RESEARCH ARTICLE

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Direct Measurement with Bioelectrical Impedance Analysis Can Overestimate Muscle Mass Compared to Formula-Based Calculation Using Tissue Resistance

Objective: Measurement of the skeletal muscle mass (SMM) is recommended to diagnose sarcopenia. Multifrequency bioelectrical impedance analysis (mBIA) is the preferred method for measuring SMM. However, its accuracy can be low in certain instances, like obesity and edema, and different devices can give different results. We aimed to compare the direct BIA measurement of SMM with the formula-based calculation using tissue resistance.

Materials and Methods: A total of 210 healthy volunteers aged 18-40 years were included in the study. Participants' SMM_1 were measured directly using mBIA, and SMM_2 was calculated using the Janssen formula with tissue resistance. SMMI (kg/m^2) was calculated with SMM divided by height. Two standard deviations (SD) below the mean values of both measurements were accepted as cut-off points for low muscle mass.

Results: A total of 114 females (54.3%) and 96 males (45.7%) were included in the study (mean age: 26.6±5.5 years, mean BMI 23.7±4.0 kg/m^2). Mean $SMMI_1$ and $SMMI_2$ for males were 19.43±1.67 and 9.73±0.75 kg/m^2, which were 16.09±1.68 and 7.28±0.67 kg/m^2 for females. The cut-off points for low muscle mass according to $SMMI_1$ and $SMMI_2$ measurements were 16.19 and 8.23 kg/m^2 in males and 12.73 and 5.94 kg/m^2 in females, respectively.

Conclusion: The present study showed that Janssen's formula-based calculation of the SMM using tissue resistance of BIA is significantly lower than the SMM measured by BIA itself. BIA results obtained by direct measurement lead to higher cut-off values, so using formula-based SMM in clinical practice may prevent the overestimation of muscle mass and the prevalence of sarcopenia.

Key Words: *Muscle, skeletal muscle, bioelectrical impedance, sarcopenia*

Biyoelektrik Empedans Analizi ile Doğrudan Ölçüm, Doku Direnci Kullanan Formül Tabanlı Hesaplama ile Kıyasla Kas Kütlesini Fazla Tahmin Edebilir

Amaç: Sarkopeni tanısında iskelet kas kütlesinin (SMM) ölçülmesi önerilmektedir. SMM ölçümünde tercih edilen yöntem multifrekans biyoelektrik empedans analizidir (mBIA) fakat obezite, ödem gibi durumlar ve cihaz farklılıkları BIA değerlerini etkilemektedir. Çalışmamızda SMM' nin doğrudan BIA ölçümü ile doku direncini kullanan formül tabanlı hesaplamayı karşılaştırmayı amaçladık.

Gereç ve Yöntem: Çalışmaya 18-40 yaş arası 210 sağlıklı gönüllü dahil edildi. mBIA kullanılarak doğrudan ölçümle SMM_1 ve doku direnciyle Janssen formülü kullanılarak ise SMM_2 hesaplandı. SMMI (kg/m^2), SMM'nin boya bölünmesiyle hesaplanmıştır. Her iki ölçümün ortalama değerlerinin iki standart sapma (SD) altı düşük kas kütlesi için sınır değer olarak kabul edilmiştir.

Bulgular: Çalışmaya 114 kadın (%54,3) ve 96 erkek (%45,7) dahil edildi (ortalama yaş: 26,6±5,5 yıl, ortalama VKİ 23,7±4,0 kg/m^2). Erkekler için ortalama $SMMI_1$ ve $SMMI_2$ 19,43±1,67 ve 9,73±0,75 kg/m^2, kadınlar için 16,09±1,68 ve 7,28±0,67 kg/m^2 saptandı. $SMMI_1$ ve $SMMI_2$ ölçümlerine göre düşük kas kütlesi için sınır değerler sırasıyla erkeklerde 16,19 ve 8,23 kg/m^2, kadınlarda 12,73 ve 5,94 kg/m^2 saptandı.

Sonuçlar: Doku direncini kullanarak hesaplanan formül tabanlı SMM, direk ölçüme kıyasla önemli ölçüde daha düşük saptandı. Doğrudan ölçümle elde edilen mBIA sonuçları daha yüksek sınır değerlerle sonuçlanır bu yüzden klinik uygulamada formüle dayalı SMM kullanılması kas kütlesinin ve sarkopeni prevalansının fazla tahmin edilmesini önleyebilir.

Anahtar Kelimeler: *Kas, iskelet kası, biyoelektrik empedans, sarkopeni*

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Introduction

Sarcopenia is characterized by the diffuse progressive loss of muscle mass, strength, and physical capacity (1). Muscle mass measurement can be defined with skeletal muscle mass (SMM), appendicular skeletal muscle mass (ASM), SMM index (SMMI), and ASM index (ASMI) (2). Although dual X-ray absorptiometry (DEXA), computerized tomography (CT) and magnetic resonance imaging (MRI) are the gold standards for the measurement of the muscle mass, bioelectrical impedance analysis (BIA) is the most preferred method due to its practical usage, easy to access, and low cost.

European Working Group on Sarcopenia in Older People (EWGSOP) recommended using 2-SD below the mean of reference healthy young adults as the cut-off value for sarcopenia (3). EWGSOP suggests that each population should determine its cut-off values in healthy young individuals to assess muscle mass. Therefore, we need formulae and population-specific cut-off values for these formulae to account for the effect of these variables on muscle mass.

BIA is a rapid, non-invasive, and easy-to-use method of measuring body composition (4). It uses a weak electrical current passed through electrodes to estimate the body's water, fat, and muscle mass (5). However, the accuracy of BIA can vary from individual to individual, and sensitivity problems can arise due to technological factors (6). It may need to be used cautiously, particularly in standardization and accuracy. Measure skeletal muscle mass by BIA varies depending on factors such as BIA resistance index, population, gender, and anthropometric measurements (7). Moreover, direct muscle mass measurement with BIA itself can overestimate muscle mass. In this study, we aimed to compare the direct BIA measurement of SMM with Janssen's Formula-based calculation using tissue resistance in the healthy adult population.

Materials and Methods

Research and Publication Ethics: Ethical approval was obtained from the Ethics Review Committee of Istanbul Faculty of Medicine, Istanbul University, Türkiye. Ethical approval number: 2023/2240

Study Design and Participants: This cross-sectional observational study involved 210 healthy adult volunteers aged 18-40 in December 2023. Individuals with any acute or chronic diseases and/or medical disorders, chronic drug usage, history of surgery within the last three months, those with metal implants (prosthesis, pacemaker), and pregnancy were excluded.

Anthropometric Measurements: Body mass index (BMI; kg/m^2) was calculated by measuring height and weight in the morning after an overnight fast and with an empty bladder. Anthropometric analysis was performed with a multifrequency BIA device (Tanita MC780 MA, Japan).

Skeletal Muscle Mass (SMM) Measurement: SMM was measured or calculated with i) mBIA (SMM_1) and ii) Janssen's Formula [SMM (kg) = ($Ht^2/R \times 0.401$) + ($3.825 \times$ gender) + (age $\times$ 0.071) + 5.102], where "Ht" is height in centimeters, "R" is resistance in ohms measured with mBIA, and for the gender, male=1 and the female=0 (SMM_2) (12). SMM index (SMMI) was calculated with SMM (kg) divided by the height in meters.

Statistical Analysis: Data were analyzed using SPSS 26.0 for Windows (Armonk, NY: IBM Corp.). Data were expressed as mean, SD, median, frequency (n), ratio, maximum and minimum. The normal distribution of variables was assessed using the Kolmogorov-Smirnov test. Continuous variables were compared using independent samples, t-tests, and Mann-Whitney U tests. Categorical variables were compared using the Chi-square test or Fisher's exact test, as appropriate. A p-value less than 0.05 was considered statistically significant.

Results

The study included 210 participants, 114 (54.3%) female and 96 (45.7%) males, with a mean age of 26.6±5.5 years and a mean BMI of 23.7±4.0 kg/m^2 (female: 22.4±3.9 kg/m^2, male: 25.2±3.8 kg/m^2).

The mean SMM and SMMI measurements of both genders according to different measurement tools are shown in Table 1. In males, mean SMM_1 and SMM_2 were 60.7±7.5 and 30.3±3.1 kg, respectively, while in females, they were 43.5±5.2 and 19.7±2.1 kg. Mean $SMMI_1$ and $SMMI_2$ were 19.43±1.62 and 9.73±0.75 kg/m^2 in males and 16.09±1.68 and 7.28±0.67 kg/m^2 in females.

Table 2 shows the cut-off values determined with 2-SD below the mean values for male and female participants. The SMMI cut-off for low muscle mass in males was 16.19 kg/m^2 using direct mBIA measurement, which was 8.23 kg/m^2 using Janssen's formula ($p<0.001$). Similarly, the SMMI cut-off for low muscle mass in females was 12.73 kg/m^2 using direct mBIA, compared to 5.94 kg/m^2 using Janssen's formula ($p<0.001$).

Table 1. Mean SMM and SMMI measurements of the participants by two different methods

	Male		p Value	Female		p Value
	Mean	SD		Mean	SD	
SMM_1 (BIA measurement, kg)	60.7	7.5	<0.001	43.5	5.2	<0.001
SMM_2 (Janssen's Formula, kg)	30.3	3.1		19.7	2.1	
$SMMI_1$ (SMM_1/m^2) (kg/m^2)	19.43	1.62	<0.001	16.09	1.68	<0.001
$SMMI_2$ (SMM_2/m^2) (kg/m^2)	9.73	0.75		7.28	0.67	

SMM: Skeletal muscle mass, SMMI: Skeletal muscle mass index, SD: Standard deviation

Table 2. Cut-off values of SMM and SMMI for both gender (2-SD below the mean values) by two different methods

Cut-off Values	Males	p Value	Females	p Value
SMM_1 (BIA measurement, kg)	45.7	<0.001	33.1	<0.001
SMM_2 (Janssen's Formula, kg)	30.3		15.5	
$SMMI_1$ (SMM_1/m^2) (kg/m^2)	16.19	<0.001	12.73	<0.001
$SMMI_2$ (SMM_2/m^2) (kg/m^2)	8.23		5.94	

SMM: Skeletal muscle mass, SMMI: Skeletal muscle mass index, SD: Standard deviation

Discussion

Sarcopenia is associated with frailty, quality of life, morbidity, and mortality. Low muscle strength and muscle mass are the hallmarks of sarcopenia (8), and population-specific cut-off values for muscle strength and muscle mass need to be established in different populations (9).

The accuracy of muscle mass measurement depends on the population examined and the method of analysis. MRI, CT, and DEXA are difficult to access and implement and impractical for evaluating large populations in different settings (10). BIA is the method of choice for measuring muscle mass. It is a widely available, rapid, non-invasive, inexpensive, and easy-to-use analysis that does not require advanced training. It can be used in both outpatients and inpatients (3). It uses the electrical permittivity of tissues, and the bioelectrical impedance consists of resistance (R) and reactance (Xc). EWGSOP recognizes it as a favorable alternative to DEXA (2,10). However, its accuracy can be low in certain instances, like obesity and edema, and different devices can give different results. Recently, multifrequency BIA devices have provided more accurate results regarding body water distribution, lean body mass, fat mass, tissue resistance, and reactance measurements (8). In our study, the mean SMM and SMMI of the participants and their cut-off values for low muscle mass (2-SD below the mean values) were significantly higher with direct mBIA measurements when compared to Janssen's formula calculation using R of mBIA. Higher cut-off values lead to false positives, overestimation, and unnecessary treatment. As direct BIA assessments falsely overestimate FFM cut-off values, population-specific formulae for the BIA have been developed. These formulae are usually determined by comparison with the gold standard DXA. In the Caucasus, a BIA equation was developed by Kyle et al. in 2003 using multiple regression, and in 2014, Sergi et al. developed a more efficient equation for ASMM (11, 12). Also, in 2014, a prediction equation was developed by Yoshida et al. (13). A very recent study compared many BIA equations with DXA and suggested that population-specific cut-offs need to be established in older adults (14).

Many populations have reported different results regarding muscle mass cut-off values using BIA. As the Janssen formula is used in many ethnic groups, we wanted to evaluate the cut-off values of this formula in our study. SMMI cut-off values for older men and women were 8.87 kg/m^2 and 6.42 kg/m^2 in Taiwan (Maltron BioScan 920, Rayleigh, UK), 8.6 kg/m^2 and 6.2 kg/m^2 in France (Impedimed, Brisbane, Australia), 8.3 kg/m^2 and 6.7 kg/m^2 in Spain (RJL Systems BIA 101) using the Janssen formula (15-17). In the NHANES IV study, healthy individuals aged 20-30 years were used as the reference population to determine the low SMMI threshold, defined as 2-SD below the mean SMMI, which was 6.81 kg/m^2 for men and 5.18 kg/m^2 for women using DEXA (18). BIA typically has higher cut-off values than DXA.

Previous studies in young reference groups from two different provinces of Turkey have reported SMMI thresholds of 9.2 kg/m^2 for males and 7.4 for females using direct BIA measurement of SMM, and 8.33 kg/m^2 for males and 5.70 kg/m^2 for females using the Janssen formula (8, 19). In our study, using the Janssen formula, the SMMI cut-off values for low muscle mass were 8.23 kg/m^2 for males and 5.94 kg/m^2 for females (Table 2). The difference in cut-off values between our study and Ates Bulut et al. (19) is due to the use of a more advanced Tanita device in our study.

The study's limitations were that it was a single-center study, and there was no comparison with DEXA or MRI, considered gold standards for measuring muscle mass.

In conclusion, the Janssen formula using resistance obtained by mBIA shows better results than previous data. Direct BIA measurement of SMM may overestimate muscle mass. Muscle mass cut-offs obtained with direct BIA measurements may lead to false positive diagnoses of sarcopenia in clinical practice.

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