Original Article
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Obesity

Early Changes of Abdominal Adiposity Detected with Weekly Dual Bioelectrical Impedance Analysis during Calorie Restriction

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Objective: To elucidate early change of intra-abdominal fat in response to calorie restriction in patients with obesity by weekly evaluation using a dual bioelectrical impedance analysis (Dual BIA) instrument.

Design and Methods: For 67 Japanese patients with obesity, diabetes, or metabolic syndrome, intra-abdominal fat area (IAFA), initially with both Dual BIA and computed tomography (CT), and in subsequent weeks of calorie restriction, with Dual BIA were measured.

Results: IAFA by Dual BIA (Dual BIA-IAFA) correlated well with IAFA by CT (CT-IAFA) in obese patients ($r = 0.821$, $P < .0001$, $n = 67$). Ten males and 9 females (age 49.0 ± 14.4 years, BMI 33.2 ± 7.3 kg/m^2) lost more than 5% of baseline body weight (BW) in 3 weeks, and their Dual BIA-IAFA, BW, and WC decreased by 18.9%, 5.3%, and 3.8%, respectively ($P < .05$, ANCOVA).

Conclusion: Dual BIA instrument could detect the weekly change of Dual BIA-IAFA under calorie restriction in obese patients and demonstrated a substantially larger change of IAFA compared with changes of BW and WC in early weeks. This observation corroborates the significance of evaluating IAFA as a biomarker for obesity, and indicates the clinical usefulness of the Dual BIA instrument.

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Introduction

Abdominal adiposity is associated with development of obesity and metabolic abnormalities in obesity-related diseases (1-3). The adipose tissue distribution has been quantitatively evaluated by computed tomography (CT) (4) or magnetic resonance imaging (MRI) (5), and intra-abdominal fat area (IAFA) is used as a clinical parameter of abdominal adiposity (6). Although waist circumference (WC) is casually employed to evaluate abdominal adiposity (7), WC is known to reflect both the intra-abdominal and the subcutaneous abdominal adiposity. In addition, the correlation of WC with intra-abdominal adiposity is influenced by age and sex as shown in epidemiological studies (5). Thus, WC does not necessarily provide the precise information about abdominal fat distribution. Therefore, a new practical method for detecting early change in abdominal adiposity is needed to elucidate its consequence during acute phase of calorie restriction in obesity treatment (8). There have been a few proposals of methods (9,10) that assess IAFA as alternatives to CT (4) or MRI (5). However, there has been no report on clinical application of these methods analyzing the weekly change of IAFA during calorie restriction. We have developed the dual bioelectrical impedance analysis (Dual BIA) instrument that can determine IAFA by measuring truncal impedance and surface impedance at the abdomen separately, each of which reflects the truncal adiposity and the subcutaneous adiposity respectively (11-13). The Dual BIA instrument has been optimized with aims at robustness for use in a wide range of human variation by analyzing the size of effect that each parameter, such as age and gender, can have on the calculation outcomes utilizing information technology (11-13). In this study, we report on application of the Dual BIA instrument to compare the weekly change in IAFA and body weight (BW) of obese patients with the metabolic syndrome or diabetes mellitus resulting from calorie restriction.

Methods

Dual BIA method and instrumentation

Dual BIA instrument calculates the cross-sectional area of intra-abdominal fat at the level of umbilicus based on the measurement of electrical potentials resulting from applying small electrical currents in two different body space. Principles of IAFA determination by Dual BIA instrument have been described previously (11-13) in detail. Briefly, the Dual BIA instrument consists of bioelectrical impedance

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component that measures truncal and surface impedance of the body, and a device that measures physical size of the abdomen. The two sets of electrodes are for limb and truncal placement. The limb electrodes consist of four clip-on electrodes placed on wrists and ankles. The truncal electrodes are eight pairs of electrodes 6 cm apart longitudinally that are fixed to a belt where four pairs each for front and back are positioned at an equal inter-electrode distance. The belt is adjustable so that the electrodes are positioned centered on mid-sagittal line at the level of umbilicus in supine position. The truncal impedance is measured by applying electrical currents between upper and lower limb leads and reading voltage from the electrodes around the abdominal circumference. The surface impedance is measured by applying and reading voltage from the abdominal circumferential electrodes. IAFA by Dual BIA (Dual BIA-IAFA) is calculated as follows.

$$\text{Dual BIA} - \text{IAFA} = \alpha_1 A + \alpha_2 B^2 - \alpha_3 \left(A^2 + B^2\right)^{1/2} Z_s - \alpha_4 / Z_t + \varepsilon \quad (1)$$

A: abdominal antero-posterior diameter, B: abdominal transverse diameter, Z_s: surface impedance, Z_t: truncal impedance, ε: residual constant.

There was a good agreement of Dual BIA-IAFA and IAFA measured by CT (CT-IAFA) with the correlation coefficient of 0.888 ($n = 98$, $P < .001$) (13).

Patient selection

The study was performed according to the protocol approved by Kyoto University Medical Ethics Review Board (no. 080116). The patient gave a written consent to participate in this study which took place at the endocrinology and metabolism ward of Kyoto University Hospital. We collected data from 67 Japanese patients (36 males and 31 females; mean ± SD age, 54.7 ± 14.7 years, BMI 29.3 ± 6.5 kg/m^2) with obesity ($n = 56$), diabetes mellitus ($n = 45$), or the metabolic syndrome ($n = 38$) who were hospitalized for calorie restriction therapy or diet education, and had measurement of IAFA by both Dual BIA method and CT method at the start of calorie restriction. Obesity was diagnosed as BMI 25.0, and metabolic syndrome was diagnosed according to 2005 Japanese criteria of metabolic syndrome (14). Average daily calorie intake was 1437.3 ± 201.4 kcal/day (19.3 ± 4.3 kcal/ideal BW). Out of 67 patients, 35 patients could be followed for longer than 3 weeks, while the other patients were discharged earlier after examination of complications and diet and lifestyle education. Total daily energy was varied individually during hospitalization based on consultation between the patient, a dietician, and a physician. Out of 35 patients who had their Dual BIA-IAFA monitored every week for at least 3 weeks (four times), 19 patients lost more than 5% of baseline BW, and were included in the analysis of weekly change in Dual BIA-IAFA, WC, and BW during weight reduction.

Measurement of Dual BIA, CT, and anthropometric parameters

Dual BIA-IAFA was measured every week in the morning before breakfast depending on individual patient's treatment schedule (Figure 1A). Abdominal CT was performed for calculation of CT-IAFA within 7 days before the initial Dual BIA-IAFA measurement. CT-IAFA was calculated at umbilical level by the software, Virtual Place Lexus (AZE of Japan, Ltd). BW was measured to the nearest 0.1 kg in the morning of the Dual BIA-IAFA measurement.

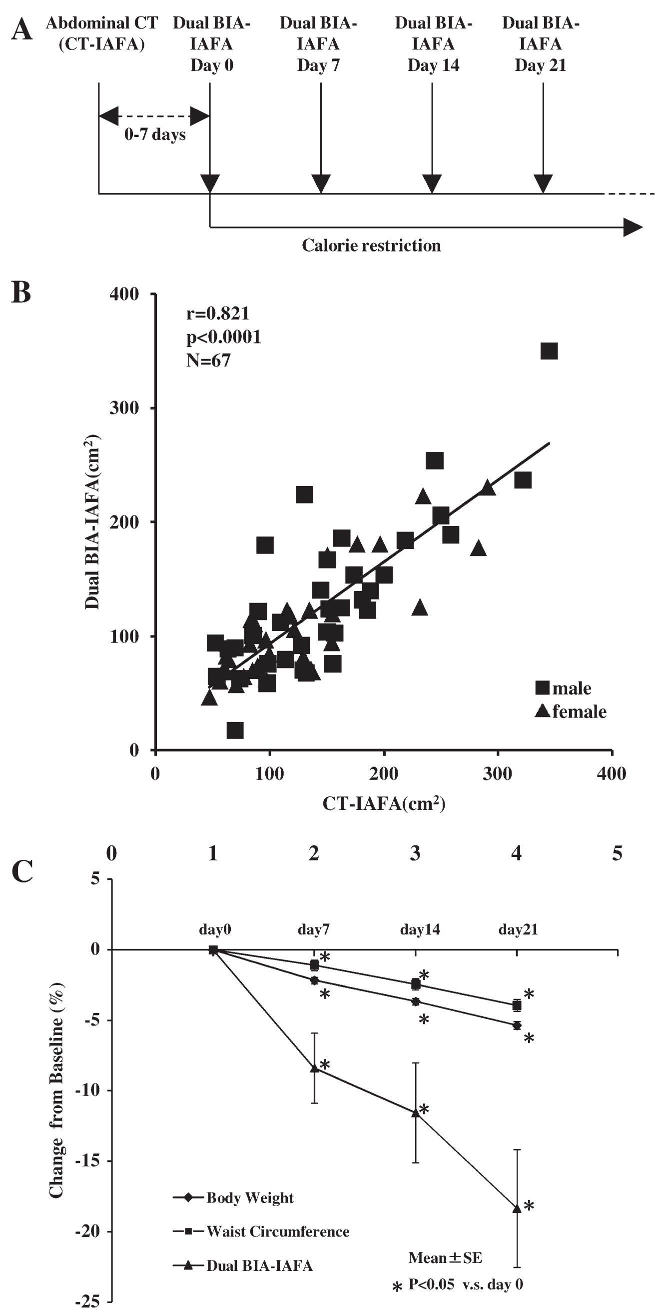

FIGURE 1 A: Diagram of IAFA assessment schedule during the calorie restriction. Patients started fixed calorie diet within 7 days of taking the abdominal CT image. Dual BIA-IAFA assessment took place in the morning before meal every week. CT imaging took place either in the morning or in the afternoon. **B**: Correlation between CT-IAFA and BIA-IAFA in 67 patients who were with obesity-related disorders. Square symbols: male, Triangle symbols: female. $r = 0.821$, $P < .001$ by Pearson's analysis. **C**: Weekly change of Dual BIA-IAFA plotted along with BW and WC during weight loss. Nineteen patients who underwent the calorie restriction and had abdominal CT examined at baseline were monitored for their anthropometric parameters and Dual BIA-IAFA weekly for at least 3 weeks. They lost more than 5% of BW during the period. Size of the change from baseline values (mean ± SE) is expressed as %. *$P < .05$ by Student's paired t-test.

WC was measured at the level of the umbilicus to the nearest 0.1 cm in the standing position at the end of expiration while breathing gently at the time of Dual BIA measurement.

Statistical methods

Correlation between values obtained by Dual BIA and CT were evaluated using Pearson's correlation analysis. Weekly values of Dual BIA-IAFA, BW, and WC were compared with the baseline values of day 0 by Student's paired *t*-test. Analysis of covariance was applied for comparison of Dual BIA-IAFA, BW, and WC at week 3.

Results

In 67 patients with obesity and related conditions, Dual BIA-IAFA correlated well with CT-IAFA ($r = 0.821$, $P < .0001$) (Figure 1B).

Thirty-five (17 males and 18 females) out of 67 patients were monitored with Dual BIA for longer than 3 weeks, and 19 (10 males and 9 females) out of 35 patients achieved weight loss of more than 5% of the initial BW. In order to elucidate the change in IAFA during weight loss, Dual BIA-IAFA, BW, and WC of the 19 patients were analyzed. Baseline characteristics of the 19 patients were (mean ± SD); age, 49.0 ± 14.4 years, height 163.0 ± 10.5 cm, BMI 33.2 ± 7.3 kg/m^2, and CT-IAFA 143.6 ± 47.4 cm^2. BW, WC, and Dual BIA-IAFA at baseline and at week 3 were: 89.2 ± 26.2 kg and 84.5 ± 25.1 kg, 110.6 ± 14.1 cm and 106.0 ± 14.2 cm, and 150.4 ± 73.7 cm^2 and 124.3 ± 70.3 cm^2, respectively.

Figure 1C shows the weekly change of Dual BIA-IAFA, BW, and WC in 19 patients whose BW decreased more than 5% during the 3 weeks of monitoring. Dual BIA-IAFA, BW and WC showed a significant reduction after 1 week during the calorie restriction compared with the baseline values ($P < .05$). Dual BIA-IAFA decreased every week for the initial 3 weeks and the average reduction in Dual BIA-IAFA was 18.9%, which was larger than in BW (5.3%) and WC (3.8%) (ANCOVA, $P < .05$).

Discussion

The present study demonstrates that the weekly change in IAFA can be detected with the Dual BIA instrument during the calorie restriction. Due to the practical limitations such as instrumentation and cost, CT and MRI are unsuitable for weekly monitoring of change in IAFA. There is also a problem of X-ray exposure in CT scanning. Consequently, it has been impractical to monitor IAFA weekly or frequently, in clinical follow-up period with CT or MRI. There have been several attempts to evaluate the IAFA by BIA (9-13). They include calculation from whole body impedance and from measuring abdominal impedance by the electrodes placed on the abdomen (9,10). Some of the estimates of IAFA incorporate gender and age of the subject in order to attain high correlation with CT (9,10). In contrast, Dual BIA, which is a method that is not dependent on external variables, such as gender or age, had shown a good correlation between Dual BIA-IAFA and CT-IAFA (11-13). In the present study, we confirmed the good correlation of Dual BIA-IAFA and CT-IAFA in obese patients. The correlation coefficient for the Dual BIA-IAFA and CT-IAFA was 0.821 ($n = 67$) with our subjects whose average BMI was 29.3. This indicates that Dual BIA produced reliable measurements with obesity patients and the result was comparable to the correlation coefficient of 0.888 obtained with subjects whose average BMI was around 25 (13). It must be noted that CT-IAFA and Dual BIA-IAFA was not measured on the same day in the present study, unlike the previous report in which Dual BIA- and CT-IAFA was taken on the same day (13), and therefore direct comparison has its limitations. By applying Dual BIA to monitoring the weekly change of individual body component during the calorie restriction, we could detect the characteristic change of IAFA. The significant decrease in Dual BIA-IAFA, BW, and WC at week 1 supports the suitability of selecting 5% of BW change at week 3 as a criterion for including in weekly analysis of these parameters.

On average, IAFA showed a larger reduction than BW and WC during the initial 3 weeks of calorie restriction. The rapid response of intra-abdominal adipose tissue to calorie restriction has been suggested in an ultrasonography study that examined a portion of peritoneal fat thickness (15). The larger decrease of Dual BIA-IAFA observed is also in agreement with a study which showed larger reduction in IAFA evaluated with MRI than that of BW up to 12 weeks on very low calorie diet (16). Together with these results, the present study established that the intra-abdominal fat decreases rapidly in the initial period of calorie restriction by measuring Dual BIA-IAFA, and demonstrates the usefulness of monitoring the change in IAFA during the treatment of obesity and its related disorders.

Weakness of our study is that its design was not of a prospective weight reduction where every participant was prescribed daily calorie that could produce predetermined level of weight loss within the study period. Instead we selected participants that had their weight decreased by at least 5% in order to illustrate the change in abdominal adiposity on weekly basis. It is also of note that the BW and Dual BIA-IAFA at week 1 may be affected by salt restriction and loss of body water that is observed early in calorie restriction. Because of the small sample size, the observed change in Dual BIA-IAFA could be larger than actual change. It also depends on the precision of the instrument. In a separate population, the coefficient of variation was 7.6% (Ida, M. manuscript in preparation).

In conclusion, the present study demonstrated that Dual BIA instrument can be used to measure IAFA in obese patients, allows frequent measurement, and is useful for detecting the early change in IAFA during calorie restriction. Information thus obtained along with other changes in metabolic parameters will be indispensable for understanding the role of abdominal adiposity, and especially useful as a diagnostic marker for monitoring obesity and its related disorders (1). In addition, the instrument's safety and convenience could be suitable for large population studies. O

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