# A New Simple Method for the Measurement of Visceral Fat Accumulation by Bioelectrical Impedance

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We and others (1–9) have shown that the accumulation of visceral fat is associated with multiple risk factor syndrome more closely than with the BMI itself or the amount of subcutaneous fat. In these studies, computed tomography (CT) scan at the umbilical level (10) was used for the assessment of visceral fat area (VFA). However, the method is not cost-effective and/or radiation exposure is problematic; thus, it is often unsuitable for screening large groups of individuals. There is a need for a simple and noninvasive method to assess visceral fat accumulation. The bioelectrical impedance analysis (BIA) method, which is based on the electric resistance difference between the fat and components of other organs (11–14), should meet this need. Conventional BIA approaches have estimated total fat content but not regional fat distribution (11–13). Recently, attempts to assess the amount of abdominal subcutaneous fat by the local BIA method were reported (14). Here, we developed a new technique to specifically evaluate VFA by using the abdominal BIA method.

## RESEARCH DESIGN AND METHODS

The study subjects were 59 healthy volunteers and 32 inpatients with suspected cardiovascular disease at Osaka University Hospital. Waist circumference (Wc) at the umbilical level was measured in the late exhalation phase while standing. All subjects underwent the abdominal BIA method to estimate VFA. The voltage occurring at the flank to the flow of current between the umbilicus and the back correlates significantly with VFA and is unaffected by subcutaneous fat area. The voltage becomes larger as visceral fat accumulates even in the subjects with the same Wc because the electric resistance of intra-abdominal fat is greater than that of fat-free mass, and the density of the equipotential lines between two electrodes becomes denser (15) (Fig. 1*A*). The voltage correlates with the ratio of VFA to the total cross-sectional area of the abdomen, which can be approximated by using $Wc^2$ (Fig. 1*B*). Thus, the VFA can be expressed as

$$VFA = a_0 + a_1 Vo' Wc^2 \quad (1)$$

where $a_0$ and $a_1$ are constants and Vo′ is the voltage measured at the flank. Equation 1 means that the distance between two measuring electrodes on the flank must change in proportion to Wc. The voltage Vo′ used in equation 1 can be approximately related to the voltage Vo measured with the electrodes with a fixed distance in the form of

$$Vo' = bWcVo \quad (2)$$

where b is a constant. Hence, substituting equation 2 into equation 1, we obtain

$$VFA = a_0 + a_1' VoWc^3 \quad (3)$$

where $a_1'$ is a constant. Then, we calculate presumed VFA by using linear regression equation for volunteers and patients. The correlation between presumed VFA and VFA determined by CT and the effects of posture and respiration on abdominal BIA were investigated. The usefulness of abdominal BIA on evaluating metabolic syndrome was also investigated. Factors characteristic for the metabolic syndrome were defined as follows. Hypertriglyceridemia: serum triglyceride concentration ≥150 mg/dl and/or on medication; low HDL cholesterol: serum HDL cholesterol concentration <40 mg/dl; hypertension: systolic blood pressure ≥130 mmHg and/or diastolic blood pressure ≥85 mmHg and/or having received antihypertensive medication; and high fasting glucose: serum glucose concentration ≥110 mg/dl and/or having received antidiabetic medication. In the Japanese subjects, the best combination of sensitivity and specificity for detecting subjects with multiple risk factors was VFA level ≥100 $cm^2$ (3). All statistical analysis was performed with Stat View J 5.0 (SAS). The $\chi^2$ test and Mann-Whitney's *U* test were used to compare the risk factors between two groups: the high and normal VFA groups.

## RESULTS

The VFA presumed by abdominal BIA correlated significantly with VFA determined by CT ($r = 0.88$, $P < 0.0001$) (Fig. 1*C*). This correlation

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**Abbreviations:** BIA, bioelectrical impedance analysis; CT, computed tomography; VFA, visceral fat area; Wc, waist circumference.

A table elsewhere in thise issue shows conventional and Système International (SI) units and conversion factors for many substances.

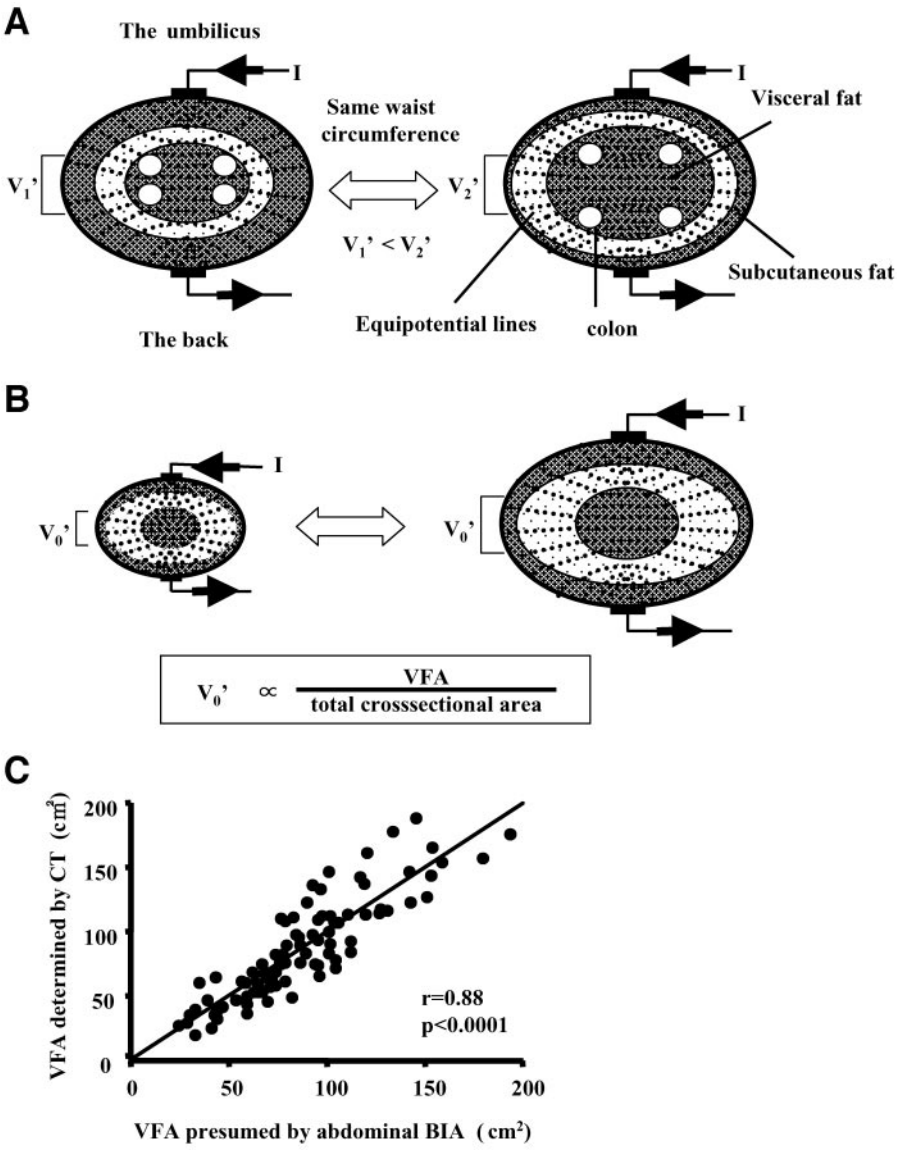


**Figure 1—***Abdominal bioelectrical impedance analysis (BIA) method. (A) The electric current (I) flows across the abdomen between the umbilicus and the back. Equipotential lines, form inside the peritoneal cavity, penetrate the visceral fat and emerge on the body surface at the flank. The voltage ($V_1'$, $V_2'$) measured at the flank becomes large with accumulation of visceral fat. (B) The voltage ($V_0'$) measured at the flank correlates with the ratio of visceral fat area (VFA) to the total cross-sectional area of the abdomen. (C) Correlation between VFA presumed by abdominal BIA and VFA determined by computed tomography (CT) (n = 91). Voltage measurement condition was the standing-late exhalation.*

was significantly stronger than those between VFA determined by CT and Wc ($r = 0.77$), BMI ($r = 0.62$), and percent body fat × weight ($r = 0.73$–$0.76$) measured by the conventional BIA method based on induction between both hands (HBF-302; Omron, Kyoto, Japan) and both feet (TF-701; Tanita, Tokyo, Japan). In considering the reproducibility and correlation, the best measurement condition was the standing posture and late exhalation in both sexes (data not shown). The high VFA group (presumed VFA ≥100 cm$^2$) showed a higher prevalence of hypertriglyceridemia (48.3 vs. 12.9%, $P < 0.001$), low HDL cholesterol (17.2 vs. 11.3%), high fasting glucose (13.8 vs. 9.7%), and hypertension (24.1 vs. 22.6%) than the normal VFA group (<100 cm$^2$). The number of risk factors was also significantly higher in the high VFA group than the normal VFA group (no risk factor: 37.9 vs. 61.3%, single risk factor: 24.1 vs. 22.6%, two risk factors: 24.1 vs. 12.9%, and three risk factors: 13.8 vs. 3.2%, $P < 0.05$).

**CONCLUSIONS** — Conventionally, Wc is a well-used anthropometric measure for the assessment of visceral fat. Furthermore, the criteria for the metabolic syndrome according to National Cholesterol Education Program (16) include Wc. In fact, Wc correlates with VFA determined by CT (3,9,17). However, these parameters are considerably variable among individuals. It has been reported (3), for example, that men with Wc between 85.0 and 86.0 cm had VFA in the range of 67 and 137 cm$^2$ in a Japanese population. Furthermore, in premenopausal women, Wc underestimates visceral fat amount because of the accumulation of abdominal subcutaneous fat (18). For the above reason, we decided to develop a new method that is simple and accurately measures VFA.

Our new method using BIA is quite simple and noninvasive for evaluation of visceral fat amount. The time required for measurement is only a few minutes, and the instrument is inexpensive and portable. This method requires no advanced skills on the part of the operator, and, on the other hand, subject cooperation is minimal. Excellent correlation was observed in the estimation of visceral fat accumulation between abdominal BIA method and CT. Indeed, the prevalence of multiple risk factors was significantly higher in the high VFA group than in the normal VFA group.

Collectively, the abdominal BIA method should become a useful instrument in routine clinical practice for the evaluation of visceral fat accumulation associated with the metabolic syndrome.

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