A new simple measurement system of visceral fat accumulation by bioelectrical impedance analysis

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Abstract— **Measurement of visceral fat accumulation is essential for the diagnosis of obesity. Currently, the visceral fat area (VFA) obtained from the abdominal cross-sectional image measured by X-ray CT is used as the gold standard. However it has problems of complexity, cost, and X-ray exposure. On the other hand, the waist circumference is used as a simple index, but it is indirect method and is affected by subcutaneous fat. Bioelectrical impedance analysis (BIA) is a proven method practically used to measure total body fat, and is the most suitable for the measurement of visceral fat accumulation. For the latter purpose, we developed a new simple measurement system using dual current pathways bioelectrical impedance analysis (dual-BIA). This proposed system measures impedance reflecting the subcutaneous fat volume (SFV) and the fat free volume (FFV) in the abdomen by passing current via respective pathways. Regarding to measure these two impedance values we adopted the four electrodes method. The VFA was calculated by using these two impedance values and abdominal body shape data to minimize the influence of FFV and SFV. We compared the VFA measured by dual-BIA system with that measured by X-ray CT in 98 subjects, and found a high correlation coefficient (r=0.888, p<0.001). Our proposed system is suggested to be useful for a simple visceral fat accumulation measurement.**

Keywords— **BIA, visceral fat, measurement, dual impedance, simple measurement**

I. INTRODUCTION

The measurement of visceral fat accumulation is essential for the diagnosis and treatment of obesity [1]. The measurement of the VFA by the X-ray CT image at the umbilicus level is used as the gold standard [2]. Although visceral fat volume (VFV) is necessary to evaluate visceral fat accumulation, this method can only measure the VFA. Moreover, this method cannot avoid X-ray exposure, and its use is limited due to its complexity and cost. Accordingly, this method is not suitable for general outpatient services, clinics, and medical checkups. The waist circumference (W_c) is measured as an alternative index because of its simplicity, and diagnostic standard values have been established. However, the W_c is affected by the SFV and the FFV. Thus, the development of a simple method for the measurement of visceral fat accumulation is desired.

The VFA measurement method by applying BIA to the abdomen (abdominal BIA) was proposed in previous study [3]. This method measures impedance of the abdomen in the cross-sectional direction, which may not be affected by the limbs. However, it has a problem with regard to the influences of the SFV because it measures the entire abdomen utilizing impedance in a single current pathway passed from the front side to the back side.

In response to the problem mentioned above, we proposed a method (dual BIA) [4], which eliminates the major influential factors: SFV and the FFV, by measuring impedance reflecting these factors by passing current via their respective pathways. To evaluate visceral fat accumulation, VFV measurement is desirable, but VFA by X-ray CT is the current gold standard. Therefore, we developed an algorithm to calculate the VFA using VFA by X-ray CT as a reference. In this study, we newly developed the system that measures the VFA, and found better performance compared with the previous system [4] through the evaluation study.

II. MATERIALS AND METHODS

A. Methods

Principle: The dual-BIA measures impedance reflecting the FFV and the SFV by passing current via respective pathways. Figure 1 shows the notion of the dual-BIA. A constant current, I_1 (50 kHz, 500 μA), is passing between the hands and legs, as shown in Figure 1(a). Impedance of the entire abdomen (Z_t) is obtained from voltages (V_1) measured at a distance of L in the axial direction centering on the umbilicus level. Four pairs of electrodes are placed on the abdominal and dorsal regions, respectively (8 pairs in total). Only 4 pairs on the abdominal side are shown in Figure 1. V_1 is the mean of values obtained by the 8 pairs of electrode. Since the current flows mainly through the fat free tissues, FFV between-electrode region L is presented as

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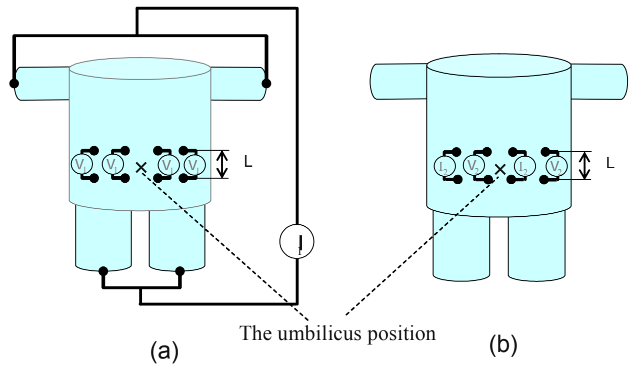

Fig.1 Schematic diagrams of the principle of the dual-BIA

FFV= $\rho L^2/Z_t$ [5], where ρ represents the mean resistivity of fat free tissues in the abdominal measurement region. Since ρL^2 is constant, $1/Z_t$ serves as a parameter reflecting FFV.

The constant current I_2 (50 kHz, 500 μA) is supplied on the abdominal surface using the same electrodes, as shown in Figure 1(b). The voltage V_2 is measured using a pair of voltage electrodes placed on the same sides as the current electrodes. Voltage electrodes are positioned at 2 sites on the abdominal and dorsal regions, and the mean voltage value is designated as Z_s. Z_s serves as a parameter roughly reflecting the SFV [6].

The cross-sectional abdominal shape is close to an oval. Therefore the frontal diameter: A and the sagittal diameter: B at the umbilicus level are measured for the parameters of abdominal shape. The VFA is calculated from the two impedance data, Z_t and Z_s combined with abdominal shape parameters, A and B.

Algorithm: Using the VFA measured by X-ray CT as a reference, we constructed an algorithm to calculate the VFA using 1/Zt, Zs, reflecting FFV and SFV respectively and A,B reflecting the abdominal shape. We selected the following 4 parameters using AIC (Akaike Information Criterion) method and the calculation formula (1) was established with these parameters [7]. The constants (v1-α_4 and ε) were determined by validation study.

$$VFA = \alpha_1 A + \alpha_2 B^2 - \alpha_3 \sqrt{A^2 + B^2} Z_s - \alpha_4 \frac{1}{Z_t} + \varepsilon \qquad (1)$$

B. Apparatus

Dual-BIA system: The VFA measurement equipment consists of 3 functional units; i.e., the main unit, abdominal shape measurement unit, and electrode units. Figure 2 shows the block diagram of the dual-BIA system.

The control unit (CPU) controls the entire system, inputs and outputs data, and calculates the VFA. It also controls functions such as key input and display output. The constant-current power supply converts the basic cycle signal (50 kHz) sent by the CPU to a constant-current sinusoidal signal (50 kHz, 500 μA). The pathway of this current signal is switched by the electronic SW and connected to the electrodes on the limbs and abdominal and dorsal regions, and the signal is sent as a current passing through the body. Voltage signals reflecting the bioelectrical impedance detected by the abdominal and dorsal electrodes are input into a similar electronic SW, where the measurement electrode is selected, and the signals are sent to the impedance measurement unit. The voltage signals are averaged in the impedance measurement unit, digitized by the A/D conversion unit, and input into the CPU as an impedance value. The CPU also receives the measured values (A and B values) from the abdominal shape measurement unit.

Electrode units: The subsystem of the electrode unit is outlined in Figure 3. In each electrode, the passage of current signals and detection of voltage signals are output and input, respectively, through switching by the electronic SW. For voltage detection, each electrode is equipped with a buffer. Since signals are converted to low impedance in the electrode unit, and input into the main unit via a cable connection, influences of external noise and contact resistance are minimized. To measure Z_t, the current is passing through the 4 limbs, and the voltage is detected by combinations of electrodes 1-2, 3-4, 5-6, and 7-8. To measure Z_s, the current is passing via electrodes 1-2 followed by voltage measurement via electrode pair 3-4, and then, inversely, the current is passing via 3-4 followed by voltage measurement via 1-2. Similar measurements are performed by combinations of electrodes 5-6 and 7-8. To switch the electrodes, the electronic SW receives control signals from the CPU. Two electrode units are prepared for abdominal and dorsal use, respectively.

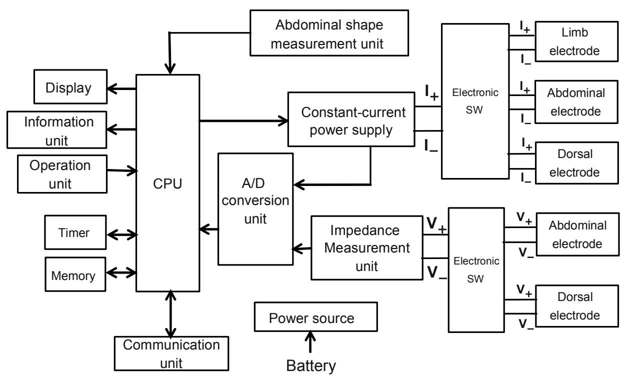

Fig.2 Block diagram of the dual-BIA system

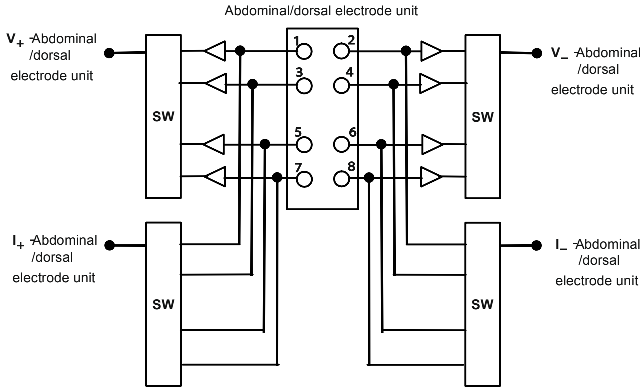

Fig.3 System block of the abdominal/dorsal electrode unit

Electrodes have a cylindrical shape (ϕ22), and the distances between them are 9 cm for the axial direction and 10 cm for the circumferential direction. Electrodes are placed on an elastomer sheet to fix the positions, and are attached to the base unit that is made of an elastomer foam-like cushion to maintain tight contact with the body surface. The limb electrodes are clip-type stainless steel electrodes, and are attached to both hands and legs by clipping. The abdominal and limb electrodes are applied with cardio cream used for electrocardiography to reduce resistance on skin contact.

Abdominal shape measurement unit: The measurement unit of the abdominal shape is shown in Figure 4. Measurement plates plate 1 and plate 2 moves in parallel longitudinally and transversely, respectively. The plates are connected to cables in the unit, and the cables are retracted using wheels. The distance of the plates shift is measured by counting the number of wheel rotations using a rotary encoder, and calculated by the CPU.

Measurement procedure: Firstly, the abdominal shape measurement unit measures the abdominal shape parameters (A, B) to input the data into the CPU. After the unit is removed, the abdominal, dorsal, and limb electrodes are attached for impedance measurement. The VFA is calculated using the abdominal shape parameters and impedance in the main unit to be displayed.

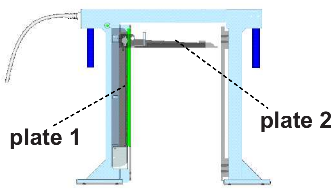

Fig 4 Structure of the abdominal shape measurement unit

C. Subjects

The subject group (validation group) used for the constructing algorithm consisted of 50 males and 48 females, whose BMI was normal distribution between 18 and 35 with 25 as the central value, and ages ranged from 20 to 70, with an almost equal number of people for every 10 years. We used a subject group different from the validation group as the cross validation group that consisted of 51 males and 47 females, with almost the same distribution of BMI and ages as the validation group.

III. Results

Figure 5 shows the relationship between VFA by dual-BIA and VFA by the X-ray CT cross-sectional image at the umbilicus level in the cross validation group. The correlation coefficient of all subjects was r=0.888 (p<0.001). Figure 6 shows the results of a Bland-Altman plot in the cross validation group.

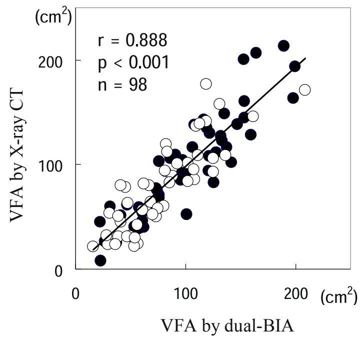

Fig. 5 Relationship between VFA by dual-BIA and VFA by X-ray CT cross sectional image at the umbilicus level in cross validation group. Black dots represent male and white dots represent female.

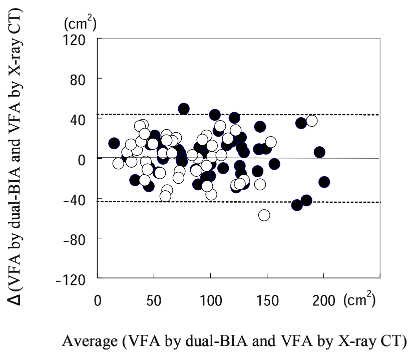

Fig. 6 Bland-Altman plot of VFA for the cross validation group. Black dots represent male and white dots represent female.

IV. Disccusion

We investigated whether each impedance value reflected the corresponding volume. The impedance values of $1/Z_t$ and Z_s were correlated with the area of FFV and SFA by X-ray CT at R=0.796 and 0.799, respectively. They suggested that the impedance values well reflected the target volumes. However these two impedance parameters do not fully represent FFV and SFA. Regarding to the abdominal shape parameters A and B, they used for VFA calculation also does not fully represent the geometric volume. Therefore, in our study we used the AIC method for selecting the parameters and also the conventional BIA method to determine a formula by multiple regression analysis of the reference value.

The superiority to an alternative and simple index of waist circumference was investigated. The correlation coefficients between VFA by X-ray CT and two measurements are as follows; i.e., r=0.758 with the waist circumference and r=0.888 with the dual-BIA. This proves that dual-BIA is superior compared with the waist circumference. These two correlation coefficient were also compared in obese (BMI: 25 or higher) and non-obese (BMI: less than 25) groups. We found that the correlation coefficient of the waist circumference case was r=0.504 in the obese and r=0.557 in the non-obese group. These results were remarkably low because the assessment range was narrower. On the other hand, that of dual-BIA case was r=0.801 in the obese and r=0.807 in the non-obese group. These results showed the better value than the waist circumference case. The difference suggested that the waist circumference is strongly affected by the body shape although the dual-BIA is less affected by that. The correlation coefficient between the waist circumference and VFA by X-ray CT was lower in the obese group than that in non-obese group to suggest a strong influence of the SFA. The correlation coefficient between the VFA measured by dual-BIA and VFA by X-ray CT was showed at a high level even in the obese group to show that the influence of the SFA was reduced on VFA measurement.

We also investigated the influences of attributes: not only gender, which markedly reflects individual SFA variation, but also other attributes including age, which is generally used as an explanatory variable in BIA. In the algorithm below, age and gender were added to the parameters selected by AIC in the derivation. The correlation coefficient between VFA by X-ray CT and one by the new formula including gender and age was r=0.904. However, it is not significantly different from r=0.888 between X-ray CT and the original according to the statistical test. Based on the above findings, the dual impedance method physically measures the VFA without any attribute dependency.

The visceral fat accumulation should be evaluated as the volume. In our future study we will try to measure the VFV by the dual-BIA, and believe that this will be proper method.

V. Conclusions

In VFA measurement by dual-BIA described in this paper, the influences of the FFV and SFA were reduced, and the measured value was more accurate than the waist circumference. This method is based on BIA, but it is not dependent on age or gender. The proposed system employing the dual-BIA will be very useful in clinical practice because it measures the VFA in a simpler and more cost-effective way without X-ray exposure.

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