Evaluation of Segmental Bioelectrical Impedance Analysis (SBIA) for Measuring Muscle Distribution

Kichul Cha, Ph.D., Sunyoung Shin[1], B.S., R.D., Cheongmin Shon[2], M.S., R.D., Seunghoon Choi[3] M.D., Ph.D., Douglas W. Wilmore[4] M.D.

1.Bioengineering Research Institute, Biospace Co., Ltd., Seoul, Korea
2.Division of Food and Nutrition. Seoul Nonal University Hospital, Seoul, Korea
3.Department of Surgery, College of Medicine, Yonsei University, Seoul, Korea
4.Department of Surgery, Brigham & Women's Hospital, Harvard Medical School, USA

Kichul Cha, Ph.D., Sunyoung Shin[1], B.S., R.D., Cheongmin Shon[2], M.S., R.D., Seunghoon Choi[3] M.D., Ph.D., Douglas W. Wilmore[4] M.D. Evaluation of Segmental Bioelectrical Impedance Analysis (SBIA) for Measuring Muscle Distribution. *J ICHPER · SD-ASIA. P.11-14, 1997* -A method using segmental bioelectrical impedance analysis (SBIA) has been evaluated for measuring segmental body composition.
Dual-energy X-ray absorptiometry(DEXA), anthropometry and SBIA were conducted simultaneously in 144 healthy adults (M=58, F=86). Muscle mass of the right arm, trunk, and right leg measured by DEXA were predicted by using anthropometry and SBIA methods. Using anthropometric measurements, a segmental cross-sectional area of muscle was calculated by measuring its circumference and skin-folds thickness. Using SBIA method, segmental impedance indexes ($Height^2/Resistance_{segment}$) were used for these calculations. DEXA results were closely related with segmental muscle areas by anthropometry in the arm (r=0.750) and leg (r=0.871). However, Similarly calculated area in abdomen was not related with DEXA soft lean mass of the trunk (r=0.253). The SBIA method estimated segmental muscle better than anthropometry method; r=0.953 (arm), 0.823(trunk), and 0.929(leg).
When the multiple regression technique was employed, the correlation coefficients were increased; r= 0.957 (arm), 0.948(trunk) and 0.929(leg). In conclusion, the SBIA method estimated whole body muscle mass as well as segmental muscle mass accurately. It was found that the distribution of muscle was significantly different between genders and between ages. This may indicate that the distribution of lean mass is related with the physical fitness and body shape.

Segmental BIA(Bioelectrical Impedance Analysis)

Bioelectrical impedance analysis (BIA) has been used to determine body compartments in health individuals (Kushner & Schoeller 1986 ; Lukaski et al., 1986 ; Segal et al., 1985) and in patients (Chertow et al., 1995; Fredrix et al., 1990; Guglielmi et al., 1991). BIA is an electrical method for estimating total body water in principles (Hoffer, 1969).Multifrequency BIA can also estimate intra- and extra-cellular fluid volumes (Cha et al., 1995 ; Kanai et al., 1983). Assuming that lean body mass(LBM) is hydrated in a constant and uniform manner, BIA can be used to estimate LBM By subtracting LBM from the weight, fat mass (the nonhydrated portion of the body) can be also calculated.

In traditional BIA methodology, a subject assumes the supine position and four ECG-type adhesive electrodes are placed on the right wrist and hand, and right ankle and back of the foot (Lukaski & Bolonchuk 1988). These electrodes connect to two current and two voltage terminals from an impedance meter. While an alternating current (often 50Khz, 800μA) is administered across hand and foot electrodes, the meter reads a voltage difference across wrist and ankle electrodes. Whole body resistance between the wrist and ankle is determined by the application of Ohm's law, that is the ratio of the voltage measured to the current administered. Then $height^2$/resistance is proportional to hydrated portion of the body such as total body water. Further details about these principles are available elsewhere (Ackmann & Seitz 1970; Kushner 1992).

The traditional BIA is based on the assumption that the hydrated portion of the body is uniform cylinder in its shape. However, body segments are significantly different in the size. Especially, the cross-sectional area of the arm is much smaller than that of the trunk. As a reasult the distal extremities, with their small cross-sectional areas, contribute disproportionately to whole body resistance and the body shape affects the accuracy of

BIA (Cha et al., 1995; Guglielmi et al., 1991; Thompson et al., 1993).

We have evaluated a segmental BIA method in which the body is assumed five cylindrical conductors (arms, trunk and legs), and the cross-sectional area of each segment is relatively constant. We have tested whether the segemtnal BIA method measures muscle mass of segments accurately and whether there are differences in the distribution of segmental lean and fat tissues between genders and between ages.

METHODS

Subjects :144 healthy subjects (male=58, female =86) participated in the present study. This study was approved by The Yonsei University, College of Medicine,Youngdong Severance Hospital, Seoul, Korea. Each subject submitted written consent.

Anthropometric Measurement : The sizes of the body were measured at various segments of the body while wearing light gowns. The measurements includes the height, weight, body circumferences, and skin-folds thickness. Height was measured to the nearest 0.5cm by using a linear height scale and weight was measured to the nearest 0.2Kg by using an electronic weight scale (150A,Computer Aided Systems, Seoul, Korea).

The circumferences of the body segments were measured by a non-extensible flexible linear scale. The measurement sites were the mid-upper arm, waist, hip and mid-thigh. The skin-folds thickness was measured by an analog skin-fold caliper (Eiyoken Type, Meikosha Co., Japan).The measurement sites were triceps, abdomen, and mid-thigh.

Segmental BIA: A conductor model of the human body was constructed (Fig 1). The body was approximated by five conductors; right arm, left arm, trunk, right leg, and left leg. Their resistances were R_{RA}, R_{LA}, R_T, R_{RL}, and R_{LL}, respectively.

A pair of resistances R_1 and R_2, representing thumb and palm, branched out distally from the wrist at the end of each arm resistance (R_{RA}, R_{LA}). Another pair of resistances R_3 and R_4, representing heel and front foot, branched out distally from the ankle at the end of each leg resistance (R_{RL}, R_{LL}). When measuring a subject, the individual stood upright stepping onto the foot electrodes and loosely gripping the hand electrodes, with his / her arms held vertically. The eight tactile electrodes were made of stainless steel. A hand electrode consisted of thumb (E2, E4) and palm (E1, E3) electrodes.

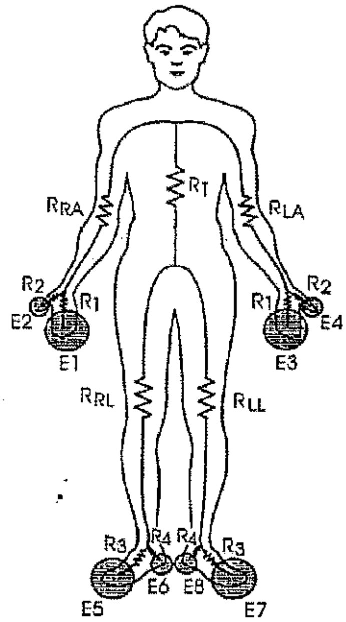


Fig1. A conductor model of the body: The body was approximated by five cylindrical conductors. R_{RA}, R_{LA}, R_T, R_{RL}, and R_{LL} were segmental resistances for right arm, left arm, trunk, right leg and left leg, respectively. Resistances(R1-R4) of thumb, palm, heel, and front foot were branched out distally from the end of each limb resistance.

Palm electrodes were made of pipes which were 10 cm long and 2.5 cm in diameter. Thumb electrodes were made of cylinders of 2.5 cm in diameter with a 45° cut face. A foot electrode consisted of two pieces of metal plates 2 mm thick; front sole (E5, E7) and rear sole (E6, E8) electrodes. Rear sole electrodes were 6.6×4.3 cm rectangle plates. Front sole electrodes were 6.6 × 13.5 cm rectangle plates. These electrodes were connected to current and voltage terminals from an impedance meter via electronic on-off switches, which were regulated by a microprocessor.

By regulating the switches in the appropriate on or off position, a target segment could selectively be measured. In order to measure R_{RA}, current terminals were connected to E1 and E5, and voltage terminals were connected to E2 and E4. While the current passed through R1, R_{RA}, R_T, R_{RL} and R3, voltage difference was measured across R2, R_{RA}, R_{LA} and R2. In this way, only the voltage drop occurring in the right arm was measured, where both current pathway and voltage detection circuits were overlapped.

The magnitudes of the peripheral resistances R1 - R4 did not affect segmental resistance measurement as input impedances of voltage pick up terminals were relatively high with respect to body resistances,indicating contact resistance changes did not affect the measurements.

While current terminals connected the same electrodes as for R_{RA}, voltage terminals were connected to E4 and E8 for R_T, and between E6 and E8 for R_{RL}. For the left side of the limbs, current terminals were connected between E3 and E7, voltage differences were measured similarly as the measurements for the right side of the body.

While a subject remained in the measurement posture, segmental measurements were made serially-one after another by changing the on-off switches automatically.

Segmental impedance was measured by a segmental impedance analyzer (InBody 2.0, Biospace Co. Ltd., Seoul, Korea). After explaining the measurement posture to the subjects, the individual stood onto the sole electrodes and gripped the hand electrodes, the microprocessor-controlled switches and impedance analyzer were started to measure segmental resistances of right arm, trunk and right leg. An alternating current at $100\mu A$ in the magnitude and 50 Khz in the frequency were used.

These results were stored on a personal computer and also printed on a data sheet. The trunk resistance showed slight fluctuations with respiratory and cardiac functions. Thus the mean of 11 serial resistances measured every second was used to determine trunk resistance.

DEXA Measurement: Dual Energy X-ray Asoptiometry (DEXA) was used to determine the composition of the body segements. When the subjects were supine, whole body scanns were made by a commercial DEXA machine (Lunar, Lunar Radiation Co., Wisconcin, USA). The results were printed out, including segmental fat, segmental soft lean, and segmental bone mass.

Calculations and Data Analysis: Impedance index representing conductive volume was defined as Ht^2/R, where Ht was height(cm) and $R(\Omega)$ was resistance. Assuming that the length of segmental body conductor was proportional to Ht, segmental indexes were Ht^2/R_{RA}, Ht^2/R_T, Ht^2/R_{RL} for the right arm, trunk and right leg, respectively. Using anthropometric measurements, muscle cross-sectional areas of body segments were estimated by segmental cross-sectional area subtracting the subcutaneous fat area.

Muscle circumference (S_m)

$= \text{Circumference} - \pi \times \text{skin-fold thickness}$

$$\text{Muscle area } (A_m) = \frac{S_m}{4\pi}$$

Segmental muscle masses determined by DEXA were predicted by segmental impedance indexes and muscle cross-sectional area of segments.

Statistical analysis were assessed by using SPSS/PC+ (SPSS Inc., Chicago, IL). One-way ANOVA (Duncan) was used to assess the significance of body characteristics between genders.

P-values < 0.05 were considered significant and data were expressed as mean and standard deviation(SD). Correlation of coefficient(r) and standard error of estimation (SEE) were calculated in the prediction of LBM by DEXA with segmental impedance indexes and anthropometric measurements.

RESULTS

The characteristics of subjects, the anthropometric data, body compartments by DEXA, and segmental resistance measurements are shown on Table 1.

Table 1. Subject Characteristics(MEAN±SD)

	Male (N=58)	Female (N=86)
Age (Yr)	33.6±14.1	42.8±14.0
Weight (Kg)	66.8±9.5	56.4±6.9
Height (cm)	170.4±6.1	158.0±5.3
BMI (Kg/m^2)	23.0±3.0	22.6±2.9
FAT (Kg)	11.3±5.9	17.2±5.3
Muscle (Kg)	51.3±4.8	35.5±2.8
Bone Mass (Kg)	2.94±0.43	2.33±0.29
Percent Body Fat (%)	16.3±6.5	29.8±6.2
R_{RA}	298.5±29.5	376.7±45.9
R_{LA}	307.1±31.1	381.8±47.8
R_T	24.1±2.7	26.4±2.6
R_{RL}	243.5±24.0	272.1±31.0
R_{LL}	248.5±24.6	273.0±29.3
Circumference arm	28.3±2.7	27.1±2.7
Circumference abdomen	78.1±8.6	78.7±9.7
Circumference hip	92.1±5.0	91.9±5.0
Circumference thigh	50.0±3.9	47.5±3.5
Skin-folds triceps	15.6±4.6	22.0±4.6
Skin-folds abdomen	24.6±10.9	29.5±8.0
Skin-folds thigh	16.8±6.3	27.5±6.6

BMI indicated that mean of the body size was approximately standard in both genders

Compositional differences between genders were similar to those previously described. Weight, height, and LBM were much greater in males, and fat mass and percent body fat were greater in females when compared to the other gender ($P < 0.05$).

Table 2. Segmental Distribution of Muscle and Fat by DEXA

	Ht	Wt	Muscle (kg)				Fat (kg)			
			Whole	Arm	Leg	Trunk	Whole	Arm	Leg	Trunk
Male										
17-29 y N=31	172.6	67.3	52.2 (78.5%)	3.15 (4.7%)	8.99 (13.5%)	24.5 (36.8%)	10.9 (15.2%)	0.58 (0.8%)	1.80 (2.52%)	5.3 (7.4%)
30-49 y N=13	169.0	67.4	51.1 (76.1%)	3.13 (4.7%)	8.54 (12.7%)	24.5 (36.5%)	12.2 (17.9%)	0.61 (0.9%)	1.79 (2.63%)	6.5 (9.5%)
50-65 y N=14	166.9	65.0	49.6 (76.7%)	2.95 (4.6%)	7.97 (12.3%)	24.5 (37.9%)	11.6 (17.3%)	0.59 (0.9%)	1.64 (2.50%)	6.3 (9.4%)
Female										
17-29 y N=18	163.9	54.2	36.3 (67.3%)	1.76 (3.25%)	6.42 (11.9%)	17.2 (32.0%)	14.1 (25.5%)	0.75 (1.35%)	2.72 (5.0%)	6.0 (10.7%)
30-49 y N=39	157.8	56.2	35.5 (63.6%)	1.90 (3.38%)	5.92 (10.62%)	17.3 (31.0%)	16.8 (29.2%)	0.90 (1.55%)	2.85 (5.0%)	8.0 (13.9%)
50-65 y N=29	154.7	58.1	35.0 (60.5%)	1.91 (3.30%)	5.60 (9.68%)	17.4 (30.1%)	19.5 (33.2%)	1.11 (1.88%)	2.87 (4.9%)	10.0 (17.0%)

In all body segments, segmental body resistances were lower in males than in females. While body circumferences on various body segments were similar in both genders, skin-folds thicknesses were much greater in females.

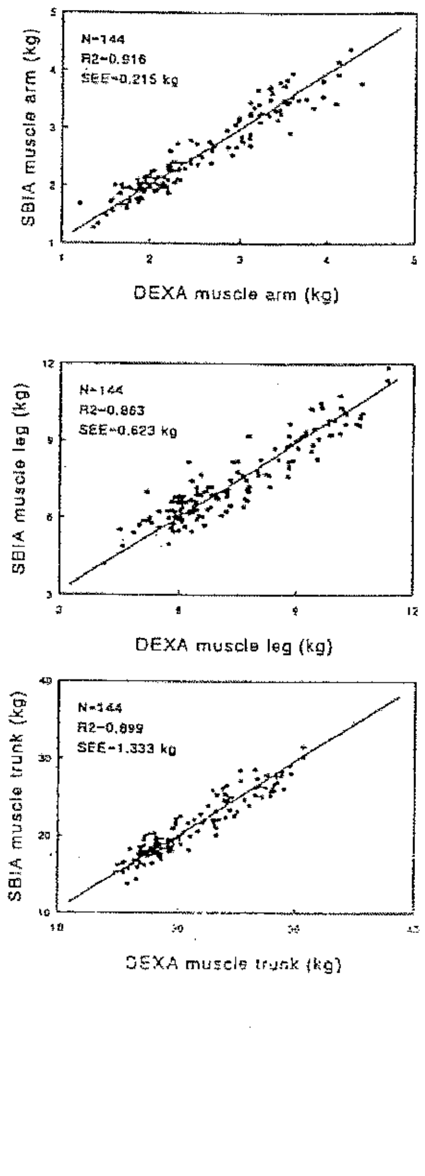
Muscle mass measured by DEXA (DEXA muscle) was closely related to the cross-sectional muscle areas calculated by anthropometric measurements and segmental impedance indexes in each segment as shown Fig.2. DEXA muscle of the right arm was related to the muscle area of the right mid-upper arm (r=0.750) and to impedance index of the right arm, Ht^2/R_{RA} (r=0.953). DEXA muscle of the right leg was related to the muscle area of the mid-thigh (r=0.871) and to impedance index of t-he right leg, Ht^2/R_{RL} (r=0.929). DEXA muscle of the trunk was related to impedance index of the trunk, Ht^2/R_T (r=0.823). However similarly calculated area of the abdomen was not related to DEXA muscle of the trunk (r=0.253). Muscle mass of a segment can be estimated more accurately by the segmental bioimpedance method than by anthropometric measurements.

When the regression using $Ht^2/(R_{RA}+R_T+R_{RL})$ was imployed for the measurement of whole body muscle mass, r was 0.940 and SEE was 2.76 kg. The results indicate that the impedance method can estimate segmental muscle mass as accurately as whole body muscle mass.

Table 2 shows segmental distribution of muscle mass and fat mass measured by DEXA.

In order to compare compositional differences, The subjects were divided into 6 groups according to their gender and age. In general, whole body muscle mass decreased and fat mass increased in older subjects. Arm muscle decreased in male but increased in females. Fat mass was increased more dramatically in female than in males. The fat increment in females was mainly occured in the trunk and in the arm.

Fig2. Segmental muscle mass determined by DEXA was related to segmental impedance index (a) arm, (b) leg, and (c) trunk.



DISCUSSION

This paper presents a segmental bioelectrical impedance method for measuring the distribution of muscle mass. In comparison with the conventional method, segmental resistance measurements were made with this new method rather than simply relying on one whole body measurement. Another characteristic of this method was the ability of the subject to assume an upright posture with 8-tactile electrodes rather than be measured in the supine position with relying on four electrodes a fixed to the skin with adhesive.

Since BIA has been introduced for body composition analysis in 1969(Hoffer et al.,1969), BIA has been proven to be accurate in the estimation of lean body mass or total body water in health subjects (Kushner & Schoeller 1986; Lukaski et al., 1986; Segal et al., 1985). The present study showed that the SBIA method could measure segmental muscle mass as accurately as the whole body muscle mass.

Among the body segments, the trunk showed the lower correlation coefficients. This may reflect the technical difficulties in measuring the impedance of the trunk. Because of resperation and cardiac functions, the impedance of the trunk with a relatively small resistance was fluctuating significantly during measurements. When multiple regression technique was imployed, using impedance index and weight, the correlation coefficient increased in the trunk (r=0.948).

Before the introduction of this methodology, segmental resistance measurements have been inaccurate. In a semental measurement method, measurements require the use of multiple electrodes and the manual connections and disconnections of cables for each segment (Chumlea et al., 1988). As a result, there has been a poor precision in repeated measurements.The present electrode method minimized these more cumbersome procedures and technical problems. Measurements with upright posture were made quickly without the concern of fluid redistribution which has been observed with supine measurements (Kushner et al., 1996).

In conclusion, a new segmental BIA method was utilized, which was extremely reproducible and accurate. Furthermore this technique had multiple advantages; it saves time, measures body segments conveniently and allows the subjects to make their own measurements. Further studies require to apply the results of segmental lean and fat distributions in clinical fields.

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