Estimating Visceral Fat Area by Multifrequency Bioelectrical Impedance

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OBJECTIVE — We developed a new method of estimating visceral fat area (VFA) using multifrequency bioelectrical impedance (BI).

RESEARCH DESIGN AND METHODS — We considered abdominal composition as a parallel circuit model composed of VFA and subcutaneous fat area and calculated the impedance of VFA (IP_{VFA}) from this model. The methods were tested against measures of VFA by computed tomography (CT). Multiple regression analysis was performed on 103 participants to estimate VFA. We cross-validated the regression equation against CT-measured VFA in 30 additional participants.

RESULTS — The regression equation was VFA = 3.57 × sagittal abdominal diameter + 311.97 × waist-to-height ratio + 0.71 × age + 23.93 × sex + 1.57 × IP_{VFA} (250 kHz) − 174.35 ($r = 0.904$, $P < 0.01$). We observed a strong correlation by cross-validation ($r = 0.905$).

CONCLUSIONS — Our method using BI is a simple and convenient method for accurately estimating VFA.

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The accumulation of visceral fat area (VFA) induces several health risks (1–3), thus there is a need for a simple method of determining how much VFA has accumulated. The efficacies for estimating VFA using bioelectrical impedance (BI) have been reported (4–6). Because such studies found that the obtained impedance differed according to body posture (7–9), electrode arrangement (10,11), and frequency (12), we previously developed a method of estimating VFA using BI by selecting appropriate measurement conditions (13). However, we could not eliminate the effect of subcutaneous fat area (SFA). In the present study, we overcame this problem and developed a new method of estimating VFA using BI.

RESEARCH DESIGN AND METHODS

— We recruited 84 men and 49 women, aged 20–67 years, from among the students and teaching and administrative staff at our university. All participants were fully informed of the procedures, risk, and discomfort. The study protocol was approved by the bioethics committee of Utsunomiya University.

The details of the study method have been described previously (13). Briefly, we measured anthropometry parameters. BMI was calculated as body weight (in kilograms) divided by the square of height (in meters). Waist-to-height ratio (WHtR) and waist-to-hip ratio were calculated as waist circumference (*W*) divided by height and by hip circumference, respectively. We took computed tomography (CT) at the umbilical level and calculated VFA and SFA using the image analysis software Fat Scan version 3.0 (N2 System, Hyogo, Japan). The methods were tested against measures of VFA by CT. We measured impedance by the tetrapolar impedance method using multifrequency BI (MFBIA-07; Tanita, Tokyo, Japan). The repeatability of this device was confirmed in the same participants (data not shown). We measured impedance more than 2 h after exercise, eating, and drinking. Impedance was measured at the frequencies of 5, 25, 50, 100, and 250 kHz in the supine posture, and the value measured the first time was used. We used two types of electrode arrangement. First, we placed sensing electrodes symmetrically about the body axis, at a separation of 10 cm. Current electrodes were placed to the right and left of the sensing electrodes. The distance between the current electrodes and sensing electrodes was 10 cm (13). From this electrode arrangement, we obtained the impedance of the whole abdomen ($IP_{VFA+SFA}$). After measuring $IP_{VFA+SFA}$, we brought the right sensing electrode closer to the right current electrode, to 3 cm. From this electrode arrangement, we obtained the impedance of SFA (IP_{SFA}) from just under the skin (10). In this study, we considered abdominal composition as a parallel circuit model composed of VFA and SFA. We calculated the impedance of VFA (IP_{VFA}) for each frequency as $IP_{VFA} = (IP_{VFA+SFA} \times IP_{SFA})/(IP_{VFA+SFA} - IP_{SFA})$.

Statistical analysis

We randomly assigned participants into two groups, one composed of 103 participants and the other of 30 participants. Stepwise multiple regression analysis was performed on the 103 participants to estimate VFA. Their mean BMI and VFA by CT were 22.67 kg/m^2 (range 17.19–34.07) and 51.71 cm^2 (5.55–212.20), respectively. Independent variables were sex, age, anthropometry parameters, and IP_{VFA} at each frequency. We cross-validated the regression equation against CT-measured VFA in 30 additional participants (VFA range 12.6–159.1 cm^2). The Bland-Altman method was used to examine the mean difference and 1.96 SD between VFA observed by CT and that

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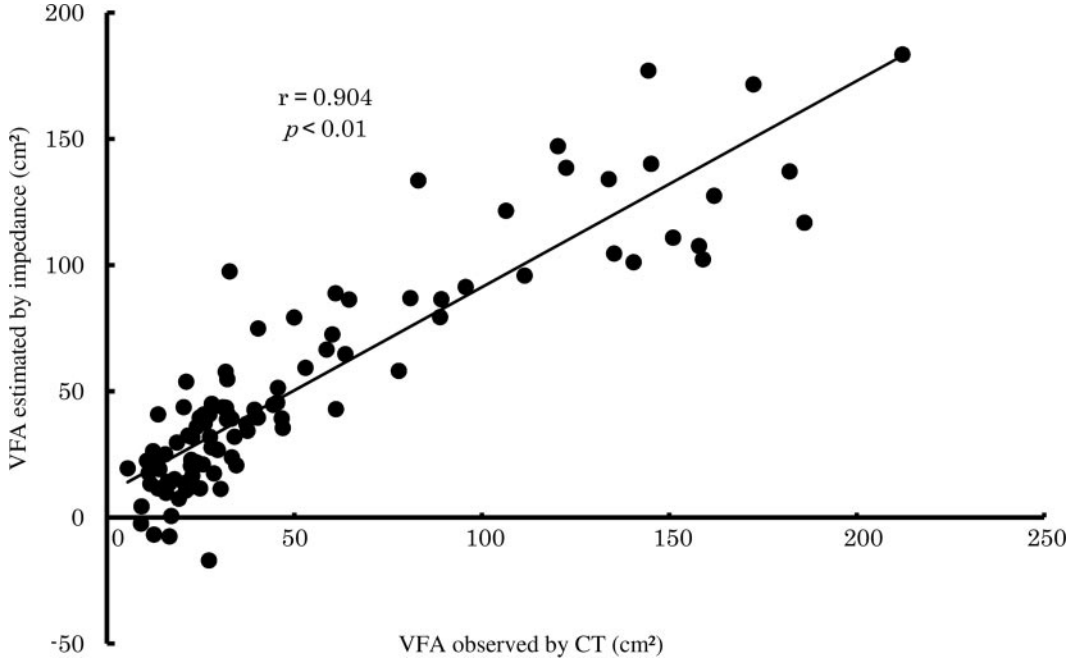

Figure 1—*Correlation plot between VFA observed by CT and VFA estimated by impedance.*

estimated by IP_{VFA} (14). We calculated the sensitivity and specificity at VFA ≥100 cm^2 by the regression equation (15). The correlation between impedance and VFA and SFA was examined by Pearson correlation coefficient. All *P* values were two-tailed, and $P < 0.05$ was accepted as statistically significant.

RESULTS — The weakest and strongest correlation between impedance obtained at the five frequencies and VFA and SFA were $r = 0.734–0.747$ (IP_{VFA}) and $r = 0.834–0.872$ (IP_{SFA}), respectively.

The regression equation was VFA = 3.57 × sagittal abdominal diameter + 311.97 × WHtR + 0.71 × age + 23.93 × sex + 1.57 × IP_{VFA} (250 kHz) − 174.35 ($r = 0.904$, $P < 0.01$) (Fig. 1).

Also, we observed a strong correlation in the cross-validation subsample ($r = 0.905$, $P < 0.01$). The Bland-Altman method showed a mean difference and 1.96 SD of 0.00 ± 40.78 cm^2. There was no increasing bias for heavier participants. We observed a high sensitivity and specificity (0.941 and 0.988, respectively) when we discriminated VFA ≥100 cm^2 or <100 cm^2 by the regression equation. Meanwhile, waist circumference (*W*) at the umbilicus level (men: $W \geq 85$ cm, women: $W \geq 90$ cm) is used for screening of VFA ≥100 cm^2 in Japan (15), thus sensitivity and specificity were 0.882 and 0.919, respectively, by *W* in our participants.

CONCLUSIONS — In this study, because subcutaneous fat layer thickness affected the impedance when electrodes were placed on the abdomen (6), we considered abdominal composition as a parallel circuit model and calculated IP_{VFA} using the formula for a parallel circuit. Therefore, we eliminated the effect of SFA by this model.

In Japan, waist circumference at the umbilicus level was used to screen for VFA ≥100 cm^2 because CT has some problems such as radiation exposure (15). However, our regression equation demonstrated higher sensitivity and specificity than waist circumference.

A major strength of our study is that the number of study participants was more than in any previous study (4–6,13). Additionally, we cross-validated the regression equation and obtained a strong correlation ($r = 0.905$, $P < 0.01$). On the other hand, our study has several limitations. First, the study participants were young (mean age ± SD: 30.3 ± 10.8 years), and the proportion of VFA ≥100 cm^2 was small (16.5%), so we may not be able to adapt this regression equation for middle-aged people who have a higher proportion of VFA ≥100 cm^2 than young people. Second, the data are limited to the Japanese population, which may have different VFA characteristics than other populations.

Our new method using BI is a simple and convenient method for accurately estimating VFA. We can easily screen excess accumulation of VFA, which is associated with metabolic syndrome. The method may be a useful tool for primary prevention of metabolic syndrome.

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References

1. Boyko EJ, Fujimoto WY, Leonetti DL, Newell-Morris L. Visceral adiposity and risk of type 2 diabetes: a prospective study among Japanese Americans. Diabetes Care 2000;23:465–471
2. Fujimoto WY, Bergstrom RW, Boyko EJ, Chen KW, Leonetti DL, Newell-Morris L, Shofer JB, Wahl PW. Visceral adiposity and incident coronary heart disease in Japanese-American men: the 10-year follow-up results of the Seattle Japanese-American Community Diabetes Study. Diabetes Care 1999;22:1808–1812
3. Itoh H. Metabolic domino: new concept in lifestyle medicine. Drugs Today (Barc) 2006;42 (Suppl. C):9–16
4. Fernandes RA, Rosa CS, Buonani C, Oliveira AR, Freitas Junior IF. The use of bioelectrical impedance to detect excess

visceral and subcutaneous fat. J Pediatr (Rio J) 2007;83:529–534
5. Ryo M, Maeda K, Onda T, Katashima M, Okumiya A, Nishida M, Nishida M, Yamaguchi T, Funahashi T, Matsuzawa Y, Nakamura T, Shimomura I. A new simple method for the measurement of visceral fat accumulation by bioelectrical impedance. Diabetes Care 2005;28: 451–453
6. Scharfetter H, Schlager T, Stollberger R, Felsberger R, Hutten H, Hinghofer-Szalkay H. Assessing abdominal fatness with local bioimpedance analysis: basics and experimental findings. Int J Obes Relat Metab Disord 2001;25:502–511
7. Pinilla JC, Webster B, Baetz M, Reeder B, Hattori S, Liu L. Effect of body positions and splints in bioelectrical impedance analysis. JPEN J Parenter Enteral Nutr 1992;16:408–412
8. Roos AN, Westendorp RG, Frolich M, Meinders AE. Tetrapolar body impedance is influenced by body posture and plasma sodium concentration. Eur J Clin Nutr 1992;46:53–60
9. Scharfetter H, Monif M, Laszlo Z, Lambauer T, Hutten H, Hinghofer-Szalkay H. Effect of postural changes on the reliability of volume estimations from bioimpedance spectroscopy data. Kidney Int 1997; 51:1078–1087
10. Baker LE. Principles of the impedance technique. IEEE Eng Med Biol Mag 1989; 8:11–15
11. Caterine MR, Yoerger DM, Spencer KT, Miller SG, Kerber RE. Effect of electrode position and gel-application technique on predicted transcardiac current during transthoracic defibrillation. Ann Emerg Med 1997;29:588–595
12. Zhu F, Leonard EF, Levin NW. Body composition modeling in the calf using an equivalent circuit model of multi-frequency bioimpedance analysis. Physiol Meas 2005;26:S133–S143
13. Nagai M, Komiya H, Mori Y, Ohta T, Kasahara Y, Ikeda Y. Development of a new method for estimating visceral fat area with multi-frequency bioelectrical impedance. Tohoku J Exp Med 2008;214:105–112
14. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307–310
15. Oda E. New criteria for 'obesity disease' in Japan. Circ J 2002;70:150