6</td>
<td>638.1 ± 93.4</td>
<td>558.2 ± 119.8</td>
</tr>
<tr>
<td>ACSCFA (cm²)</td>
<td>93.7 ± 36.8</td>
<td>182.6 ± 72.9</td>
<td>138.2 ± 72.6</td>
</tr>
<tr>
<td>VFAC (cm²)</td>
<td>111.1 ± 24.0</td>
<td>129.3 ± 20.6</td>
<td>120.2 ± 23.9</td>
</tr>
<tr>
<td>VFALBIA (cm²)</td>
<td>116.5 ± 31.7</td>
<td>152.8 ± 15.7</td>
<td>134.6 ± 30.8</td>
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<td>Total</td>
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<tr>
<td>Age (years)</td>
<td>n = 34</td>
<td>n = 18</td>
<td>n = 52</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
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VFALBIA of all subjects is shown in Fig. 1, where the solid line is the regression line: VFACT = 0.490 VFALBIA + 56.054 (r² = 0.50, standard estimate of error (SEE) = 21,960 cm², p < 0.001), the 50% of the VFALBIA Variation may be explained by VFACT. Further, VFACT and VFALBIA showed significant difference after applying independent sample t-test, this result may cause the accuracy of LBI in estimating VFA to be limited.

The diagram showed in Fig. 1 indicates a majority of female participants were distributed on the upper left while male participants distributed on the lower right of the equivalent line (y = x). Two groups both have its own corresponding correlation coefficient, but when calculated together, they complement one another. As result, total subject group would have a larger correlation coefficient value than male and female groups.

The bias and the ranges of the LOA with Bland-Altman analysis for VFACT and VFALBIA of the male and female subjects were 14.4 cm², −39.4 to 68.3 cm² and −21.97 cm², and −71.3 to 27.4 cm², respectively. The bias and the LOA ranges for VFACT and VFALBIA of the total subjects were −4.49 cm² and −67.46 to 58.48 cm². The results are shown in Fig. 2, where the solid line represents the difference between VFALBIA and VFACT, which increased proportionately with the increase of (VFACT and VFALBIA)/2 (p < 0.01).

The mean differences between VFALBIA and VFACT of the non-overweight group and the overweight group were −11.2 ± 28.6 and 4.7 ± 33.2 cm² respectively for the total subjects, 5.4 ± 26.1 and 23.5 ± 25.0 cm² for the male subjects, and −21.8 ± 24.6 and −20.4 ± 25.5 cm² for the female subjects, as shown in Fig. 3. Independent samples t-tests revealed significant different BMIs for the VFALBIA and VFACT measures of the male, female and total subjects (p < 0.001).

When evaluating the coefficient of variation (CV) in LBI, it was measured 5 times with a 15 min interval between each measurement per day. The within-day coefficient of variation (CV; 100 × [SD/mean]) for VFALBIA was 0.13–0.25%. The corresponding between-day CV was 0.32–0.53%. The correlation coefficient r and Cronbach’s alpha of the VFACT measured by CT scanning from five participants were both 0.99.

4. Discussion

Using CT imaging to determine the nature of the tissue and to accurately calculate the abdominal visceral fat and abdominal subcutaneous fat with related software has shown a high degree of repeatability and is now considered the gold standard for the detection of fat distribution and content. Compared to the traditional supine postur hand-to-leg BIA, the estimation of body composition by standing BIA is not only safe, convenient, and non-invasive, but widely applied in clinical practice, research, and personal health monitoring. However, its built-in VFA estimation equation is propriety to the manufacturer and is not available for appropriate comparisons; thus, this study of the assessment and verification of commercial BIA measurements is particularly important.

In the present study, the abdominal VFACT of the female subjects was lower than that of the male subjects, and the SFACT of the male subjects was lower than that of the female subjects. These findings are similar to the VFA results measured by MRI in a study by Browning et al. for the elderly and a study by Wang et al. for adults. When the VFA is greater than the 100 cm² cut-off point, the risk for coronary artery disease and diabetes mellitus is
In this study, the average VFACT of the subjects was 105.8 ± 30.9 cm². However, the average BMI of the subjects in our study was 24.4 ± 3.6 kg/m², which did not reach the overweight standard of the World Health Organization (WHO). Based on the VFA alone, the risk for type 2 diabetes mellitus was relatively high. The BMI of the male subjects in the non-overweight group was only 22.4 ± 2.0 kg/m², but the VFA was 111.1 ± 24.0 cm², while the BMI of the total group of male subjects was 25.1 cm², and the VFA was as high as 120.2 ± 23.9 cm². Although the determination of the obesity level using BMI is simple and easy, the results do not correlate with gender and age; therefore, this measurement is applicable for general and trend assessments of a population with a large sample scale and is not appropriate to estimate individual abdominal obesity. To further assess the risk of abdominal obesity on cardiovascular disease or type 2 diabetes, particularly among the elderly, VFA also provides a reference value. However, for the female subjects of this study in both the non-overweight and overweight groups, VFACT calculations were undervalued by 21.8 ± 24.6 and 20.4 ± 25.5 cm² compared to VFACT. The underestimation in the VFA of the subjects using LBIA may result in underestimations in the risk of cardiovascular disease or type 2 diabetes.

Several studies have been reported on the validation of the standing leg-to-leg BIA for VFA. For example, a study by Wang et al. showed that the correlation coefficient, bias, and LOA of VFACT (VFA obtained by MRI) and VFACT using a Tanita BC-532 device (Tanita, Tokyo, Japan) for adults were 0.77, 40 cm², and −6.0 to 87.0 cm², respectively. Bosy-Westphal et al. estimated VFA using the same BIA device, and the correlation coefficient, bias, and LOA with VFACT were 0.83, 2.7 cm², and −24.8 to 54.5 cm², respectively. Subjects average age in Wang et al. and Bosy-Westphal et al. were 48 and 45 year old adults while the current study mainly focuses on the older adults segment (68.5 ± 7.4). Further, different BIA brand, model, and methodology could affect the correlation coefficient value and reliability analysis. Based on the above considerations, the accuracy and reliability analysis needed to be reported separately by different age groups.

Although the estimation of VFA using a standing leg-to-leg BIA is convenient and safe, the available literature and the results of this study indicated that the correlation coefficient of VFACT with VFACT or VFAMRI reflects a high correlation between these values ($r > 0.7$), but the LOA was almost always greater than 80 cm², indicating the restriction of its application in clinical practice, research and individual health care. In this study, the comparison of the VFA measurement results by CT and by LBIA showed that, regardless of gender or obesity level, the measurement results of the two methods were significantly different.

In addition to the standing leg-to-leg BIA for VFA estimation, standing hand-to-leg BIA is also available for the estimation of VFA. A study by Wang et al. using an Omron HBF-359 device (Omron, Kyoto, Japan) found that the correlation coefficient, bias, and LOA of VFA$^B$ and VFA$^M$ were 0.84, 39.0 cm², and −2.0 to 81.0 cm², respectively. A study by Bosy-Westphal et al. using an Omron HBF-500 device (Omron, Medizintechnik, Mannheim, Germany) found that the correlation coefficient, bias, and LOA of VFA$^B$ and VFA$^M$ were 0.92, 1.9 cm², and −34.3 to 38.1 cm², respectively. Compared to the standing leg-to-leg BIA device, the standing hand-to-leg BIA device showed a higher correlation with a smaller LOA range in the VFA estimation. This variation might have occurred because the accuracies of the VFA estimate models from different manufacturers were different; moreover, one of the actual factors for this difference is that the impedance value derived using the leg-to-leg model did not pass through the abdomen, while that derived using the hand-to-leg model did. Therefore, in estimating abdominal visceral fat, the performance of the hand-to-leg model may be better, though the reason for this difference remains to be further clarified. For the limited accuracy in VFA estimations by LBIA discussed in this study, the existing simple VFA measurement method is still based on the more relevant variables in anthropometric measurements, such as waist circumference, age and abdominal skinfold thickness, to estimate the abdominal visceral fat, as these measures are convenient and somewhat accurate.

This study’s subjects were limited to the Chinese elderly in Taiwan, with no consideration for other populations. Additionally, subjects with abnormal body water ratios caused by bad behavior, severe obesity, or other diseases were not included in this study. In addition, for the investigation of abdominal VFA, this and most other studies have conducted monolithic scans at the lumbar L4-L5 level. However, a study by Shen et al. found that the VFA and the total volume of the visceral adipose tissue measured by the monolithic image at 5–10 cm above the L4-L5 lumbar spine showed the highest relevance. Thus, the optimal anatomical
position of VFA measurement for Chinese elderly individuals by monolithic imaging needs to be further explored.

5. Conclusion

In summary, the results of abdominal VFA assessment obtained using a four-plate standing bioelectrical impedance analyzer and CT scanning in Chinese elderly individuals were highly positive correlated, but the LOA range was large. Interpretations and applications of the estimate results of individual’s VFA by leg-to-leg BIA needs to be made with care.

Conflict of interests

The authors declare no conflict of interest.

References