Evaluation of Body Composition Using Dual-energy X-ray Absorptiometry, Skinfold Thickness and Bioelectrical Impedance Analysis in Japanese Female College Students

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Summary We compared three methods for evaluating body composition: dual-energy X-ray absorptiometry (DXA), skinfold thickness (Skinfolds), and bioelectrical impedance analysis (BIA). Subjects were 155 healthy young college-aged Japanese females whose mean±SD (range) age, body height, body weight and body mass index (BMI) were 20.1±0.3 (19.6–21.1) y, 158.9±4.7 (145.4–172.6) cm, 52.0±6.8 (39.4–84.6) kg and 20.6±2.3 (16.5–32.5), respectively. Their mean skinfold thickness at the triceps and subscapular were 16.9±4.7 (8.0–31.0) and 16.0±5.7 (7.0–40.0) mm, respectively. Mean body fat mass percentages evaluated by DXA, Skinfolds and BIA were 29.6±5.1, 22.8±5.3 and 25.8±4.7%, respectively. Body fat mass was 15.4±4.4, 12.1±4.5 and 13.6±4.5 kg, respectively. Simple correlation coefficients between the three methods for body fat mass percentages provided the following coefficients: r=0.741 for DXA vs. Skinfolds, r=0.792 for DXA vs. BIA and r=0.781 for Skinfolds vs. BIA. Simple correlation coefficients for body fat mass were as follows; r=0.898 for DXA vs. Skinfolds, r=0.927 for DXA vs. BIA and r=0.910 for Skinfolds vs. BIA (all p<0.001). There were significant differences in the values among the three methods with the Skinfolds providing the lowest body fat mass and percentage, and DXA the highest (p<0.001). They all appear to be strongly correlated for evaluating body composition; however, different cut-off values for defining obese and lean need to be defined for each method.

Key Words skinfold thickness, bioelectrical impedance, dual-energy X-ray absorptiometry, body composition, Japanese female college student

While the importance of body composition measurements for the assessment of nutritional status is well recognized, the methods available for this measurement are widely variable. They include the traditional technique of underwater weighing (UWW) as well as newer technologies such as nuclear magnetic resonance (NMR), computerized tomography (CT) and dual-energy X-ray absorptiometry (DXA). Each method has its advantages and problems. For instance the skinfold thickness (Skinfolds) measurements are based on UWW and are convenient for general population surveys, but have less precision than other methods because the method is more reliant on operator technique. NMR, CT and DXA provide more information about body composition (for example bone mineral content, soft tissue (fat and lean) mass volume in total body and/or body region) than Skinfolds but are inconvenient and expensive for general population surveys. Bioelectrical impedance analysis (BIA) is a technique for estimation of body composition; however, there has been considerable discussion on its reliability (1). BIA is a convenient method which has less technical error than Skinfolds, and its increasing availability could make it a suitable instrument for population-based surveys.

Gutin et al. (2) reported there were significant differences for body fat mass percentages in 9–11-y-old children measured by DXA, Skinfolds and BIA. These results indicated that factors considered to be contributing to the change in body weight and body composition in longitudinal observations may need to be included along with individual variation, because of differences in physical activity, nutritional status and other, but also the method of measurement.

We conducted a comparative study using DXA, Skinfolds, and BIA for the evaluation of body composition in Japanese female college students.

SUBJECTS AND METHODS

Subjects. Subjects were 155 Japanese female college students aged 19–20 years old. Their physical characteristics and skinfold thickness are shown in Table 1.

Methods
Dual-energy X-ray Absorptiometry (DXA). The basic theory of measurement and the methodology for DXA technology have been described in detail elsewhere (3). For this study all DXA measurements were performed with a whole-body scanner operated in the single-beam configuration with version 7.10B software (QDR-2000;
Skinfold thickness (Skinfolds). Skinfold thickness measurements for estimating body composition for Japanese subjects were based upon the Nagamine and Suzuki model (4). The measurements were made on the right side of the body with an EIKEN Skinfolds (Eiken Kagaku Co., LTD., Tokyo, Japan) at two sites: the triceps and subscapular. The same person performed all skinfold measurements.

Bioelectrical Impedance Analysis (BIA). Body weight and body fat mass percentages were measured simultaneously with the subjects in the standing position using a TBF 102 model (Tanita Corp., Tokyo, Japan). Estimations of body fat mass percentages were calculated from an equation based on body density measured by underwater weighing. This model has been described in detail elsewhere (5).

Body weight measurement. We measured body weight three times in this study. First, body weight was measured by an electric balance scale (TKK-442a: Takei Corp. Niigata, Japan) for skinfold thickness, and the data was used to calculate body fat mass and free fat mass based on Brozek’s equation (6). Secondly for BIA, the BIA instrument used in this study measured body weight simultaneously with calculating body composition. Thirdly for DXA measurement, body weight was calculated as the sum of the total soft tissue and bone mineral mass values. Body weight was measured with subjects wearing a T-shirt and training shorts without shoes on each of the occasions.

Measurements for the three methods for one subject were conducted on the same day.

Statistical analysis. The data are presented as mean±SD. Statistical analyses were performed by using Super ANOVA 1.1 and Stat View 4.0(J) software packages (Abicus Concepts Inc, Berkeley, CA, USA).

This study was conducted in conformity with the Declaration of Helsinki: Subjects were recruited only after being informed of the protocol and methods.

RESULTS

The data on body weight, body fat mass, body fat free mass, body fat mass percentages and body fat free mass percentages obtained using the three methods are shown in Table 2. Results of one way analysis of variance (ANOVA) and one way repeated measures analysis of variance (RM-ANOVA) among the methods are shown in Table 3. Body weight from the DXA, Skinfolds and BIA measurements were 51.3±6.8, 52.0±6.9 and 51.6±6.9 kg, respectively. There was no significant difference among the three measurement methods when the data were analyzed by one way ANOVA. However, there was a significant difference in the data obtained from the three measurement methods when the data were analyzed by one way RM-ANOVA. The body fat mass estimated by DXA, Skinfolds and BIA were 15.4±4.4, 12.1±4.5 and 13.6±4.5 kg, and the body fat percentages estimated by DXA, Skinfolds and BIA were 29.6±5.1, 22.8±5.3 and 25.8±4.7%, respectively. The body fat free mass estimated by DXA, Skinfolds and BIA were 35.9±3.6, 39.9±3.7 and 38.0±3.1 kg and the body fat free mass percentages estimated by DXA, Skinfolds and BIA were 70.4±5.1, 77.2±5.3 and 74.3±4.7%, respectively. There were significant differences among the three methods: the lowest values for body fat mass and

Table 1. Physical characteristics of the subjects (Japanese female college students, n=155).

|                      | mean±SD | Min. | Max. |
|----------------------|---------|------|------|
| Age (y)              | 20.1±0.3| 19.6 | 21.1 |
| Body height (cm)     | 158.9±4.8| 145.4| 172.6|
| Body weight (kg)     | 52.0±6.9| 39.4 | 83.6 |
| Body mass index (BMI)| 20.6±2.3| 16.7 | 32.7 |
| Skinfold thickness (mm) |       |      |      |
| Subscapular          | 16.0±5.7|  7.0 | 40.0 |
| Triceps              | 16.9±4.7|  8.0 | 31.5 |
| Sum                  | 33.0±9.5| 17.5 | 71.0 |

Table 2. Results of the body composition measured by DXA, Skinfolds and BIA methods (Japanese female college students, n=155).

| Body weight (kg) | Mean±SD | Min. | Max. |
|------------------|---------|------|------|
| DXA              | 51.3±6.8| 38.7 | 82.9 |
| Skinfolds        | 52.0±6.9| 39.4 | 83.6 |
| BIA              | 51.6±6.9| 38.7 | 83.0 |

| Body fat mass (kg) | Mean±SD | Min. | Max. |
|--------------------|---------|------|------|
| DXA                | 15.4±4.4|  8.2 | 34.4 |
| Skinfolds          | 12.1±4.5|  6.1 | 37.6 |
| BIA                | 13.6±4.5|  7.8 | 39.3 |

| Body fat free mass (kg) | Mean±SD | Min. | Max. |
|-------------------------|---------|------|------|
| DXA                     | 35.9±3.6| 28.0 | 50.4 |
| Skinfolds               | 39.9±3.7| 32.2 | 56.0 |
| BIA                     | 38.0±3.1| 30.6 | 49.3 |

| Body fat mass percentage (%) | Mean±SD | Min. | Max. |
|-----------------------------|---------|------|------|
| DXA                         | 29.6±5.1| 17.7 | 41.5 |
| Skinfolds                   | 22.8±5.3| 14.3 | 45.0 |
| BIA                         | 25.7±4.7| 16.9 | 47.3 |

| Body fat free mass percentage (%) | Mean±SD | Min. | Max. |
|-----------------------------------|---------|------|------|
| DXA                               | 70.4±5.1| 58.4 | 82.2 |
| Skinfolds                         | 77.2±5.3| 55.0 | 85.7 |
| BIA                               | 74.3±4.7| 52.7 | 83.1 |

DXA: dual-energy X-ray absorptiometry, Skinfolds: skinfold thickness, BIA: bioelectric impedance analysis.
Table 3. Results of one way ANOVA and one way repeated measures ANOVA for body composition measurement (Japanese female college students, n=155).

|                    | One way ANOVA | One way repeated measures ANOVA |
|--------------------|---------------|---------------------------------|
|                    | F value       | p value                         | F value     | p value     |
| Body weight        | 0.34          | 0.7151                          | 234.1       | <0.001      |
| Body fat mass      | 21.03         | <0.001                          | 238.0       | <0.001      |
| Body fat mass      | 70.05         | <0.001                          | 301.4       | <0.001      |
| percentage         |               |                                 |             |             |
| Body fat free mass | 48.73         | <0.001                          | 312.7       | <0.001      |
| percentage         | 70.06         | <0.001                          | 301.3       | <0.001      |

1: There were significant differences between DXA vs. Skinfolds, DXA vs. BIA and Skinfolds vs. BIA by Bonferroni/Dunn. All p values <0.01.

DXA: dual-energy X-ray absorptiometry, Skinfolds: skinfold thickness, BIA: bioelectric impedance analysis.

There were significant differences between DXA vs. Skinfolds, DXA vs. BIA and Skinfolds vs. BIA by Bonferroni/Dunn. All p values <0.01.

DXA: dual-energy X-ray absorptiometry, Skinfolds: skinfold thickness, BIA: bioelectric impedance analysis.

There were significant differences among the three methods; the lowest values for body fat free mass and body fat free mass percentages were obtained from the DXA, the highest from Skinfolds by one way ANOVA, and Bonferroni/Dunn test (p<0.001). There were significant differences among the three methods by RM-ANOVA.

The distribution of body fat mass percentages by three methods is shown in Fig. 1 with a clearly normal distribution of data obtained by the DXA measurement. The smallest median value was obtained from Skinfolds and the largest was from DXA.

Simple correlation coefficients between each pair of the three methods are shown in Table 4. There were strong simple correlation coefficients among these three methods for body fat mass percentages and for body fat mass (all, p<0.001). Also, simple correlation coefficients among them for body fat free mass and body fat free mass percentages were obtained (all, p<0.001).

**DISCUSSION**

The Skinfolds method was established by Nagamine and Suzuki in 1960, and Yamagishi et al. demonstrated significant differences in the data on body fat composition in young Japanese females between the Skinfolds and UWW (7). This may be due to an increase in body fat mass in Japanese females (8) because of the current lifestyle of less physical activity compared at the time when the model was developed. Apparently the Nagamine and Suzuki model cannot accommodate this change.

BIA is a newer and more reliable measurement of body fat compared to Skinfolds (9, 10). The accuracy of this method has been reported previously using comparisons with DXA, which have shown high correlation between the estimates of body composition by the two methods (11). Ellis compared data obtained from BIA and DXA, and showed a significant difference for body fat mass percentages; however there was a strong correlation for body fat mass percentages in healthy children and young adults aged 5–22 years old (12). Yamagishi et al. reported that the data obtained from Skinfolds showed the lowest body fat mass and body fat mass per-

|                    | Body weight | Body fat percentage | Body fat mass | Body fat free mass |
|--------------------|-------------|---------------------|---------------|-------------------|
| DXA vs. Skinfolds  | 0.999       | 0.741               | 0.898         | 0.837             |
| DXA vs. BIA        | 0.999       | 0.792               | 0.927         | 0.879             |
| Skinfolds vs. BIA  | 0.998       | 0.781               | 0.911         | 0.844             |

DXA: dual-energy X-ray absorptiometry, Skinfolds: skinfold thickness, BIA: bioelectric impedance analysis. All p values <0.001.
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percentage compared with BIA and UWW. While there was no significant difference in the data for body fat mass and body fat mass percentage obtained from BIA and UWW in healthy young Japanese females aged 19–22 years old (13).

While it is also known that DXA provides more acute values about body composition than BIA, there are also problems with standardization. For instance Van et al. (14) and Ellis et al. (15) reported that different versions of DXA software demonstrated differences in total body composition, lean and fat tissue distribution and bone measurement.

The results reported here have also found significant difference among the three methods for Japanese female college students. However, each of the methods correlated strongly with the others and therefore all appear to be suitable for evaluation of body fat mass. It is important to consider the different results for body composition were caused by each of the methods. Because there is no golden standard method for the evaluation of body composition and especially body fat mass percentage, it is not possible to identify the most accurate method.

DXA, Skinfolds and BIA all appear to be strongly correlated for estimating body composition although different cut-off values for obese and lean differentiation are need to be defined for each method. While Skinfolds and BIA are suitable for population studies because of their simplicity, DXA provides more accurate values and detailed information about body composition.

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