Author(s): Sillanpää, Elina; Cheng, Sulin; Häkkinen, Keijo; Finni Juutinen, Taija; Walker, Simon; Pesola, Arto; Ahtiainen, Juha; Stenroth, Lauri; Selänne, Harri; Sipilä, Sarianna

Title: Body composition in 18 to 88-year-old adults - comparison of multifrequency bioimpedance and dual-energy X-ray absorptiometry

Year: 2014

Version:

Please cite the original version:

Sillanpää, E., Cheng, S., Häkkinen, K., Finni Juutinen, T., Walker, S., Pesola, A., Ahtiainen, J., Stenroth, L., Selänne, H., & Sipilä, S. (2014). Body composition in 18 to 88-year-old adults - comparison of multifrequency bioimpedance and dual-energy X-ray absorptiometry. Obesity (Silver Spring), 22(1), 101-109. https://doi.org/10.1002/oby.20583

Body Composition in 18- to 88-Year-Old Adults—Comparison of Multifrequency Bioimpedance and Dual-Energy X-ray Absorptiometry

Elina Sillanpää[1], Sulin Cheng[1], Keijo Häkkinen[2], Taija Finni[2], Simon Walker[2], Arto Pesola[2], Juha Ahtiainen[2], Lauri Stenroth[1], Harri Selänne[3] and Sarianna Sipilä[1]

Objective: This study compared bioimpedance analysis (BIA) in the assessment of body composition with dual-energy X-ray absorptiometry (DXA) in 18- to 88-year-old adults.

Design and Methods: Body composition of 882 adults was estimated by eight-polar BIA and DXA. In addition, estimates of lean mass, fat mass, and percentage of fat were investigated across a range of age and leisure time physical activity (LTPA) groups.

Results: Compared to DXA, larger lean masses (mean difference 2.9 and 1.6 kg) and smaller fat masses (3.1 and 2.6 kg) were estimated by BIA in both women and men, respectively. Differences between the methods' mean values were evident in all age and LTPA groups, except in the oldest men (over 70 years). Age, waist circumference, grip strength, and LTPA explained 21% or less of the variance observed in the differences between methods.

Conclusions: Compared to DXA, BIA provided systematically different body composition estimates throughout the adult age span with considerable amount of intraindividual variation. The differences between estimates may be related to the BIAs' algorithm or body geometry or composition of the population used in this study. Knowledge about the methodological limitations and device comparability is essential for researchers, clinicians, and persons working in rehabilitation and sport centers.

Obesity (2014) **22**, 101–109. doi:10.1002/oby.20583

Introduction

Human body composition is altered throughout the human life span by genetically determined aging processes and external factors such as nutrition, exercise, and diseases. Optimal body composition may vary among individuals, but generally high ratios of fat free mass (FFM) and relatively low values of fat mass (FM) are favorable for health, functional capacity, and physical performance (1).

During aging, body weight, and the amount of FM increases slowly up to the sixth decade with a gradual decline thereafter in body weight (2). Advancing adult age is usually associated with more profound changes in body composition; body fat is redistributed so that subcutaneous fat tends to decline at the same time as visceral and intramuscular fat tend to increase (3,4). Increases in total adiposity can also occur independently of changes in body weight (4). These age-related changes are closely related to the development of several diseases such as metabolic syndrome, type II diabetes, sarcopenia, and osteoporosis.

Concomitantly with changes in FM and redistribution with aging, the amount, and quality of muscle mass changes. Muscle mass reaches its peak during the third decade and decreases slowly thereafter. After the fifth decade, a steeper decline begins. It has been estimated that, on average, 5% of muscle mass is lost per decade (5). The absolute loss of muscle mass is greater in men compared to women. However, a physiologically lower muscle mass and the accelerated loss of muscle mass after menopause (6) pre-dispose women to functional limitations caused by an insufficient amount of muscle mass associated with decreases in strength in different muscle groups.

Accurate measurement of body composition is a valuable evaluative/diagnostic tool to assess health related biological processes, such as

[1] Gerontology Research Center and Department of Health Sciences, University of Jyväskylä, Jyväskylä, Finland. Correspondence: Elina Sillanpää (elina.sillanpaa@jyu.fi) [2] Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, Finland [3] LIKES Research Center, Jyväskylä, Finland

Funding agencies: We acknowledge the support from the EC FP7 Collaborative Project MYOAGE (GA-223576), Academy of Finland SKID-KID program (project #135038) and Ministry of Education and Culture, Finland (project 42/627/2010/Finni).

Received: 14 November 2012; **Accepted:** 21 July 2013; **Published online 26 July 2013. doi:10.1002/oby.20583**

maturation, aging and physical training. Typically, evaluation of body composition in health care includes an estimate of the individuals' body FM and FFM and/or fat distribution.

The bioelectrical impedance method (BIA) is considered a valid method of total and regional body composition analysis that is widely available, rapid, non-invasive, relatively inexpensive, and without a requirement for high-level operator training (7). In general, estimations of body composition by different BIA devices are based on measurements of impedance, resistance, reactance, or phase angle to electrical current. Raw values will be converted into different body composition parameters by using special algorithms. The details of equations used by each device are generally unavailable to the users, but with newer devices raw values are available. In addition, these population-specific equations may not be applicable in body composition measurements in all subject groups. Due to these challenges and the fact that BIA is also quite sensitive to hydration status, temperature, the time of day of the measurement, body symmetry, and position (8) previous validation studies of the accuracy of BIA technique have shown contradictory results.

Direct segmental multi-frequency bioimpedance analysis has been shown to have better accuracy compared to other BIA devices (9). This technique has widespread use in research and clinical settings, but also in public and private health care and in sport and rehabilitation centers. Segmental multifrequency BIA measures the flow of an electrical current by using several frequencies, which allows estimations based on both intracellular and extracellular water. In addition, compared to simple BIA devices, segmental analysis allows estimations of different body segments separately. In theory, predictions of total body composition based on sum of individual segments are more reliable. Even this BIA method has, however, been shown to produce conflicting results in body composition estimates, especially when these machines have been validated against dual-energy X-ray absorptiometry (DXA) (7,9-13). So far, it seems that segmental BIA does not have reasonable accuracy for clinical purposes (14), but research in this area is limited to studies with a narrow age span, low statistical power due to small number of subjects or within subgroups limited for BMI.

DXA is generally accepted gold standard method for bone density measurement and also widely used technique for body composition assessments. It permits the direct measurement of LM, FM, and bone mineral with high precision and accuracy (precisions for soft tissue measurements 2-3%) (15). However, the equipment is rather expensive and, due to the ionizing radiation, measurement requires a health care professional. Therefore, DXA is not widely available outside clinical and research settings.

This study investigated the accuracy of direct segmental multi-frequency bioimpedance analysis in the assessment of total body composition in a large sample of adult Finnish women and men using DXA as a reference method. In addition, relationships between estimates of body FM and LM and percentage of fat were investigated among healthy men and women across a range of age and physical activity groups.

Methods

Subjects

Study material consists of six different research projects conducted during the years 2005-2011 at the same university research laboratory. All subjects were recruited from Central Finland area, Baseline data from four intervention studies and two cross-sectional studies were pooled into one database. In intervention studies 1-3 (n = 134, 24, 81) voluntary subjects were recruited to exercise intervention studies by the advertisements in the local newspapers, e-mail-lists and posters around the university and local shops (18, J. Ahtiainen, unpublished data; S. Walker, unpublished data). Subjects with a background in systematic physical training during the year before the study were excluded. The fourth intervention study was a family based tailored counseling intervention (17). Healthy men and women having an occupation where they self-reportedly sit more than 50% of their work time were recruited (n = 105). Studies 5 and 6 were cross-sectional studies. In study 5, young healthy men and women (18-30 years) and physically active and less active older men and women (69-81 years) were recruited (n = 106; McPhee et al., unpublished data). All participants regularly attended social or group activities to improve their knowledge or skills. Thus, younger participants were university students and older participants were recruited through University of the Third Age. In study 6, families of 9-13 years old girls were recruited via class teachers in 61 schools (19). In this study, follow up measurements after 7.5 years were used in the analysis (n = 429).

The pooled sample consists of 882 apparently healthy 18- to 88-year old women (n = 522) and men (n = 360). Exclusion criteria included: Pregnancy and breast feeding, BMI $<$ 18.5 kg/m^2 or $>$ 32.5 kg/m^2. In addition, persons with serious metabolic, cardiovascular, or endocrine diseases were excluded from the study. Subjects signed a written consent form before participation and all data were handled according to the good scientific practice. The Ethical Committee of the Central Hospital of Central Finland has approved all studies.

Measurements

Subjects were instructed to sleep at least 8 h during the previous night and to avoid strenuous exercise for 24-h. All metal items were removed from the participants to ensure the accuracy of the measurement. 57% of the BIA and DXA measurements were performed on the same day within 1 h from each other, 22% of the measurements were performed within 1 week, and 21% were performed within 1 month due to service of the DXA machine. Data was excluded from the study if there was more than 2 kg body weight difference between the BIA and DXA measurements that were taken 1 week or more apart.

Dual energy X-ray absorptiometry (DXA). Body composition was estimated by DXA (LUNAR Prodigy, GE Healthcare). The subjects were positioned supine in the center of the table. They were scanned using the default scan mode for total body scanning automatically selected by the Prodigy software (enCORE 2005, version 9.30 and Advance 12.30). During data pooling all data was reanalyzed by the same software (Advance 12.30). The system software provides the mass of lean soft tissue (LM), fat (FM), and bone minerals. Quality assurance was performed every measurement day with multipoint phantom. Precision of the repeated measurements expressed as the percent coefficient of variation was 2.2% for percentage of fat and 1.0% for LM in our laboratory (20).

Bioelectrical impedance analysis (BIA). BIA measurements were performed in the post-absorbtive state after a 12-h overnight

TABLE 1 Physical characteristics of the female (n = 522) and male subjects (n = 360) in different age categories

Age		18-29 years		30-39 years		40-49 years		50-59 years		60-69 years		Over 70 years	
Variable		Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
n (women/men)		135/45		42/49		139/69		75/51		50/67		81/79	
Height (m)	Women	166.4	(5.5)	165.0	(6.6)	164.5	(6.0)	164.8	(6.6)	161.2	(4.4)	158.6	(5.9)
	Men	179.1	(5.6)	179.1	(6.5)	178.9	(6.7)	176.0	(5.9)	175.6	(5.3)	173.3	(5.7)
Weight (kg)	Women	62.2	(8.2)	62.0	(6.8)	65.5	(9.2)	66.0	(8.0)	66.5	(8.3)	64.5	(9.2)
	Men	74.4	(8.8)	80.2	(10.3)	80.5	(7.8)	77.3	(8.9)	79.9	(8.9)	76.6	(8.9)
BMI (kg/m^2)	Women	22.5	(2.7)	22.8	(2.0)	24.2	(3.0)	24.3	(2.6)	25.5	(2.7)	25.6	(3.1)
	Men	23.2	(2.6)	25.0	(2.8)	25.2	(2.2)	24.9	(2.4)	25.9	(2.3)	25.5	(2.6)
Waist circumference (cm)	Women[a]	74.4	(8.3)	84.1	(9.1)	81.4	(8.7)	83.5	(8.4)	86.1	(7.8)	85.5	(9.8)
	Men[b]	82.4	(5.2)	91.8	(8.5)	92.4	(5.8)	90.5	(6.8)	95.3	(7.6)	92.0	(8.7)
Hand grip strength (kg)	Women[c]	28.9	(6.8)	34.7	(4.9)	31.5	(6.8)	29.7	(5.3)	25.1	(5.1)	24.6	(6.6)
	Men[d]	52.1	(9.7)	58.7	(6.9)	49.5	(10.4)	46.6	(7.6)	42.1	(7.7)	41.0	(7.3)

[a]Data available from 461 subjects.
[b]Data available from 202 subjects.
[c]Data available from 483 subjects.
[d]Data available from 260 subjects.
Significant difference between age groups in all variables ($P < 0.05$).

fast and measurements were performed between 7:00 AM and 9:00 AM. During the measurement, subjects wore light clothing. Before measurements, the subject's palms and foot soles were wiped with an electrolyte cloth provided by the manufacturer. Subjects stood with the ball and heel of each foot on two metal electrodes on the floor scale and held handrails with metal grip electrodes. Arms were fully extended and abducted approximately 20 degrees laterally. Body composition was estimated by an eight-polar bioimpedance method using multifrequency current (Inbody^{TM} 720, Biospace Co., Seoul, Korea). The device was pre-set by the manufacturer and calibrated regularly according to manufacturer's instructions. This device takes readings from the body using an eight-point tactile electrode method, measuring resistance at five specific frequencies (1 kHz, 50 kHz, 250 kHz, 500 kHz, and 1 MHz) and reactance at three specific frequencies (5, 50, and 250 kHz). The Inbody^{TM} bioimpedance device estimates total body water using the sum of five segmental resistances, which are calculated for all frequencies. The prediction equation for FFM includes the sum of segmental resistances (trunk, leg, and arm), as well as body weight and height (7,9). FFM is estimated based on the assumption that hydration of FFM is 73.2% and it includes both lean mass (LM) and bone mass. BIA LM is calculated by subtracting bone mass from FFM (7,21). Bone mass is predicted using predicted FFM, and this prediction equation uses DXA values as a reference (detailed equations have not been published). This might cause a small error to BIA LM values. LM was selected instead of FFM in the analysis, because it is more comparable to DXA LM, which does not include bone mass. BIA FM is calculated by subtraction of FFM from total weight. Before the test, subjects were instructed to excrete. After the measurement, data was electronically imported to Excel using Lookin'Body software (Biospace).

Anthropometrics. Height was measured using a fixed wall-scale to the nearest 0.1 cm. Body weight was measured by a calibrated weight scale (d = 0.1 kg]. These variables were used to calculate body mass index (BMI, kg/m^2).

Waist circumference was measured at the middle of the space between the lowest rib and iliac crest using inelastic tape. Measurements were performed three times and an average value was used in the analysis.

Assessment of leisure-time physical activity

Leisure-time physical activity (LTPA) was recorded by using self-reported questionnaires or interviews. Detailed questions involved a list of physical activities (type of activity), frequency, duration and/or intensity of each activity. From these questions LTPA was categorized into low, moderate and high levels. *Low activity* was defined as once per week or less, or 60 min or less moderate or 45 min or less vigorous physical activities per week, which is less than the current physical activity recommendations for maintaining and promotion health in adults (22). *Moderate activity* was defined as 2-5 times or 1-5 h per week moderate physical activities, or 2-3 times or 60-180 min per week vigorous physical activities. *High activity* was defined as more than 5 times or more than 5 h per week moderate physical activities or more than 3 times or 180 min per week vigorous physical activities. The intensity was dichotomized into moderate and vigorous physical activity by using self-reported breath status of physical activity or activity definitions based on MET's by Ainsworth (23).

Hand grip strength was measured using an isometric device. Subjects were encouraged verbally to produce maximal contraction. Hand grip strength was recorded in kilograms with an accuracy of 0.1 kg and the best attempt of three trials was used in analysis.

Statistical methods

Data was checked for normality by Kolmogorow–Smirnow W test. Descriptive results are reported as means and standard deviations (SD). The associations among body composition estimates measured

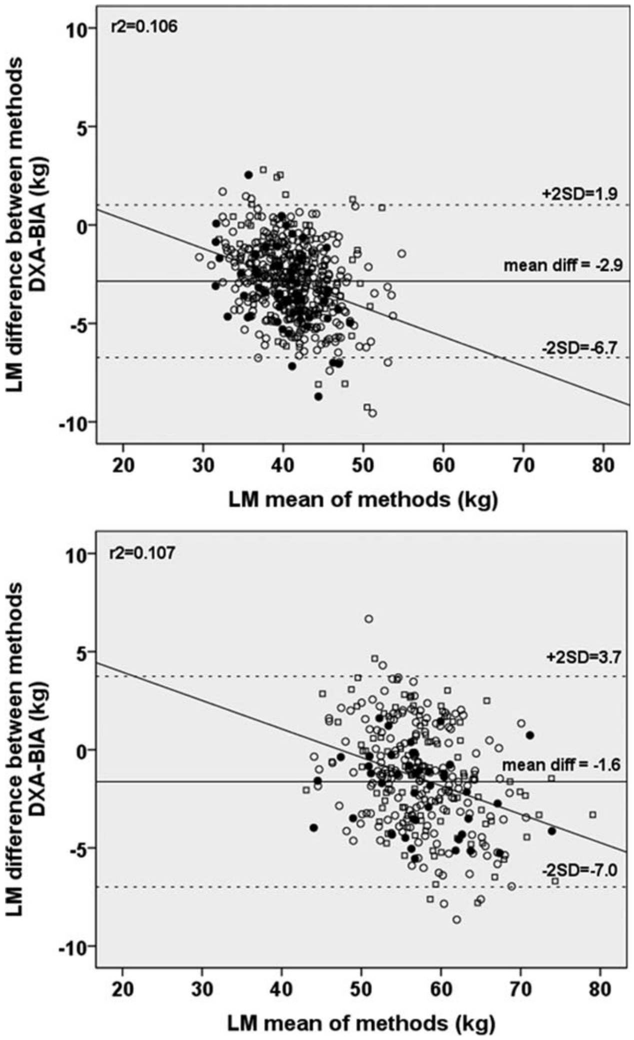

FIGURE 1 Bland Altman plots of women (upper panel) and men (lower panel) showing the difference versus mean value of whole body lean mass (LM) measured on dual-energy X-ray absorptiometry (DXA) and bioimpedance (BIA) with low physical activity (filled circles), moderate physical activity level (open circles) and high physical activity (open squares). The solid line represents the mean difference between methods and the broken line ±2SD for the whole sample.

by DXA and BIA were estimated using intraclass correlation coefficient (24). To investigate effects of age on anthropometric variables and estimates of body composition, men and women were split into six age categories (18-29, 30-39, 40-49, 50-59, 60-69, and 70 years and over). BIA and DXA were compared in LM, FM, and FAT% as the mean of the difference ±2 SD across the range of age and physical activity groups by using the Bland–Altman analysis (25). To assess the determinants of the difference between BIA and DXA measurements in body composition estimates a linear regression analysis was performed. Age, grip strength, waist circumference, and physical activity levels were investigated as potential predictors. An independent *t*-test was used to compare gender differences. One way ANOVA with Tukey post-hoc test were used to compare age and physical activity groups. Paired *T*-tests were used to test differences between DXA and BIA in LM, FM, and FAT%. A *P* value of <0.05 was considered statistically significant.

Results

Anthropometrics

Subject characteristics are presented in Table 1. Men were taller (+12.9 cm), had greater body mass (+13.9 kg), and BMI (+1.1 kg/m^2), waist circumference (+11.1 cm) and hand grip strength (+17.5 kg) than women (all $P < 0.001$).

In age categories 18-30, 50-59, 60-69, and 70 years and over, there were no differences in BMI between sexes. In other age categories BMI was higher in men ($P < 0.05$). In all age categories, weight, height, waist circumference, and hand grip strength were significantly greater in men compared to women ($P < 0.05$).

Device comparison in women and men

The device comparison in the total group of women and men showed that the mean difference between the methods in LM was −2.9 kg in women and −1.6 kg in men (Figure 1). Limits of agreement were wide, but slightly smaller in women (from −6.7 to 1.9 kg) than in men (from −7.0 to 3.7 kg). Assessment of bias showed that, compared to DXA, BIA seems to give lower values especially at the higher levels of LM both in women ($r = -0.298$, $P < 0.001$) and in men ($r = -0.332$, $P < 0.001$).

Estimations of FM were 3.1 and 2.6 kg smaller in BIA compared to DXA in women and in men, respectively (Figure 2). Larger absolute limits of agreement were observed in men (from −7.0 to 3.7 kg) compared to women (−6.7 to 1.9 kg). Correlations between the mean FM and the difference between methods in FM estimate were $r = 0.201$ ($P < 0.001$) in women and $r = 0.199$ ($P < 0.001$) in men.

Also in FAT% analysis, mean difference between methods was larger in women (4.7% unit) than in men (3.1% unit) and the data collected from women showed slightly smaller limits of agreement (from −0.9 to 10.3%) than that of men (from −3.7 to 9.9%). Differences between the estimates of FAT% were not associated with the amount of fat.

Body composition estimates and device comparison in different age categories

BIA provided higher estimation of LM (Figure 3A) and lower estimations of FM (Figure 3B) and FAT% than DXA in both women and in men in all age categories (for all measured variables $P < 0.001$) except in men 70 years and older (all n.s.; Table 2). In women and in men, there were significant differences between age groups in estimates of LM, FM, and FAT% (*P* for trend <0.001). Post-hoc analysis showed that, among older groups, the difference between the methods was smaller than among younger subjects in both genders.

Body composition estimates and device comparison in different LTPA groups

DXA provided lower estimates of LM and higher estimates of FAT% in all LTPA categories both in women and in men (all $P < 0.001$; Table 3). In women, there was a significant difference among the LTPA groups in LM measured by DXA (*P* for trend 0.041). In women, the high LTPA group showed a 1.6 kg higher LM than low LTPA group (between groups $P = 0.031$). A similar significant difference was not observed by BIA. In men, there were no differences in LM among LTPA groups (Figure 2).

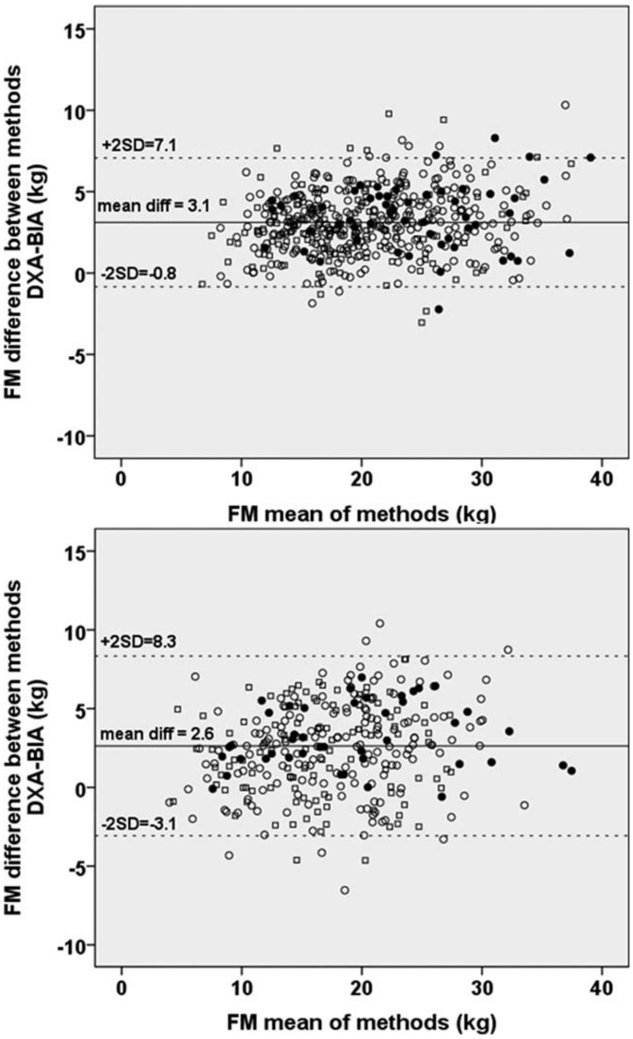

FIGURE 2 Bland Altman plots of women (upper panel) and men (lower panel) showing the difference versus mean value of whole body fat mass (FM) measured on dual-energy X-ray absorptiometry (DXA) and bioimpedance (BIA) with low physical activity (filled circles), moderate physical activity level (open circles) and high physical activity (open squares). The solid line represents the mean difference between methods and the broken line ±2SD for the whole sample.

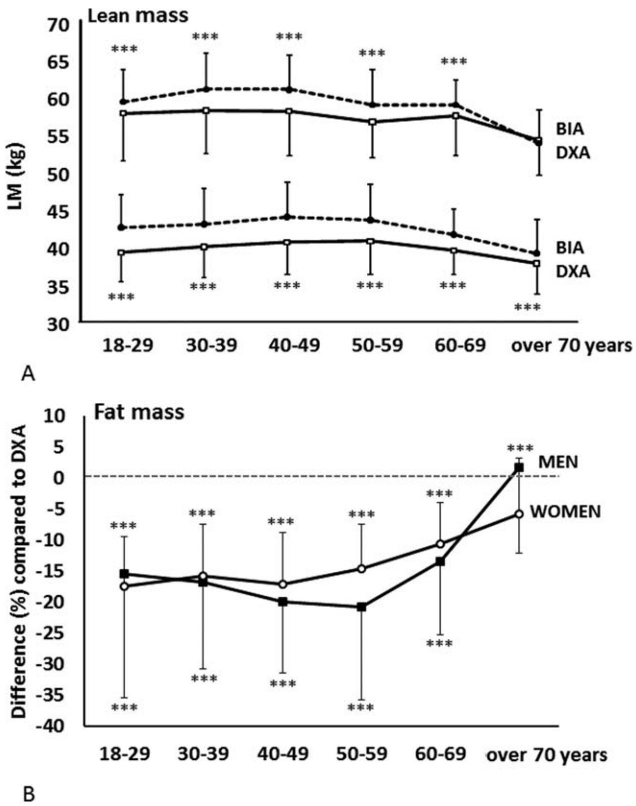

FIGURE 3 A: Body lean mass (LM, mean and SD) estimated by dual-energy X-ray absorptiometry (DXA) and bioimpedance (BIA) in different age groups in women (upper lines) and men (lower lines). **B**: Percent difference in fat mass (FM, mean and SD) estimated by BIA and DXA in women and men in different age groups. ***$P < 0.001$ significant difference between methods in body composition estimate.

FM and FAT% differed among the LTPA groups both in women (both P for trend <0.001) and in men (P for trend <0.001 in FM and 0.008 in FAT%) estimated by DXA. As estimated by BIA FM and FAT% differed among groups in women (both P for trend <0.001), but not in men. Post-hoc analysis showed statistically significant differences in FM and FAT% between all LTPA groups in women, but in men only between low and high activity groups estimated by DXA (Figure 3).

Predictors of methodological differences in body composition estimates

Strong correlations were observed for absolute values of LM (r = 0.721 and 0.764), FM (r = 0.857 and 0.821) and FAT% (r = 0.728 and 0.8698) between DXA and BIA, in women and in men respectively (all $P < 0.001$). To evaluate the determinants of differences between estimates of LM, FM, and FAT%, regression analysis was performed (Table 4). Analysis showed that differences between DXA and BIA in FAT% were explained by age, hand grip strength and physical activity level. These predictors explained 12% of the variance in the overall sample of women ($P < 0.001$). In men, only waist circumference and age were significantly associated with the fat% difference explaining 11% of the variance ($P < 0.001$). In women, significant predictors of the difference between DXA and BIA in LM analysis were age, waist circumference, hand grip strength, and physical activity level, which explained 17% of the variance ($P < 0.001$). In men, significant predictors were waist circumference and age, which explained 21% of the variance in the difference of LM ($P < 0.001$).

Discussion

This study compared two commonly used measurement techniques in assessing whole body composition in a large sample of 18- to 88-year-old Finnish women and men. In addition, DXA and BIA devices' comparability in LM, FM, and FAT% assessment with different levels of LTPA were analyzed and possible predictive parameters to the differences between the methods were evaluated. Inbody™ BIA was found to systematically overestimate the amount of LM both in

TABLE 2 Comparison of DXA and BIA in estimating body composition within and between groups according to age categories

Age group		18-29 years	30-39 years	40-49 years	50-59 years	60-69 years	Over 70 years	All
Variable		**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
n (women, men)		n = 135, 45	n = 42, 49	n = 139, 69	n =75, 51	n = 50, 67	n = 81, 79	n = 522, 360
Lean body mass (kg)								
DXA	Women	39.3 (3.9)	40.0 (4.1)	40.7 (4.3)	40.8 (4.5)	39.6 (3.1)	37.8 (4.0)	39.7 (4.2)
BIA		42.6 (4.4)[a]	43.1 (4.8)[a]	44.1 (4.6)[a]	43.7(4.7)[a]	41.7 (3.4)[a]	39.2 (4.5)[a]	42.6 (4.7)[a]
DXA	Men	57.7 (6.4)	58.1 (5.8)	58.0 (5.9)	56.6 (4.8)	57.4 (5.3)	54.1 (4.6)	56.8 (5.6)
BIA		59.2 (6.8)[a]	60.9 (6.8)[a]	60.9 (6.2)[a]	58.8 (5.7)[a]	58.8 (5.7)[a]	53.8 (4.8)	58.5 (6.5)[a]
Fat mass (kg)								
DXA	Women	20.4 (6.5)	19.3 (4.4)	22.6 (7.4)	23.1 (6.2)	25.1 (6.9)	24.3 (7.0)	22.3 (6.9)
BIA		16.9 (5.7)[a]	16.3 (4.2)[a]	18.8 (6.8)[a]	19.7 (5.6)[a]	22.3 (6.1)[a]	22.9 (6.9)[a]	19.2 (6.5)[a]
DXA	Men	14.2 (6.2)	19.3 (7.5)	20.1 (5.5)	18.9 (6.0)	20.3 (6.6)	19.7 (6.5)	19.0 (6.6)
BIA		11.6 (5.3)[a]	15.6 (6.0)[a]	16.0 (4.5)[a]	15.0 (5.3)[a]	17.6 (6.1)[a]	19.7 (6.0)	16.4 (6.1)[a]
Percentage of fat (%)								
DXA	Women	32.2 (6.4)	31.0 (4.9)	33.7 (7.4)	34.3 (6.6)	36.8 (6.4)	37.2 (6.5)	34.0 (6.9)
BIA		26.6 (6.0)[a]	26.1 (5.2)[a]	28.1 (7.0)[a]	29.4 (6.2)[a]	33.0 (5.7)[a]	34.9 (7.0)[a]	29.3 (7.0)[a]
DXA	Men	18.5 (7.0)	23.3 (7.2)	24.5 (5.5)	23.6 (5.6)	24.7 (6.3)	25.3 (6.3)	23.7 (6.6)
BIA		15.4 (5.9)[a]	19.1 (5.8)[a]	19.7 (5.0)[a]	19.1 (5.5)[a]	21.8 (6.2)[a]	25.2 (5.8)	20.6 (6.4)[a]

DXA, dual-energy X-ray absorptiometry; BIA, bioimpedance.
[a]$P < 0.001$ significantly different from DXA. Significant difference between age groups in all variables.

TABLE 3 Comparison of DXA and BIA in estimating body composition within and between groups according to leisure-time physical activity groups

Activity group			Low activity	Moderate activity	High activity	P			
			n = 54, n = 42	n = 289, n = 164	n = 142, n = 111				
Variable			**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Low-mod**	**Low-high**	**mod-high**	***P* for trend**
Lean body mass (kg)	Women	DXA	38.5 (3.9)	39.7 (4.3)	40.1 (3.4)	NS	0.031	NS	0.041
		BIA	41.7 (4.7)[a]	42.6 (4.9)[a]	42.6 (4.1)[a]	NS	NS	NS	NS
	Men	DXA	56.3 (6.1)	56.4 (5.3)	57.5 (5.9)	NS	NS	NS	NS
		BIA	58.4 (6.6)[a]	57.8 (6.1)[a]	58.9 (6.9)[a]	NS	NS	NS	NS
Fat mass (kg)	Women	DXA	22.6 (6.6)	19.4 (6.2)	20.2 (6.3)	0.001	>0.001	0.001	<0.001
		BIA	26.0 (6.8)[a]	22.5 (6.6)[a]	17.3 (5.9)[a]	0.002	>0.001	0.004	<0.001
	Men	DXA	17.9 (7.5)	19.6 (6.6)	17.8 (5.8)	NS	0.013	NS	0.012
		BIA	21.1 (7.6)[a]	16.9 (5.9)[a]	15.4 (5.6)[a]	NS	NS	NS	NS

Leisure time physical activity (LTPA) data was available from 485 women and 317 men.
DXA, dual-energy X-ray absorptiometry, BIA, bioimpedance.
[a]$P < 0.001$ significantly different from DXA. NS, not significant.

women and men in almost all age categories and all levels of LTPA compared to DXA. Furthermore, BIA provided lower estimates of FM and FAT% compared to DXA. In men over 70 years old, these two methods were comparable in body composition analysis at the group level. The bias between the assessment of LM, FM, and FAT% may be due to the algorithm used in Inbody^{TM} to estimate body composition (absence of age etc.), reference device or differences between populations in body geometry. Waist

TABLE 4 Multivariate regression model accounting for variance in difference between body composition estimates of dual-energy X-ray absorptiometry) and bioimpedance (BIA)

Dependent variable	Sex	Predictors in the model	B (SD)	β	P	R^{2a}
FAT% difference between methods (DXA-BIA)	Women	Age	−0.042 (0.007)	−0.278	<0.001	0.123
		Grip Strength	0.067 (0.019)	0.173	<0.001	
		Activity level	−0.432 (0.207)	−0.099	0.038	
FAT% difference between methods (DXA-BIA)	Men	Waist circumference	0.125 (0.031)	0.314	<0.001	0.114
		Age	−0.049 (0.018)	−0.205	0.009	
FM difference between methods (DXA-BIA)	Women	Grip strength	0.047 (0.014)	0.17	0.001	0.128
		Age	−0.029 (0.006)	−0.266	<0.001	
		Waist circumference	0.044 (0.011)	0.216	<0.001	
FM difference between methods (DXA-BIA)	Men	Waist circemference	0.14 (0.025)	0.416	<0.001	0.181
		Age	−0.04 (0.015)	−0.196	0.009	
LM difference between methods (DXA-BIA)	Women	Age	0.038 (0.006)	0.349	<0.001	0.174
		Waist circumference	−0.043 (0.011)	−0.212	<0.001	
		Grip strength	−0.042 (0.014)	−0.152	0.002	
		Activity level	0.409 (0.145)	0.131	0.005	
LM difference between methods (DXA-BIA)	Men	Waist circumference	−0.141 (0.024)	−0.431	<0.001	0.205
		Age	0.045 (0.014)	0.229	0.002	

FAT%, percentage of fat; FM, fat mass; LM, lean mass; DXA, dual-energy X-ray absorptiometry; BIA, bioimpedance.
[a]Adjusted R Square, women n = 397, men n = 152 in all models.

circumference, grip strength, and LTPA level explained methodological differences between body composition estimates.

Currently there are no standard acceptable limits of agreement for method comparisons within body composition literature. Therefore, careful scientific or practical judgment is always needed to estimate whether the mean difference and limits of agreements between two methods are within acceptable limits for the specific purpose. We found that the mean difference between estimates of LM in DXA and BIA is about 3% of total average LM in men. This is less than the measurement error in most body composition methods, and can, therefore, be interpreted as reasonable agreement at population level. In women, the difference was clearly higher, 7% units. The magnitude of difference between methods in women means that these methods cannot be used interchangeability in clinical work. For example, aging results in a 1% decrease in LM per year after the fifth decade (5), consequently a 7% mean error is more than the expected change in LM during one decade of accelerated loss. The individual difference in LM between estimates of BIA and DXA was could be considered as high and varied between −9.6 and 2.8 kg in women and −9.5 and 6.7 kg in men, indicating that individual error can be as high as 16% in women and 12% in men. Error of this magnitude makes it rather impossible to estimate effects of training or weight loss interventions on body composition as mean increases in LM, for example, during high intensity strength training for six months have been 2-3% (26). There was also a small tendency that BIA overestimates LM more at higher levels of LM compared to lower levels of LM, although correlations were quite weak.

Mean differences between DXA and BIA were approx. 14-15% in FM and FAT% both in women and in men. With very wide limits of agreement (up to −17 to 21% in FM in men) it is clear that, compared to DXA, BIA is not a reliable method for body composition estimates neither at the population level due to systematic scale difference nor at the individual level due to high inter-individual variation.

Body composition analyses *in vivo* are always based on assumptions specific to each method and device. Changes in body weight or composition that may occur with aging or physical training may violate the basic assumptions of these models (27). LM estimation of the Inbody™ BIA device is based on the common assumption that hydration of FFM is 73.2%. However, it is been reported that tissue hydration is affected by the aging process (28) and/or obesity, and can vary between 0.68 and 0.77 in healthy individuals (29). This type of error increases when the amount of LM increases, thus, it is possible that hydration assumption partly explains individual variation in BIA body composition estimates observed in this study, as well as significant correlations between mean LM and the difference between methods.

The first version of Inbody™ bioimpedance device has been validated against deuterium oxide dilution in total body water analysis (30) and against DXA in appendicular LM analysis (7). Thereafter several studies have investigated the accuracy of Inbody™ BIA (9-12,31,32). In line with a previous study that compared the same devices as in this study (Lunar Prodigy DXA and Inbody™ 720 BIA), we found that there is a wide range of individual error when assessing FM and FAT% in adults, and that BIA provides greater LM values and lower FAT% values compared to DXA in normal weight and overweight women and men (11). In contrast, Ling et al. (10) found Inbody™ BIA to be a valid method in body composition, especially LM analysis, in large sample of middle-aged adults when they estimated Inbody™ accuracy compared to Hologic QDR 4500 DXA. In summary, Inbody™ validation studies in DXA devices have produced mixed results (9,12,32). Part of these differences can possibly be explained by study populations (e.g., race, degree of obesity) and number of subjects, but it also seems clear that different DXA machines produce different results in validation studies with Inbody™ BIA. Although DXA has been accepted as a valid and reliable method for body composition analysis, different devices and software have been shown to give different estimates of body composition (33-36) and, for example, fan beam DXA has been reported to underestimate body fat by 4-7% in subjects with body fat exceeding 23% (37).

In this study, we found that waist circumference, age, grip strength, and LTPA level partly explained differences between body composition estimates of BIA and DXA. These predictors explained 11-20% of the variance between methods, depending on the variable and sex. A possible explanation why these factors were found to be significant predictors of the difference between methods is the different distribution of FM and LM in the trunk and appendages between active and inactive vs. young and old individuals. The present BIA device estimates total body FFM by using the sum of segmental resistances. Even though BIA algorithms should hold regardless of the FM/LM ratio, the arms and legs provide a higher amount of body impedance compared to total body volume (38), and simply summing these values results in the same prediction as total body analysis with bioimpedance. To increase method accuracy, different equations for limbs and trunk should be used. Predictive values of waist circumference, i.e., trunk fat has also been observed in the previous study of Shafer (12). It has been suggested that Inbody™ BIA cannot estimate trunk impedance accurately, which causes measurement errors in body composition estimates (12,32). This may result from assumptions behind BIA analysis (i.e., the body is assumed to be a cylinder), which do not take into account disparate body shapes.

In line with the study of Völgyi (11), we also found that age was a significant predictor in all body composition estimates both in women and in men. Although age and sex are often employed in BIA algorithms because of an increase in measurement accuracy (39), in Inbody™ BIA validation studies, age and sex did not improve measurement accuracy and were, therefore, excluded from the algorithms (7,30). Compared to those studies, our study was performed with a similar age span, but a greater number of subjects, which increases reliability. It must be taken into account that BIA validation studies are performed in the Korean population and, therefore, proprietary algorithms may not properly fit a European population due to different body geometry.

Higher levels of LTPA are associated with higher relative muscle mass and lower FM compared to sedentary persons. In this study, however, the differences between physical activity groups in LM were evident only between the low and high physical activity groups in women measured by DXA. A lack of between group differences in LM can be explained by higher body weight in the low and moderate activity groups compared to the high activity group. Thus, FM differed among activity groups both in women and in men, which confirms that splitting groups according to LTPA level based on activity diaries succeeded in this study. In women, both BIA and DXA found significant differences in FM in the low vs. moderate, moderate versus high, and low versus high LTPA groups. In men, there was a statistically significant difference in FM only between the low and high LTPA groups when FM was analyzed by DXA.

Strengths of this study include a very large sample of normal and mildly overweight women and men, which were measured according to the standardized practices and manufacturers detailed instructions by BIA and DXA. A representative dataset allowed us to describe estimates of body FM and LM over the adult age from 18- to 88-year-old and to investigate whether the difference between BIA and DXA methods is affected by age, sex, or level of physical activity. The large amount of subjects also allowed us to test the hypothesis that differences between estimates of body composition by BIA and DXA are affected by age, waist circumference, grip strength, and physical activity level.

In this study, baseline data from several different projects measured at the same research laboratory were merged into one database. Some of these projects were exercise interventions, thus, it is possible that the database includes a larger amount of individuals who are more interested in health, nutrition and sport than the average population. The pooled sample included Finnish women and men who were apparently healthy and whose' BMI varied between 18.5 and 32.5 kg/m^2. The results of this study are therefore limited to normal and mildly overweight 18- to 88-year-old subjects and should not be generalized to other adult populations such as underweight, obese, or those with very large/small muscle mass or to subjects whose' body geometry differs from a European population. Body composition estimates of BIA are based on electrical properties of the body tissue and, therefore, they are strongly affected by body water. Even though we performed BIA measurements in the fasting conditions, we did not control the menstrual cycle of our fertile female subjects. In this study, DXA was used as the reference method for body composition. To estimate the amount of fat and lean mass, DXA transforms dual-X-ray attenuations to the density of the two masses on a pixel-by-pixel basis. It must to be noted that possible inaccuracies in the DXA measurements cannot be clarified and there remains some uncertainty regarding the absolute truth of subjects' body composition.

Inbody™ BIA is rapid, relatively inexpensive, easy to use and, therefore, it owns a great potential for population health policy settings. Within the population of this study, eight polar BIA correlates well with DXA at the group level, thus, Inbody™ BIA has been validated against DXA in LM analysis (7). The underlying assumptions of BIA, however, produce a clear scale difference compared to Lunar Prodigy DXA, especially in fat analysis. In addition, the equations used to assess individuals in the BIA device result in high intraindividual variation between estimates of body composition. Knowledge about body composition is essential to evaluate health risks related to the accumulation of fat and risks for developing mobility limitations as a result of decreasing muscle mass with aging. Accurate measurement of body composition is difficult and results are highly dependent on the devices and algorithms used, regardless of what method is in question. Knowledge about the methodological limitations and comparability of different methods in different populations is essential, not only for researchers but also for clinicians and persons working in rehabilitation and sport centers. Based on the results of this study, persons working with these body composition devices should notice that BIA gives systematically lower estimates of body fat and higher estimates of body LM at the population level, and that use of this device is limited at the individual level due to high inter-individual variation. O

Acknowledgments

Gerontology Research Center is a joint effort between the University of Jyväskylä and the University of Tampere.

References

1. Janssen I, Ross R. Linking age-related changes in skeletal muscle mass and composition with metabolism and disease. *J Nutr Health Aging* 2005;9:408-419.
2. Starling RD, Ades PA, Poehlman ET. Physical activity, protein intake, and appendicular skeletal muscle mass in older men. *Am J Clin Nutr* 1999;70:91-96.
3. Beaufrere B, Morio B. Fat and protein redistribution with aging: metabolic considerations. *Eur J Clin Nutr* 2000;54 Suppl 3:S48-S53.
4. Zamboni M, Armellini F, Harris T, et al. Effects of age on body fat distribution and cardiovascular risk factors in women. *Am J Clin Nutr* 1997;66:111-115.
5. Greenlund LJ, Nair KS. Sarcopenia--consequences, mechanisms, and potential therapies. *Mech Ageing Dev* 2003;124:287-299.
6. Phillips SK, Rook KM, Siddle NC, Bruce SA, Woledge RC. Muscle weakness in women occurs at an earlier age than in men, but strength is preserved by hormone replacement therapy. *Clin Sci (Lond)* 1993;84:95-98.
7. Malavolti M, Mussi C, Poli M, et al. Cross-calibration of eight-polar bioelectrical impedance analysis versus dual-energy X-ray absorptiometry for the assessment of total and appendicular body composition in healthy subjects aged 21-82 years. *Ann Hum Biol* 2003;30:380-391.
8. Andreoli A, Scalzo G, Masala S, Tarantino U, Guglielmi G. Body composition assessment by dual-energy X-ray absorptiometry (DXA). *Radiol Med* 2009;114:286-300.
9. Demura S, Sato S, Kitabayashi T. Percentage of total body fat as estimated by three automatic bioelectrical impedance analyzers. *J Physiol Anthropol Appl Human Sci* 2004;23:93-99.
10. Ling CH, de Craen AJ, Slagboom PE, et al. Accuracy of direct segmental multi-frequency bioimpedance analysis in the assessment of total body and segmental body composition in middle-aged adult population. *Clin Nutr* 2011.
11. Volgyi E, Tylavsky FA, Lyytikainen A, Suominen H, Alen M, Cheng S. Assessing body composition with DXA and bioimpedance: effects of obesity, physical activity, and age. *Obesity (Silver Spring)* 2008;16:700-705.
12. Shafer KJ, Siders WA, Johnson LK, Lukaski HC. Validity of segmental multiple-frequency bioelectrical impedance analysis to estimate body composition of adults across a range of body mass indexes. *Nutrition* 2009;25:25-32.
13. Leahy S, O'Neill C, Sohun R, Jakeman P. A comparison of dual energy X-ray absorptiometry and bioelectrical impedance analysis to measure total and segmental body composition in healthy young adults. *Eur J Appl Physiol* 2011.
14. Ward LC. Segmental bioelectrical impedance analysis: an update. *Curr Opin Clin Nutr Metab Care* 2012;15:424-429.
15. Jebb SA, Goldberg GR, Elia M. DXA measurements of fat and bone mineral density in relation to depth and adiposity. *Basic Life Sci* 1993;60:115-119.
16. van der Ploeg GE, Withers RT, Laforgia J. Percent body fat via DEXA: comparison with a four-compartment model. *J Appl Physiol* 2003;94:499-506.
17. Finni T, Saakslahti A, Laukkanen A, Pesola A, Sipila S. A family based tailored counselling to increase non-exercise physical activity in adults with a sedentary job and physical activity in their young children: design and methods of a year-long randomized controlled trial. *BMC Public Health* 2011;11:944-2458-11-944.
18. Sillanpaa E, Hakkinen A, Laaksonen DE, Karavirta L, Kraemer WJ, Hakkinen K. Serum basal hormone concentrations, nutrition and physical fitness during strength and/or endurance training in 39-64-year-old women. *Int J Sports Med* 2010;31:110-117.
19. Cheng S, Volgyi E, Tylavsky FA, et al. Trait-specific tracking and determinants of body composition: a 7-year follow-up study of pubertal growth in girls. *BMC Med* 2009;7:5.
20. Xu L, Nicholson P, Wang QJ, Wang Q, Alen M, Cheng S. Fat mass accumulation compromises bone adaptation to load in Finnish women: a cross-sectional study spanning three generations. *J Bone Miner Res* 2010;25:2341-2349.
21. Pietrobelli A, Formica C, Wang Z, Heymsfield SB. Dual-energy X-ray absorptiometry body composition model: review of physical concepts. *Am J Physiol* 1996;271:E941-E951.
22. Haskell WL, Lee IM, Pate RR, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc* 2007;39:1423-1434.
23. Ainsworth BE, Haskell WL, Leon AS, et al. Compendium of physical activities: classification of energy costs of human physical activities. *Med Sci Sports Exerc* 1993;25:71-80.
24. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res* 2005;19:231-240.
25. Martin Bland J, Altman D. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;327:307-310.
26. Sillanpaa E, Laaksonen DE, Hakkinen A, et al. Body composition, fitness, and metabolic health during strength and endurance training and their combination in middle-aged and older women. *Eur J Appl Physiol* 2009;106:285-296.
27. Visser M, Gallagher D, Deurenberg P, Wang J, Pierson RN, Jr, Heymsfield SB. Density of fat-free body mass: relationship with race, age, and level of body fatness. *Am J Physiol* 1997;272:E781-E787.
28. Heymsfield SB, Gallagher D, Visser M, Nunez C, Wang ZM. Measurement of skeletal muscle: laboratory and epidemiological methods. *J Gerontol A Biol Sci Med Sci* 1995;50 Spec No:23-29.
29. Streat SJ, Beddoe AH, Hill GL. Measurement of body fat and hydration of the fat-free body in health and disease. *Metab Clin Exp* 1985;34:509-518.
30. Bedogni G, Malavolti M, Severi S, et al. Accuracy of an eight-point tactile-electrode impedance method in the assessment of total body water. *Eur J Clin Nutr* 2002;56:1143-1148.
31. Sartorio A, Malavolti M, Agosti F, et al. Body water distribution in severe obesity and its assessment from eight-polar bioelectrical impedance analysis. *Eur J Clin Nutr* 2005;59:155-160.
32. Salmi JA. Body composition assessment with segmental multifrequency bioimpedance Method. *J Sport Sci Med* 2002;2:1-29.
33. Aasen G, Fagertun H, Halse J. Effect of loss of regional fat assessed by DXA on insulin resistance and dyslipidaemia in obese men. *Scand J Clin Lab Invest* 2010;70:547-553.
34. Aasen G, Fagertun H, Halse J. Body composition analysis by dual X-ray absorptiometry: in vivo and in vitro comparison of three different fan-beam instruments. *Scand J Clin Lab Invest* 2006;66:659-666.
35. Genton L, Hans D, Kyle UG, Pichard C. Dual-energy X-ray absorptiometry and body composition: differences between devices and comparison with reference methods. *Nutrition* 2002;18:66-70.
36. Huffman DM, Landy NM, Potter E, Nagy TR, Gower BA. Comparison of the Lunar DPX-L and Prodigy dual-energy X-ray absorptiometers for assessing total and regional body composition. *Int J Body Compos Res* 2005;3:25-30.
37. Ellis KJ, Shypailo RJ. Bone mineral and body composition measurements: cross-calibration of pencil-beam and fan-beam dual-energy X-ray absorptiometers. *J Bone Miner Res* 1998;13:1613-1618.
38. Buchholz AC, Bartok C, Schoeller DA. The validity of bioelectrical impedance models in clinical populations. *Nutr Clin Pract* 2004;19:433-446.
39. Guo SS, Chumlea WC, Cockram DB. Use of statistical methods to estimate body composition. *Am J Clin Nutr* 1996;64:428S-435S.