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Short Report

Comparison of Bipolar and Tetrapolar Impedance Techniques for Assessing Fat Mass

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ABSTRACT Whole body fat mass (BF) can be predicted by different bioimpedance (BIA) techniques measuring the whole body (tetrapolar hand-to-foot technique, HF), lower body (bipolar foot-to-foot technique, FF), or upper body (bipolar hand-to-hand technique, HH). This study analyzed 146 healthy volunteers (age 18–84 years) for whether these three techniques differ in their estimates of BF, and whether sex and age of the subjects influence estimates of BF. Reproducibility of the techniques was tested by calculating the technical error (TE). Effects of BIA technique, sex, and age on predicted BF were analyzed with ANOVA for repeated measurements in a mixed effect design. Results showed high reproducibility for the three BIA techniques (TE = 0.01–0.03 kg). ANOVA indicated interactions between BIA technique and sex ($P = 0.035$), BIA technique and age ($P < 0.001$), as well as effects of sex ($P = 0.004$) and age ($P = 0.001$) on variation in BF. The HH technique gave the highest values for BF in males, but lowest values in females, whereas the reverse was found for the FF technique. The HH technique yielded the lowest values for BF in young adults, but highest values in older ones. The reverse was noted for the FF technique. The data suggest that the observed differences in the three BIA techniques in predicting BF reflect sex differences and age-associated changes in body fat patterning. Therefore, the whole body impedance method is preferred over the HH and FF techniques due to the interactions with sex and age. Am. J. Hum. Biol. 16:593–597, 2004.

Body fat mass (BF) is a useful parameter in biological, medical, nutritional, and sports sciences. Its amount has been related to genetic and environmental factors, process of aging, state of health, diseases, nutritional state, and the level of physical activity of a subject. BF can be determined by underwater weighing and imaging techniques (CT and MRI), which are the most accurate, but not suited for epidemiological studies due to sophisticated technology, limited access, and high costs. Here, other methods are applied that are based on anthropometrics, near-infrared light technology, ultrasound, or bioimpedance technology (BIA; Pietrobelli and Heymsfield, 1998).

The noninvasive BIA is increasingly applied in biomedical sciences. The measurement device passes an electrical current through the human and measures the body's impedance. The lower the impedance, the higher the amount of fat-free mass, and therefore the lower the predicted BF. In the conventional tetrapolar approach, the electrical current passes the whole body (hand-to-foot technique). In contrast, the novel bipolar approach measures only the lower part (leg impedance; foot-to-foot technique; Tyrrell et al., 2001) or upper part (arm impedance; hand-to-hand technique; Deurenberg and Deurenberg, 2002) of the body. Even if bipolar techniques measure only parts of the body, they estimate whole BF. Thus, they might be more susceptible to inexactness. This study analyzed whether bipolar and tetrapolar techniques yield differing results in predicting whole BF and whether sex and age of the subjects affect estimates of BF.

SUBJECTS AND METHODS

BF was predicted in 146 healthy volunteers (61 males, 85 females; age 18–84 years) from the same ethnic origin. Exclusion criteria were the presence of

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heart pacemaker, pregnancy, acute/chronic diseases, diseases leading to fluid/electrolyte disturbances, recent history of surgery, use of medications affecting water/salt balance, and a weight-loss diet program during last 6 months. Each subject gave written informed consent. The study protocol complied with the declaration of Helsinki.

All measurements were taken by the author on the same day in the morning during a ½-hour time period. Body height was determined to the nearest 0.01 m and weight to the nearest 0.1 kg without shoes in light indoor clothes, using an anthropometer and electronic scale, respectively. Because BIA depends on hydration state of the body, the subjects followed strict pretest conditions (12 hours of fasting, 24 hours absence of alcohol consumption, 24 hours no exercise) and emptied their bladders within ½-hour prior to measurement. The BF was estimated with three BIA techniques: a tetrapolar hand-to-foot technique (HF) using the BIA 2000-M device (Data Input, Frankfurt, Germany), a bipolar foot-to-foot technique (FF) using the Tanita body fat monitor TBF-538 (Tanita, Tokyo, Japan), and a bipolar hand-to-hand technique (HH) using the Omron body fat monitor BF-302 (Matsusaka, Japan).

Statistical analyses were performed with SPSS/PC for MS-Windows, release 8.0 (SPSS, Chicago, IL). The assumption of normal distribution was tested by the Kolmogorov-Smirnov-test. Reliability of duplicate measurements (with intermediate repositioning within a 15-minute time period) was calculated for each BIA device on 20 subjects by determining the technical error of measurement (TE) as $TE = \sqrt{di^2/2N}$ (di = difference between both measurements on the ith subject; N = number of subjects) (Malina et al., 1973). Pearson correlation coefficients for the six age/sex categories by the three techniques were computed. The Bland and Altman (1986) method was used for comparison of BIA techniques. Analysis of variance (ANOVA) for repeated measurements was performed in a $3 \times 2 \times 3$ mixed effect design with BIA technique as within-subject factor (HF vs. FF vs. HH technique), and sex and age group (<40 vs. 40–59 vs. $\geq$60 years) as between-subjects factors. Bonferroni post-hoc tests were used for age group comparisons and t-tests for independent samples for sex comparisons. Two-sided P values <0.05 were considered statistically significant.

RESULTS

Mean ± SD in males (females) was for age 53.57 ± 15.91 (51.73 ± 16.52) years, for weight 80.64 ± 11.08 (67.39 ± 11.41) kg, for height 1.77 ± 0.08 (1.64 ± 0.07) m, and for BMI 26.30 ± 5.28 (25.03 ± 4.28) kg/m^2. Table 1 shows mean BF by sex and age group, as predicted by tetrapolar and bipolar BIA techniques. Mean TE for repeated measurements was 0.03 ± 0.05 kg (range

TABLE 1. Body fat mass (kg) estimated by tetrapolar and bipolar bioimpedance techniques in 146 adult volunteers, separately by sex and age group

			Bioimpedance technique								
			Tetrapolar, hand-to-foot (HF)			Bipolar, foot-to-foot (FF)			Bipolar, hand-to-hand (HH)		
Sex	Age group (years)	N	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Males	18–39	15	16.90[a]	5.36	9.70–26.20	14.52[a]	4.84	8.72–24.28	12.49[a]	5.77	5.90–25.60
	40–59	15	20.05	5.12	10.50–31.00	20.38	7.76	6.56–35.71	19.15	4.88	9.50–30.30
	60–76	31	19.25[b]	5.74	8.60–32.30	18.96[b]	7.96	6.50–37.73	22.97[b]	6.25	13.10–40.20
	Total	61	18.87	5.54	8.60–32.30	18.22	7.49	6.50–37.73	19.45	7.17	5.90–40.20
Females	18–39	21	20.13[c]	5.43	12.70–31.10	20.38[c]	5.56	13.01–31.43	16.05[c]	5.12	7.50–27.70
	40–59	32	22.93[d]	9.03	9.40–48.80	23.78[d]	9.44	8.62–50.00	22.39[d]	8.14	11.00–45.50
	60–84	32	22.91[e]	8.29	10.80–47.30	22.82[e]	8.72	11.01–47.47	25.85[e]	7.93	14.30–47.60
	Total	85	22.23	8.00	9.40–48.80	22.58	8.37	8.62–50.00	22.12	8.27	7.50–47.60

SD, standard deviation.
Method comparisons:
[a]FF vs. HH ($P = 0.003$), HH vs. HF ($P < 0.001$), FF vs. HF ($P = 0.002$).
[b]FF vs. HH ($P < 0.001$), HH vs. HF ($P < 0.001$).
[c]FF vs. HH ($P < 0.001$), HH vs. HF ($P < 0.001$).
[d]FF vs. HH ($P = 0.004$), FF vs. HF ($P = 0.002$).
[e]FF vs. HH ($P < 0.001$), HH vs. HF ($P < 0.001$).

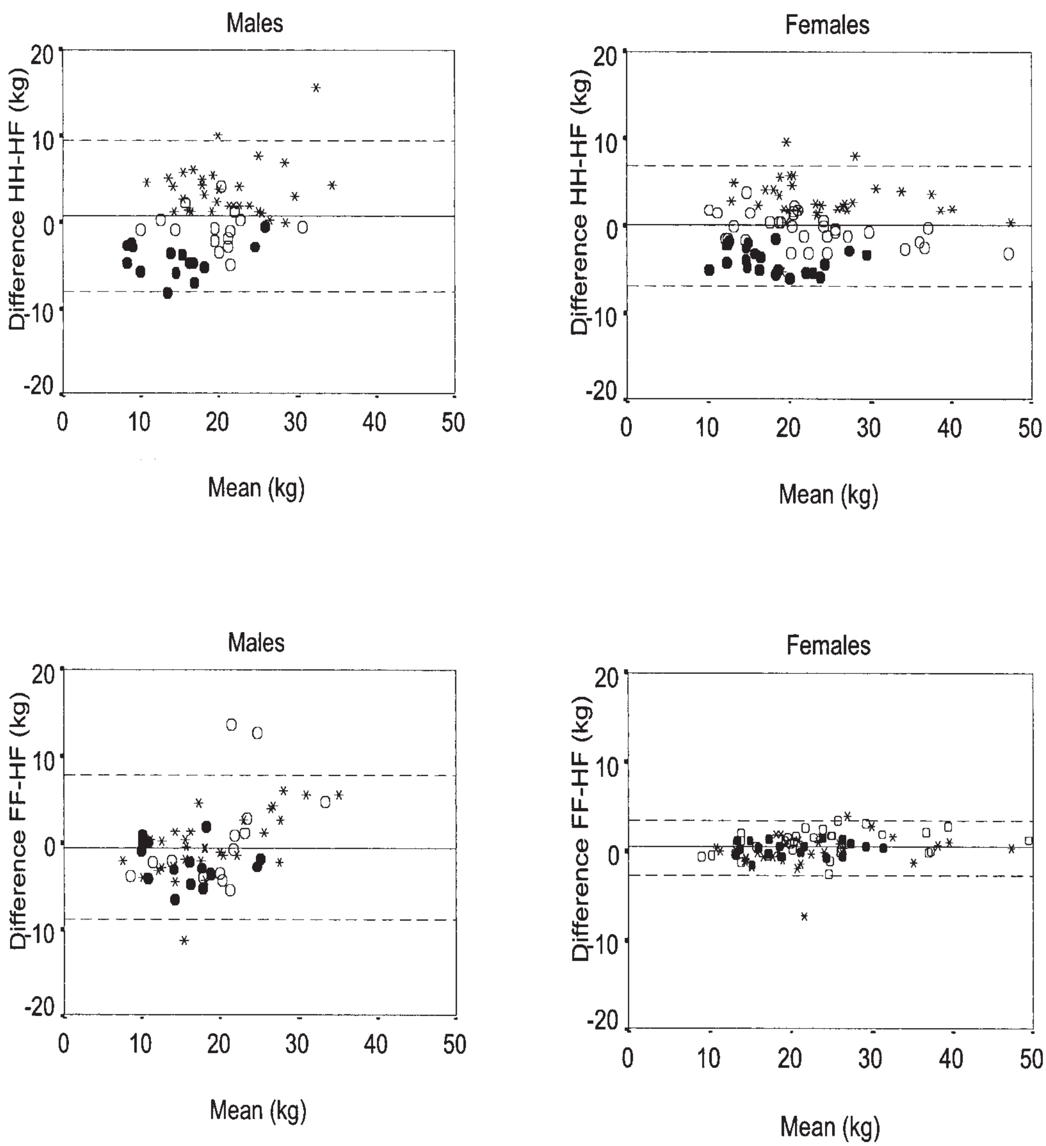

Fig. 1. Bland-Altman plot of differences between body fat predicted by tetrapolar vs. bipolar bioimpedance techniques, shown separately for males (n = 61) and females (n = 85). Differences are plotted against the mean of the compared techniques (HH, hand-to-hand technique; HF, hand-to-foot technique; FF, foot-to-foot technique). The solid lines represent mean difference (bias) and the dotted lines the limits of agreement (±2 SD). Age groups: ● 18–39 years, ○ 40–59 years, * 60–90 years. The bias ± 2 SD between the HH and HF techniques are 0.59 ± 8.73 kg (males) and 0.11 ± 6.83 kg (females). The limits of agreement between the FF and the HF techniques are 0.65 ± 8.35 kg for males and 0.35 ± 3.10 kg for females.

0.00–0.17 kg), 0.01 ± 0.02 kg (range 0.00–0.06 kg), and 0.02 ± 0.03 kg (range 0.00–0.08 kg) for the HH, HF, and FF techniques, respectively. Figure 1 displays bias and level of agreement between the tetrapolar technique and each bipolar technique for predicting BF. In general, the bias between tetrapolar and bipolar techniques as well as the limits of agreement are larger in males than in females.

Correlation coefficients between the three techniques (FF with HH, FF with HF, HH with HF) were statistically significant for young males (r = 0.93, 0.89, 0.94), middle-aged males (r = 0.86, 0.64, 0.90), older males (r = 0.87, 0.91, 0.86), young females (r = 0.94, 0.99, 0.96), middle-aged females (r = 0.97, 0.99, 0.98), and older females (r = 0.94, 0.98, 0.95), respectively.

ANOVA indicates significant interactions between BIA technique and sex (F = 3.54, $P = 0.035$), BIA technique and age (F = 54.16, $P < 0.001$), and significant effects of sex (F = 8.47, $P = 0.004$) and age (F = 6.89, $P = 0.001$) on variation in BF. There is no interaction between sex and age (F = 0.05, $P = 0.947$). Bonferroni post-hoc tests show significant age group differences in both sexes for the HH technique, but not for the FF and HF techniques. In males, highest mean BF was obtained by the HH technique and lowest by the FF technique. In females, the reverse was noted. With respect to age differences, the HH technique displayed lowest mean BF in young adults, but highest BF in older adults (both sexes). The reverse is observed for the FF technique. In general, older adults have highest BF when measured with the HH technique, but lowest BF with the FF technique.

DISCUSSION

This study found significant interactions between BIA technique and sex as well as between BIA technique and age in estimating BF. The methods of comparison yielded large intraindividual differences in estimates of BF by tetrapolar and bipolar BIA techniques. This confirms the results of Jartti et al. (2000), who compared HF and FF bioimpedance techniques, whereas Nuñez et al. (1997) found that HF and FF techniques yielded comparable values. Baumgartner et al. (1989) reported for females that arm impedance accounted for 49% of variation of fat-free mass and leg impedance only for 36%. This may partly explain the observed better agreement between HH and HF techniques in predicting BF in females.

The analysis of 95% limits of agreement show that differences between HF and HH techniques are more pronounced than differences between HF and FF techniques. In both cases, mean difference between methods is smaller in females than in males. Compared to the HF technique, the bipolar HH technique overestimates BF in males and underestimates it in females. In contrast, the bipolar FF technique yields lower BF estimates in males and higher BF in females. This agrees with the observation of Xie et al. (1999) that the FF technique overestimated BF in females when compared to DEXA as a reference method. The finding that highest BF values are obtained in females with the FF technique and in males with the HH technique can be explained by sex-specific BF distribution. The FF technique may overpredict BF in gynoid females with more glutofemoral fat, but underpredict BF in android males with less glutofemoral fat. This is in line with findings of Tsui et al. (1998), who compared the FF technique with DEXA: the FF technique overestimated %BF in females and underestimated %BF in males.

This study observed in older adults highest BF values when measured with the HH technique, but lowest values when determined with the FF technique. These differences may be due to changing patterns and redistribution of BF with aging (Borkan and Norris, 1977). Typical age-related changes are an altered pattern of fat accumulation from other areas of the body to the trunk (Kuczmarski, 1989).

In summary, regarding mean values, the FF technique approximates BF better than the HH technique when compared to the HF technique. On an individual level, both bipolar techniques display a larger bias when compared with the HF technique. This holds particularly true for males, whereas females show a better agreement. Regarding sex differences, the HH technique estimates highest values for BF in males, but lowest values in females, whereas the reverse is observed for the FF technique. With respect to age, the HH technique gives lowest values in young and highest values in older adults. The opposite is found for the FF technique. The data suggest that the observed differences in BIA techniques in predicting BF reflect sex- and age-mediated effects on the distribution of BF. It is recommended on an individual level to prefer the whole body impedance method over the HH and FF techniques due to the interactions with sex and age.

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