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Comparison of Body Composition Measurement With Whole Body Multifrequency Bioelectrical Impedance and Air Displacement Plethysmography in Healthy Middle-Aged Women

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Our purpose was to evaluate accuracy of multifrequency bioelectrical impedance analysis (MFBIA) using air displacement plethysmography (ADP) as the criterion measure. Body composition of 27 women was assessed by ADP followed immediately by MFBIA. There was a strong relationship ($p = .01$) between ADP and MFBIA in absolute lean mass ($r = 0.80$), absolute fat mass ($r = 0.99$), percent lean mass ($r = 0.91$), and percent fat mass ($r = 0.91$). Although MFBIA consistently overestimated lean mass and underestimated fat mass compared with ADP, agreement between measurements was within 2%–3% body fat. An accurate assessment tool, MFBIA can be useful in clinical settings.

Women are at high risk for loss of muscle and gains in fat with age (Hughes, Frontera, Roubenoff, Evans, & Singh, 2002; Janssen, Heymsfield, Wang, &

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Ross, 2000; Sowers et al., 2005). It is important for women to understand that even during periods of weight stability, loss of lean mass and gains in fat mass may be occurring. This phenomenon ultimately will result in sarcopenic obesity unless reversed. In fact, current statistics from the World Health Organization indicate that the worldwide prevalence of overweight and obesity in women exceeds that of men (Low, Chin, & Deurenberg-Yap, 2009). Early assessment and identification can be critical for successful interventions. Although calculation of body mass index (BMI) is considered to be sufficient for assessment of obesity, measurement of body composition provides more complete data regarding both fat and lean mass. Body composition measurement is useful for on-going assessment of obesity and sarcopenia, both of which are linked to health problems leading to early disability and mortality (Janssen, Baumgartner, Ross, Rosenberg, & Roubenoff, 2004; Janssen, Heymsfield, & Ross, 2002; Lebrun, van der Schouw, de Jong, Grobbee, & Lamberts, 2006; Vincent, Vincent, & Lamb, 2010; Walter, Kunst, Mackenbach, Hofman, & Tiemeier, 2009; Whitlock et al., 2009). Accurate evaluation of body composition is a valuable clinical tool for assessment and management of women's health care.

Measurement of body composition has clinical advantages but can be difficult in a clinical setting due to lack of access to laboratory equipment used for assessment of body composition, including hydrodensitometry, dual X-ray absorptiometry (DEXA), and ADP. Hydrodensitometry (underwater weighing) historically has been considered the *gold standard* of body composition measurement (Thompson et al., 1991). It is problematic due to its extremely high participant burden, however, including the need to remove clothing, enter a tank of water, and completely submerge oneself with air expelled from the lungs for the measurement period. Both DEXA and ADP provide less burdensome alternatives that have been validated against hydrodensitometry (Levenhagen et al., 1999). In particular, ADP has been found to agree with hydrodensitometry within 1% body fat in both lean and obese adults (Fields, Goran, & McCrory, 2002). Unfortunately, although use of ADP decreases participant burden, it is costly and its use in field settings remains problematic due to portability issues (Going, 2005).

For clinical assessment outside of laboratory settings, a portable body composition measure is needed that is both accurate and does not overly burden participants. Skinfolds have been used for body composition measurement in field settings. Access is needed to multiple sites on the body, however, so disrobing, at least partially, is necessary. This can increase the overall burden of testing by increasing the time needed for measurement and potentially causing stress and embarrassment in clients. Further, skinfold accuracy involves a level of subjective measurement and can be influenced by the technique of the practitioner (Ball, Swan, & Altena, 2006). To improve accuracy prior to the clinical use of skinfold measurement, it is recommended that practitioners complete *at least* 50–100 practice measurements (Ball et al., 2006). Finally, accuracy of skinfold measurements has been found to have a significant gender bias in different populations (Marini et al., 2007; Steiner, Barton, Singh, & Morgan, 2002).

Bioelectrical impedance provides a feasible alternative that can be useful for clinicians. It is both portable and involves minimal burden. Whole body single-frequency bioelectrical impedance analysis has been found to be accurate for estimation of body composition when compared with ADP (Levenhagen et al., 1999; Sardinha, Lohman, Teixeira, Guedes, & Going, 1998). A newer technology, whole body MFBIA is now available that can be used to estimate hydration status as well as body composition.

To our knowledge, only one study has evaluated the use of whole body MFBIA against ADP in healthy adults. Frisard and colleagues (2005) compared measurements of body composition in obese men and women before and after weight loss. Multifrequency bioelectrical impedance analysis (MFBIA) was found to be accurate, although it underestimated relative (%) and absolute (kg) body fat, and it overestimated lean mass (kg) compared with ADP. However, agreement between MFBIA and ADP measurements of both fat and lean mass was strong ($r^2 > 0.8$; Frisard, Greenway, & Delany, 2005).

Although the findings of Frisard and colleagues (2005) support the clinical use of whole body MFBIA for evaluation of changes in body composition over time, we believe more work is needed. Steiner and colleagues (2002) have identified a possible gender bias in estimation of lean mass with the use of bioelectrical impedance. Since the principle of MFBIA is based on the resistance of muscle to the flow of electricity, it may be prudent to evaluate women and men separately due to differences in lean mass. Therefore, the purpose of our study was to evaluate agreement between whole body MFBIA and ADP in measurement of lean and fat mass in a single group of healthy, middle-aged women.

METHODS

Participants

After completion of informed consent, 27 healthy women between 40 and 55 years old (Table 1) completed body composition measurement with ADP

TABLE 1 Participant Characteristics

Age (years)	46.3 ± 0.9
Body mass (kg)	67.58 ± 2.1
BMI (kg/m²)	25.7 ± 0.8
WC (cm)	69.9 ± 4.5

Data presented as mean ± SE.
BMI = body mass index; WC = waist circumference.

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immediately followed by MFBIA. All denied smoking or physician diagnosis of diabetes, heart disease, or any other major illness.

Anthropometric Measurement

All testing was conducted in the early morning, between 5:00 and 8:00 a.m. Participants were instructed to report to the testing center immediately after arising, without engaging in any unnecessary activity and in a well-hydrated state without having consumed food for at least 8 hours.

Prior to testing, measurements of height and waist circumference were obtained for all participants. All measurements were completed by the same researcher. Height was measured to the nearest 0.25 cm using a standard, wall-mounted stadiometer (Seca, Hanover, MD). For measurement, participants removed their shoes and aligned their backs against the wall with their heads erect. Waist circumference was measured to the nearest 0.25 cm at the level of the umbilicus using a Gulick tape measure (Creative Engineering, Plymouth, MI) to ensure constant tension.

Weight was measured in kilograms using a calibrated computerized scale (Life Measurement Instruments, Inc., Concord, CA, USA) during body composition measurement with ADP. Participants wore minimal clothing (bathing suit or exercise bra and shorts) and were asked to void prior to the procedure.

Body mass index (BMI) was calculated after completion of measurements using the formula:

$$\text{Weight}\,(\text{kg}) \div \text{Height}\,(\text{m}^2).$$

Air Displacement Plethysmography

Lean and fat mass were first measured with ADP (Bod Pod®, Life Measurement Instruments, Inc., Concord, CA, USA) using the Siri equation (Going, 2005) provided by the manufacturer. Lung volumes were predicted. Prior to each test, the Bod Pod® was calibrated according to manufacturer's directions. All tests were conducted in a temperature controlled room (22°–24°C). Air displacement plethysmography (ADP) applies a pressure–volume relationship to estimate body composition using a two-compartment model of lean and fat mass (Going, 2005). The ratio of the pressure created by body volume within a sealed chamber to that created by a cylinder of known volume is used to calculate body density and then estimate body fat. For accuracy, tight-fitting clothing (spandex bathing suit or exercise bra and shorts) and a Lycra® swim cap (TYR Sport, Inc., Huntington Beach, CA) to compress the hair were used in order to compensate for the potential effects of clothing and hair on body volume measurement. No shoes or socks were worn and all jewelry was removed prior to testing.

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Multifrequency Bioelectrical Impedance Analysis

Lean and fat mass were then measured with MFBIA (Bodystat® Quadscan 4000, Body Stat Ltd., Isle of Man, British Isles) using the proprietary equation provided by the manufacturer. Individual data were entered regarding gender, age, height, and weight. Participants were tested in a supine position, after a 5-minute rest period to allow stabilization of body fluid levels. All extremities were extended, feet were apart, and hands were away from the body. Four electrodes were placed on the right hand and foot in the following manner:

- Posterior wrist in line with the radial and ulnar protrusions,
- Posterior hand immediately proximal to metacarpal joints,
- Anterior ankle in line with tibial and fibular protrusions, and
- Dorsal foot immediately proximal to metatarsal joints.

The four electrodes were positioned to allow lateral attachment of the monitor leads that conduct the electrical impulses emitted by the Quadscan 4000. Body water calculations are based on measurement of the transit time of these impulses between the two emitting electrodes (one on the hand and one on the foot) and the two receiving electrodes (one on the hand and one on the foot). Lean tissue, which has greater water content than fat, allows the impulse to travel more rapidly, with less electrical impedance. Therefore, greater lean mass results in more rapid transit time.

The principle of MFBIA is based on measurement of resistance to the flow of electric current at various frequencies through body tissue. Only higher frequencies penetrate muscle or lean mass, resulting in reduced impedance (Segal et al., 1991).

The advantage of MFBIA is that intracellular and extracellular water can be accurately differentiated by use of four different frequencies. High frequencies (200 mHz) permeate cell membranes, while low frequencies (5 mHz) do not. High frequency impulses provide a measure of total body water, and low frequency impulses provide a measure of extracellular water. The difference between total body water and extracellular water represents intracellular water, the water contained in lean tissue. Shanholtzer and Patterson (2003) have reported strong test–retest reliability for Bodystat® in both males and females ($r > 0.9$).

Statistical Analysis

Data were analyzed using SPSS version 14.0 software. Descriptive statistics were calculated for all anthropometric and demographic characteristics. Repeated measures ANOVA with a Bonferroni adjustment was used to evaluate any differences in lean and fat mass between ADP and MFBIA. Pearson correlation analysis was used to calculate the strength of the relationship between ADP and MFBIA values and to evaluate any relationships between participant age, height, BMI, waist circumference, body composition estimates, and differences between ADP and MFBIA measurements. Statistical significance was set at $p \leq .05$. All data are reported as mean ± standard error (SE).

RESULTS

Participants were middle aged and slightly overweight, without notable central obesity (Table 1). All reported strict adherence to pretest instructions regarding physical activity and dietary intake. Testing was conducted as scheduled between 5:00 and 8:00 a.m. without deviation, and all tests were completed within a 30-minute period of time.

Significant differences were found between ADP and MFBIA measurements of body composition (Table 2). Multifrequency bioelectrical impedance analysis (MFBIA) overestimated absolute (kg) and relative (%) lean mass and underestimated absolute (kg) and relative (%) fat mass compared with ADP. Agreement between measurements, however, was within 2%–3% body fat.

There was strong, positive agreement between ADP and MFBIA measurements of body composition (Figure 1). Values for absolute lean mass were strongly related ($r = 0.80, p = .01$), as were values for absolute fat mass ($r = 0.99, p = .01$). Relative measures of body composition were equally in agreement, with strong relationships observed between ADP and MFBIA for relative lean mass ($r = 0.91, p = .01$) and relative fat mass ($r = 0.91, p = .01$). Pearson correlation analysis identified no significant relationship between differences in ADP and MFBIA measurements and participant age, height, BMI, waist circumference, or individual body composition characteristics.

DISCUSSION

To our knowledge, ours is the first study to evaluate MFBIA against ADP in a single cohort of healthy, middle-aged women. Consistent with previous

TABLE 2 Body Composition Comparison Between Air Displacement Plethysmography (ADP) and Multifrequency Bioelectrical Impedance Analysis (MFBIA) in Middle-Aged Women

Variable	ADP	MFBIA	Difference	*p*-value
Absolute lean mass (kg)	42.4 ± 0.7	44.2 ± 0.8	1.8 ± 0.5	.002
Absolute fat mass (kg)	25.1 ± 1.8	23.5 ± 1.5	−1.6 ± 0.5	.002
Relative lean mass (%)	63.9 ± 1.6	66.1 ± 1.2	2.2 ± 0.7	.006
Relative fat mass (%)	36.1 ± 1.6	33.9 ± 1.2	−2.2 ± 0.7	.006

Data presented as mean ± SE.

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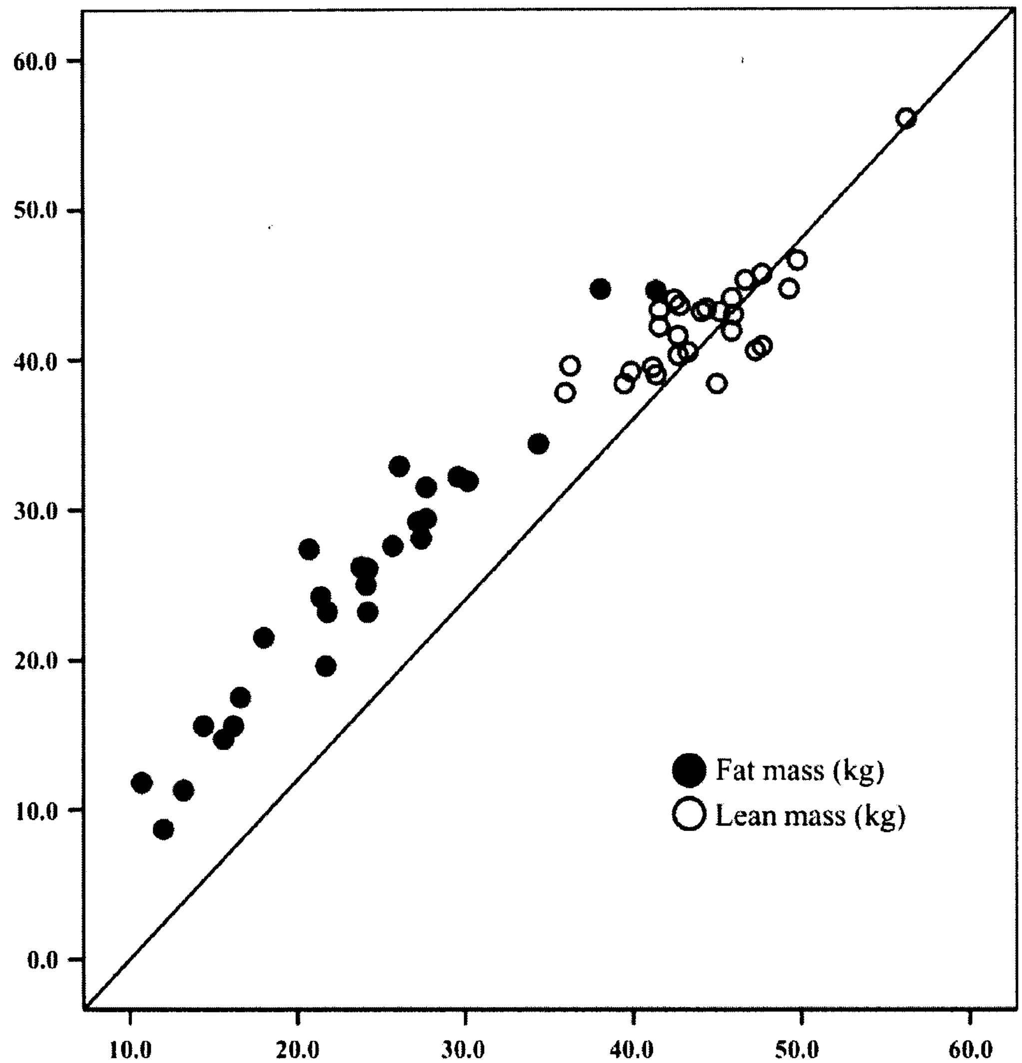

FIGURE 1 Scatter plot for air displacement plethysmography (ADP) and multifrequency bioelectrical impedance analysis (MFBIA) measurements of lean ($r = 0.80$, $p = .01$) and fat mass ($r = 0.99$, $p = .01$).

work by Frisard and colleagues (2005) who evaluated a combined group of men and women, MFBIA was observed to overestimate lean mass and underestimate fat mass compared with ADP. Although these differences were statistically significant, they were small, representing a difference in body fat of only 2%–3%; and it is questionable if they have clinical significance. Moreover, there was strong agreement between MFBIA and ADP in measurements of both relative and absolute fat and lean mass.

The principle of whole body bioelectrical impedance is based on electrical conductance between the arm and leg along one side of the body, such that local fat deposits are incorporated into the calculation through their indirect effect on resistance and transit time. Significant amounts of centralized body fat may skew calculations, resulting in overestimation of fat-free mass and underestimation of fat mass in obese individuals (Coppini, Waitzberg, & Campos, 2005). However, if central obesity had been influential in the differences we found between ADP and MFBIA, a relationship between waist circumference and differences in measurements between ADP and MFBIA would be expected. Such a relationship was not found in the current study. Our participants were on the cusp between normal and overweight, and did not display remarkably large waist circumferences. Had our participants been more centrally obese, an effect on measurement may have been observed.

Height has been identified as a possible confounder of bioelectrical impedance analysis due to variations in arm and leg length that affect the distance traveled by the electrical impulse (Allison, Ray Lewis, Liedtke, Buchmeyer, & Frank, 2005). For accuracy, prediction equations developed by the manufacturer should adjust for height. In the current study, Pearson correlation analysis identified no significant relationship between participant height and differences in measurement between ADP and MFBIA. We interpret the absence of this relationship as demonstrating that prediction equations for the Quadscan 4000 do, in fact, adequately make that correction.

Accuracy of MFBIA is dependent on calculation of both total body water and extracellular water, assuming a constant hydration of lean mass (Rosler, Lehmann, Krause, Wirth, & von Renteln-Kruse, 2009). Hydration status could therefore influence measurement outcomes. In fact, dehydration has been found to influence estimation of total body water during bioelectrical impedance analysis in males, although these were severe, exercise-induced changes in hydration that did not mimic the transient fluid shifts normally observed in healthy adults (Koulmann et al., 2000; Pialoux et al., 2004; Thompson et al., 1991). In the present study all participants were healthy and after receiving instructions not to limit fluids, they reported that they were well hydrated at the time of testing. It is therefore unlikely that the variance in estimation of lean and fat mass we observed between MFBIA and ADP was due to hydration status.

Calculation of body composition with MFBIA is based upon the ability of lean mass to conduct electrical impulses more rapidly than fat mass (Miller, Carlson, Fegelman, Quinones, & Finley, 1999). Although differences were found between estimates of lean mass by MFBIA compared with ADP, correlation analysis found no significant relationship between those differences and either absolute or relative values of lean mass. It is therefore unlikely that muscularity (absolute or relative) influenced measurement differences. Instead, the small differences noted may have been the result of proprietary equations developed by the manufacturers. What is most important is the strong and consistent agreement between MFBIA and ADP which supports

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the use of MFBIA for on-going clinical assessment of body composition for women with a normal or near-normal BMI.

There are limitations to this study. For body composition assessment with ADP, lung volumes were estimated rather than measured. Although no significant difference in measurement of body composition has been found between use of predicted and measured lung volumes in healthy adults (McCrory, Mole, Gomez, Dewey, & Bernauer, 1998), use of the prediction equation provided by the manufacturer may have influenced ADP measurements. The use of predicted lung volumes has actually been recommended by Wells and Fuller (2001) due to inaccuracies in measured lung volumes resulting from inability to correctly follow the measurement procedure. Furthermore, it should be noted that our outcomes reflect those of Frisard and colleagues (2005) who directly measured thoracic gas volume in their participants multiple times until a consistent value was obtained. In a clinical setting, direct measurement in this manner would be costly in terms of both time and equipment.

Additionally, for ADP measurements the Siri equation was used for all participants. Although accuracy of ADP has been observed to decrease in obese individuals, the Siri equation has been found to provide the most consistent level of accuracy with varying amounts of body fat (Frisard, Greenway, & Delany, 2005). Nevertheless, in obese individuals ADP may overestimate body fat. In the present study ADP did, in fact, estimate greater absolute and relative amounts of body fat compared with MFBIA. It should be recognized, though, that our participants were mildly overweight, not obese, which would support the use of ADP as our criterion method. Furthermore, if ADP measurements were skewed by body fat levels, a relationship between measurement *differences* and fat mass would be anticipated. No relationship was found. Instead, a strong and positive relationship between ADP and MFBIA estimates of fat and lean mass was observed.

CONCLUSIONS

Use of MFBIA provides a feasible and accurate tool for on-going clinical assessment of body composition in healthy, middle-aged women with normal or mildly overweight BMI levels. With use of this technology, appropriate health promotion strategies can be developed based on quantified changes in both lean and fat mass. Although more work in this area is needed, our data provide promise that clinical assessment can include accurate body composition measurement that is neither costly nor burdensome.

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