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Performance evaluation of the electrode configuration in bioelectrical impedance analysis for visceral fat measurement

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Abstract— **Excessive amount of visceral fat is considered as a crucial indicator for the metabolic syndrome (MS). Visceral fat area (VFA) at the umbilicus level measured by CT is adopted as the gold standard, but it has many limitations. Recently, Application of bioelectrical impedance analysis (BIA) for measuring VFA is widely used. However, the correlation between impedance and VFA is highly dependent on the measurement conditions. Therefore, we evaluate its measurement conditions here. In our experiment, we choose 5 different electrode configurations with changes of current and its frequency for evaluating its performance to distinguish fat and thin group with impedance. Our results indicated that electrode arrangement with fixed waist ratio is better in its performance than fixed distance electrode arrangement. Current electrode on each flank side is better than on the front and rear side. Shorter distance between current electrode and voltage electrode is better than longer distance in its performance. Our experiment results are presented.**

I. INTRODUCTION

In a recent study, Accumulation of central Obesity is considered as a major factor which can induce metabolic syndrome (MS). Much of Visceral fat area (VFA) is a major symptom of central obesity. In assessing VFA, CT scans at the umbilical level is adopted as gold standard; [1], [2] however, this method has its drawback, expensive, radiation exposure to subjects, so have difficulty in fellow up study.

There is a need for a simple and noninvasive method for estimating VFA. The bioelectrical-impedance analysis (BIA) method for estimating VFA is simple, noninvasive and thus its potential in VFA assessment is being studied widely. The BIA method flow a weak current through the body and estimate body composition by analyzing the impedance obtained. A current source supplies a constant known current through the test subject and voltmeter measures the voltage of the subject. The conductivity of subject's surface tissue is much lower than that of deep tissue, so when the current penetrates into the surface, most of it flows through the deep tissue [4], [5]. The total deep tissue impedance with tetra-polar electrode BIA method is given by the following equation:

$$Z = V/I$$

('Z' is the impedance; 'I' is the known current;
'V' is the voltage gained.)

Measurement conditions, such as body posture, electrode arrangement, and frequency are crucial to a result of impedance [6]-[9]. In our experiment protocols, we only focus on the electrode arrangement and frequency except body posture. Because supine posture is the same condition the gold standard CT. Therefore, we agreed supine posture is suitable than other posture to meet the same condition.

In our experiment, we adopted 4 pre-studied electrode arrangement methods and 1 developed method. Method 1 is our own developed method. This method is developed because most pre-studies usually arrange electrodes with fixed distance. We found fixed distance method is poor in distinguish fat and thin body because they differ in their waist circumferences. And we assumed that electrodes which arranged with the fixed ratio by waist circumference can be a solution to this problem. Method 2 is devised by Miwa Ryo et al [10]. Method 3 is devised by Masato Nagai et al [12]. Method 4 is devised by Taik-kyun Lim [13]. Method 5 is from M.Yoneda et al [11]. In each experiment, we changed frequency (25, 50, 100 KHz) and current (400, 600, 700 uA) to see how they affect the body impedance.

In this paper, we use 5 different electrode arrangement methods to evaluate its performance. The subjects were 6 healthy men volunteers who were measured for anthropometry parameters, and impedance. Impedance was measured by the tetra-polar impedance method using multi-frequency BI.

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II. Material and Method

A. Subjects

The study subjects were 6 healthy men (mean age ± S.D.: 28 ± 2 years, range: 26-29, men) recruited from students our University. We divide our subjects into three groups, fat, normal, and thin, on a basis of ATP III definition of the abdominal obesity [1]. For Asian population, except for Japan, waist circumferences ≥ 90 cm in men and ≥80 cm in women were regarded as abdominal obesity. Therefore, our subjects were classified by waist circumferences ≥ 90 cm as fat group, 80–90 cm normal, and ≤ 80 cm thin group. All subjects were fully informed of the procedures, and study protocol was approved by the Bioethics Committee of Yonsei University.

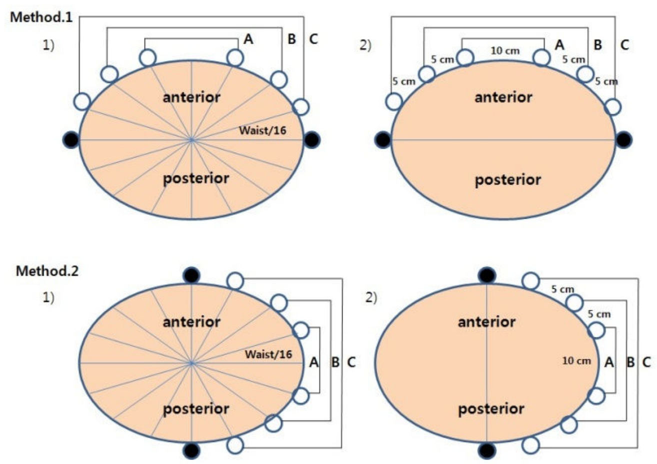

Fig. 1 Electrode arrangement method 1, 2

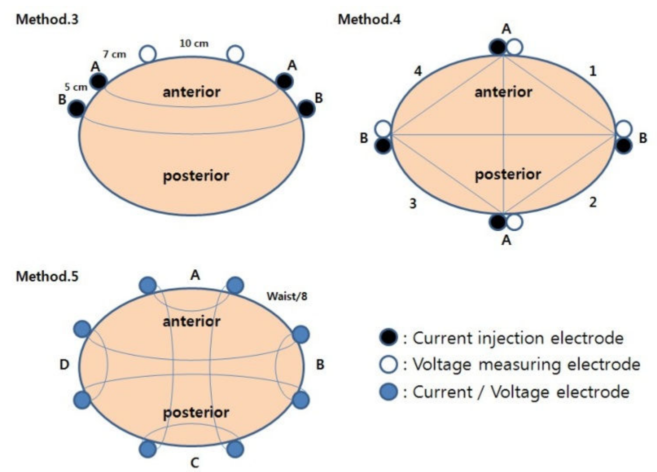

Fig. 2 Electrode arrangement method 3, 4, 5

B. Procedure

The study subjects were all prohibited from exercise, eating, and drinking before impedance measurement. They were taken physical examination which included height, body mass, Waist, Hip circumference (HIP), Sagittal abdominal diameter (SAD), and frontal abdominal diameter (FAD). Body mass index (BMI) was calculated as body mass (Kg) divided by the square of height (m). Waist-hip ratio (WHR) was calculated as W (cm) divided by HIP. Waist-height ratio (WHtR) was calculated as W (cm) divided by height. Impedance was measured with EBI- 100C (BIOPAC, USA) and also with our own developed device. Electrocardiography electrodes were used (Red Dot^{TM}, 3M Health Care, St. Paul, MN, USA)

Electrodes arrangement Method 1 is our developed method which for the comparison waist ratio distance with fixed distance electrode arrangement. We divide 1) and 2) in this method. Method 1 -1) is with the current electrodes on each flank and 6 Voltage electrodes are distributed with the waist ratio (waist/16) on the frontal of the umbilicus level. In Method 1 -2), we arrange current electrodes on the same position with 1 -1), but voltage electrodes were distributed with the fixed distance (5cm per each electrode).

Method 2 is with the current electrodes on the frontal and the rear side of the body and voltage electrodes distributed with the waist ratio (waist/16) on the right side of the body at the umbilicus level (Method 2 -1). We also divide 1) and 2) in this method. Method 2 -2) is with the current electrodes on the same position with Method 2-1) and voltage electrodes are distributed with the fixed distance (5cm per each electrode) on the right side of the body at the umbilicus level.

Method 3 is with the current electrodes on a fixed distance 7cm, and 12cm far from the voltage electrodes. And voltage electrodes are arranged 5cm from the navel in each. Method 4 mixes the first with second method. This method divides the whole abdomen impedance into subcutaneous fat impedances and visceral fat impedance. A, B are considered as the visceral fat impedances and 1-4 are considered as subcutaneous fat impedances. Method 5 is averaging method with the 8 electrodes on the waist ratio point (waist/8). This method measures the voltage on either side of Alphabet and injects current on outer side of each voltage electrodes. After getting voltage A through D, average its impedance to get abdomen averaging impedance value.

III. Results

A. Method 1 & 2

Fig. 3 shows the results from method 1, 2. Method 1 and 2 differ only from their current electrodes position. When we compare Fig.3 a) with c), a) distinguish each group more clearly than c). Therefore, we can conclude that current electrode on each flank side is better in their performance to distinguish fat and thin group than the current electrode on frontal and rear side of the body. Compare Fig.3 a) with b) and also c) with d), we also conclude that electrodes distributed with the waist ratio (waist/16) has better performance in distinction of fat and thin group than the fixed distance electrodes arrangement method. TABLE I shows their results.

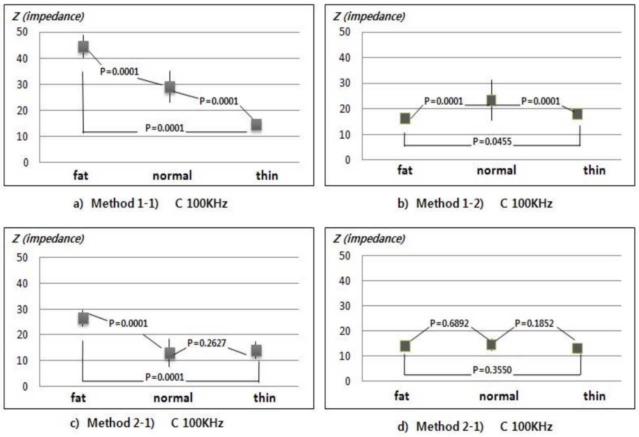

Fig. 3 Results of Method 1 & 2

We choose the best performance case in each experiment. Arrangement C and 100 KHz frequency was selected.

TABLE I
IMPEDANCE MEASURED BY METHOD 1, 2

Subject	Method 1-1	Method 1-2	Method 2-1	Method 2-2
Fat 1	40.1	15	29.7	15.3
Fat 2	48.82	17.19	23.42	12.89
Normal 1	35.18	31.22	18.5	16.67
Normal 2	23.09	15.41	7.65	12.32
Thin 1	13.15	18.73	17.49	13.84
Thin 2	16	16.85	10.9	12.5

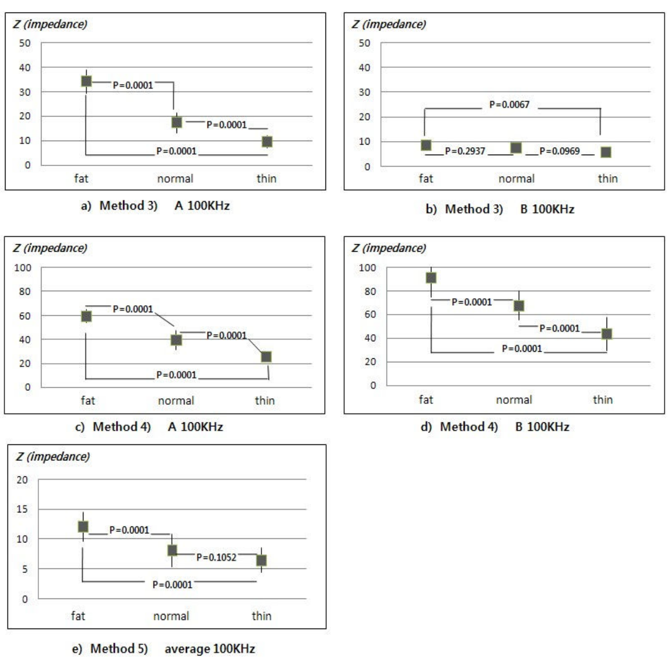

Fig. 4 Results of Methods 3, 4, and 5

B. Method 3

Fig. 4 a) b) shows the results from method 3. Method 3 was developed by Masato Nagai et al [12]. It uses four electrodes and simply arrange with fixed distance. The only difference in method A and B is the distance between current electrode and voltage electrode. 'A' method distinguishes fat and thin group more clearly than 'B'. From the results above, we conclude that the distance between current electrode and voltage electrode is the primary factor of their performance.

C. Method 4

Fig. 4 c), d) shows the results from method 4. Method 4 was devised by Taik-kyun Lim [13]. Method 4 A and B is different only from their current electrode position. 'A' is on the frontal and rear side of body. 'B' is on each flank. The distance between each electrodes of 'B' is somewhat longer than 'A'. In accordance with the distance difference, impedance is higher in 'B'. This method showed a good performance in distinction of fat and thin group. And the distinguish performance between 'A' and 'B' is not much different.

D. Method 5

Fig. 4 e) shows the results from method 5. Method 5 was devised by M. Yoneda et al [11]. This method uses 8 electrodes with the waist ratio (1/8 waist). It also showed a good performance in distinction of fat and thin group.

IV. Discussion & Conclusion

CT is the most well known and trusted method for measuring VFA. However, it costs much and involves radiation exposure problem. BIA method is simple and noninvasive for measuring VFA. But, the correlation between impedance and VFA is dependent on the measurement conditions [6]-[9].

We have evaluated performances of 5 different electrodes arrangement methods which widely used in BIA for visceral fat measurement. And we also applied current (400-700uA) and frequency (25 KHz, 50 KHz, 100 KHz) changes in each method. Result showed that, in view of performance to distinguish fat and thin group, the influence according to these changes seemed not so much. On the contrary, Electrodes arrangement made a different result in its performance to distinguish fat and thin group only with impedances.

Electrode arrangement in accordance with waist ratio is better in its performance than an arrangement with fixed distance. Current electrode on each flank side is better in its performance than on the front and rear side. Shorter distance between current electrode and voltage electrode is better in its performance than longer distance.

We can apply these results to develop a superior electrode arrangement method. For future study, we will develop a regression equation with more experiments according to ages, body shapes. And we hope to make a superior portable system to measure VFA.

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