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Review of the Cut-off Thresholds for Muscle Masses in Diagnosis of Sarcopenia and Creation of a New Appendicular Muscle Mass Estimation Equation Suitable for the Turkish Population

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ABSTRACT

Objective: The aim of our study is to compile the muscle mass index and cut-off levels of the height squared-, weight-, and body mass index-adjusted models, used in the literature for the diagnosis of sarcopenia. The study also aims to create a new appendicular skeletal muscle mass estimation equation for non-segmental bio-impedance analyzer and to determine the relationship between all these muscle mass *indices* and muscle strength.

Methods: Body composition was assessed with bio-impedance analyzer, and muscle strength was assessed by hand grip strength with hand dynamometer. Absolute muscle mass, fat free mass, skeletal muscle mass, and appendicular skeletal muscle mass levels measured by bio-impedance-analyzer were calculated with the estimation equations defined in the literature; separately, height-, weight-, and body mass-indexed models were created. The averages of these *indices*, 2 standard deviation low, as well as correlation analysis with hand grip strength were performed. Multiple linear regression analyses were performed to construct the appendicular skeletal muscle mass estimation equation.

Results: A total of 200 young healthy individuals aged 18-40 years (50% male) were included in the study. The cut-off thresholds were 28/16 for hand grip strength; 20.1/13.3 kg for appendicular skeletal muscle mass; 7.0/5.4 kg/m^2 for appendicular skeletal muscle mass/height squared; 29.7/22.8% for appendicular skeletal muscle mass/weight; 0.81/0.56 for appendicular skeletal muscle mass/body mass index based on 2 standard deviation lower in men and women, respectively. The linear regression analysis, which has a high correlation with hand grip strength (*r*: 0.719; $P < .001$), the appendicular skeletal muscle mass estimation, quite strong (adjusted R^2: 0.959), was presented as a new equation: $\text{ASMM} = 3.567 + (0.119 \times h^2/Z) + (4.323 \times \text{gender}) + (0.164 \times \text{weight})$. The height squared in cm^2; for gender men = 1 and women = 0; weight in kg; Z is bio-impedance-analyzer impedance in 50 Ω frequency.

Conclusion: This study showed us that body mass index-adjusted models were more strongly correlated with muscle strength than both height- and weight-indexed models, which differ from those commonly used in the literature.

Keywords: Appendicular muscle mass estimation equation, cut-off thresholds, malnutrition, muscle masses, sarcopenia

INTRODUCTION

The definition of sarcopenia, which is characterized by a decrease in age-related muscle function and mass, has been updated with some changes in the last decade. According to the 2010 report of the European Working Group on Sarcopenia in Older People (EWGSOP), muscle mass loss was predominant than the loss of muscle strength, and muscle mass loss without loss of muscle strength was defined as "presarcopenia." If loss of muscle strength was added to muscle mass loss, it was defined as "sarcopenia," and if loss of performance was added to sarcopenia, it was defined as "severe sarcopenia".[1] In the EWGSOP 2018 update, sarcopenia was defined as "muscle failure" and primarily focused on low muscle strength as a key characteristic of sarcopenia, uses detection of low muscle quantity and quality to confirm the sarcopenia diagnosis, and identifies poor physical performance as indicative of severe sarcopenia.[2]

There is a consensus in the literature on gender-specific cut-off levels for muscle strength loss, which is now the

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first step in the definition of sarcopenia. However, many estimation formulas have been developed especially with bio-impedance method for the detection of muscle mass loss, which is necessary for the diagnosis of sarcopenia, and thus many cut-off points have emerged in the diagnosis. In the literature, based on absolute muscle mass (MM), fat free mass (FFM), skeletal muscle mass (SMM), appendicular skeletal muscle mass (ASMM), different *indices* have been formed by correcting according to height squared or weight or body mass index (BMI), and in general, 2 standard deviation (SD) lower and sometimes 1 SD lower of the young healthy population have been determined as the cut-off point. However, global or regional standardized cut-off levels are not yet available. Therefore, a researcher who wants to do research about sarcopenia has serious confusion as to which index s/he should use during the diagnosis stage.

Due to this complexity in the literature, we planned this study. The aim of this study is to create a reference group of healthy young adults between the ages of 18 and 40 and to compile the muscle mass *indices* that have been defined in diagnosis of sarcopenia for bio-impedance method and to compare the muscle mass estimation equations developed in different countries. Starting from this, our second goal is to develop a new estimation equation suitable for body composition analyzer (BIA) unable to perform segmental analysis. Third, as the EWGSOP final report emphasizes, the aim of this study is to find the most powerful muscle mass prediction equation and index by prioritizing muscle strength.

METHODS

The study was conducted in cross-sectional fashion and complied with the Helsinki Declaration. The permission of the Ethics Committee was received prior to the commencement of the study (date: 28/11/2017 and no: 2017/514/118/12).

Participants

The sample size was calculated using the prevalence of 13%, margin error of 5%, confidence level of 95%, and missing data of 15%. The target sample size was determined as 200 participants by using $[(Z1 - \alpha)^2\, p(1 - p)]/d^2$ formula.

A total of 200 healthy individuals (100 females, 100 males) of young adults aged 18-40 years without any disease were included in the study. Participants were randomly selected from the relatives of the patients who came to the hospital and medical staff. Those with the following conditions were excluded from the study: any unstable diseases, known inflammatory disease, an acute illness, pregnancy.

Body Composition Analysis by Bioelectrical Impedance

On arrival for clinical testing, participants were asked to empty their bladders, following which their height and weight were measured. The heights and waist circumferences (WC) of the healthy adults were measured in standing position. The hand grip strength (HGS) was measured 3 times from the dominant hand with hand dynamometer to determine the muscle strength (Takei physical fitness test) and the highest values were recorded. The instructions of the manufacturer were considered in analyzing the body composition according to BIA in light clothes and bare feet without eating and drinking for at least 4 hours before the analyses.

Muscle mass was estimated using an 8-polar segmental BIA (Tanita BC 418®). Appendicular skeletal muscle mass was obtained by adding muscle masses of upper and lower extremities. This device produces an 800 μA constant sinusoidal current at a single frequency of 50 kHz. The actual parameter measured with BIA is the voltage (V) that is produced between 2 electrodes located most often at sites near to, but different from, the sites where current is introduced. The measurement normally is expressed as a ratio, V/I, which is also called impedance (Z). The measuring instrument is therefore called a bioelectrical impedance analyzer. Impedance has 2 components, resistance (R) and reactance (X). In BIA, the resistance is nominally about 250 Ω, and reactance is about 10% of that amount, so the magnitude of Z is similar to that of R.[3] Our machine reported only the impedance values. Although in many BIA reports, Z and R are used as if they are interchangeable, we calculated R and X according to this formula: $Z = \sqrt{(R^2 + X^2)}$. These values were then entered into the prediction equations, and these BIA equations were used to predict SMM and ASMM (kg).

Prediction Equations

The mean HGS was calculated for the gender-specific muscle strength of the participants from young healthy individuals, and the 2 SDs lower of the mean were determined as the cut-off point for the loss of muscle strength (dynapenia).[4] For sex-specific muscle mass assessment, in addition to MM, FFM, and ASMM which were calculated automatically by machine, the SMM formula developed by Janssen and 5 different ASMM formulas validated with Dual Energy X Ray Absorptiometry (DEXA) were developed in different countries so far for estimation. These estimation equations are as follows:

SMM (Janssen) = (h^2/R × 0.401) + (gender × 3.825) – (age × 0.071) + 5.102. (Canada/2002)[5]

ASMM (Kyle) = (h^2/R × 0.267) + (gender×1.909) + (weight × 0.095) – (age × 0.012) + (Xc × 0.058) –4.211. (Switzerland/2003)[6]

ASM (Kim) = (h^2/R × 0.104) + (gender × 2.954) – (age × 0.050) + (weight × 0.055) +5.663. (Korea/2014)[7]

ALM (Yoshida) = (h^2/Z50 × 0.197) + (weight × 0.179) – 0.019 for men,

= (h^2/Z50 × 0.221) + (weight × 0.117) + 0.881 for women. (Japan/2014)[8]

ASMM (Peniche) = (h^2/R × 0.2394) + (gender × 2.708) +(weight × 0.065) – 0.05376(Mexico/2015)[9]

ASMM (Sergi) = (RI × 0.227) + (gender × 1.384) + (weight × 0.095) + (Xc × 0.064) – 3.964. (Italy/2015)[10]

The h^2 is height square in cm^2; for gender, men = 1 and women = 0; age is in years; weight in kg; R is BIA-resistance in ohms (Ω); Xc is BIA-reactance in Ω; Z is BIA-impedance in Ω; RI is resistance normalized for stature. While Janssen, Kyle, and Peniche used 50 Ω single-frequency BIA in their studies, Kim used 250 Ω multi-frequency BIA and Yoshida used 50 Ω multi-frequency BIA.

Formation of New Appendicular Skeletal Muscle Mass Estimation Equation Suitable for Non-segmental Bio-impedance Analyzers

The currently recommended parameter for the diagnosis of sarcopenia is ASMM. With the hand-to-*foot* segmental BIA devices, individual muscle masses of the extremities can be calculated and ASMM can be obtained from the sum of these. However, ASMM cannot be calculated with *foot-to-foot* non-segmental BIA devices. Because of this need, we aimed to create a predictive equation suitable for the estimation of ASMM based on the equations developed in various countries. For this purpose, we tried to form the most appropriate equation with multiple linear regression instruments by adding the physical properties of our reference group as well as the BIA impedance level.

Creating Indices

There is consensus all over the world in the definition of BMI, which is the ratio of weight to height squares (kg/m^2). However, a large range of *indices* has been created by compiling the *indices* defined so far. Absolute muscle mass was adjusted for body size in different ways, namely using height squared (MM/h^2), weight (MM/w), and BMI (MM/BMI). Fat-free muscle mass, SMM, and ASMM (separately for all equations) were adjusted in the same ways, respectively, FFM/h^2, FFM/w, FFM/BMI; SMM/h^2, SMM/w, SMM/BMI, and ASMM/ h^2, ASMM/w, ASMM/BMI.

Statistical Analyses

The SPSS (IBM Statistical Package for Social Sciences-version 22 for Windows) and Microsoft Excel 2010 were used to analyze the data and any score was deemed significant if it was $\alpha < 0.05$. Initially, a descriptive data analysis was done to compare the population that participated in the study according to the gender. For biochemical and muscle parameters, the descriptive statistics were given with arithmetic means, SDs and 2 SD below of means. Multiple linear regression analyses were performed to create the ideal ASMM equation for our society and the most ideal equation was used. Linear correlation analysis was performed and correlation coefficients (r^2) were determined by scatter dot graphs in order to determine the correlation between the results of different methods and HGS.

RESULTS

New Appendicular Skeletal Muscle Mass Estimation Equation Suitable for Non-segmental Bio-impedance Analyzers

We created a predictive equation for ASMM estimation by BIA method. In addition to the impedance value of the BIA, the variables of height, weight, and sex were used in the estimation equation. The age variable did not have a significant effect on the formula and therefore was not used. The selected model had an adjusted $R^{2\prime}$ of 0.965 and performed each regression assumption. The equation is as follows:

ASMM = (h^2/Z × 0.119) + (4.323 × gender) + (0.164 × weight)+3.567

(The h^2 is height square in cm^2; for gender, men = 1 and women = 0; weight in kg; Z is BIA-impedance in 50 Ω frequency.)

As shown in the Figure 1, the correlation between this new estimation equation and the BIA data (r^2: 0.965) was found to be very strong.

Differences Among Muscle Mass/Indices and Cut-off Thresholds in Assessing Sarcopenia

In Table 1, means of the MM, FFM, SMM, and ASMM of young healthy adult participants according to gender;

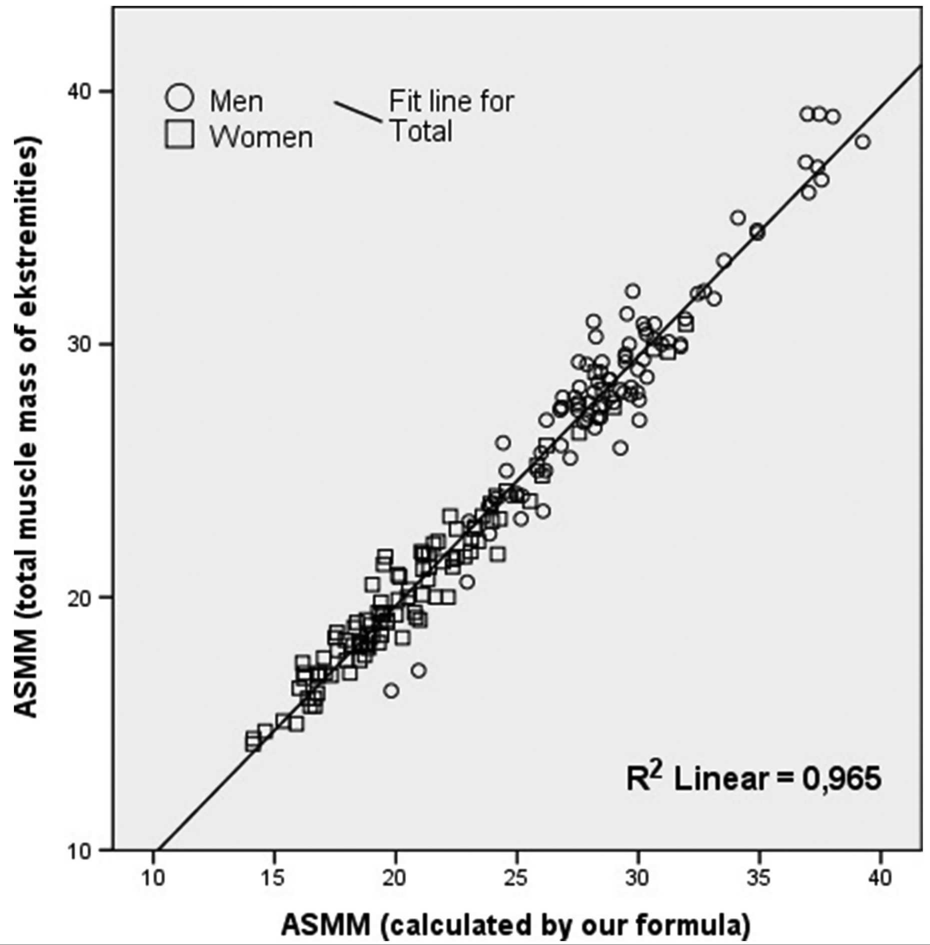

Figure 1. The correlation between ASSM of our new estimation equation and the BIA data

muscle mass index averages, *indices* corrected according to height, weight, and BMI; 2-SD below averages which were generally accepted cut-off points for sarcopenia.

The cut-off levels of HGS in men and women are respectively 28/16.

While the mean sum of extremities of the ASMM measured by BIA was 28.6 ± 4.3 kg/20.3 ± 3.5 kg in men and women, the mean ASMM calculated with our formula was 29.1 ± 3.8 kg/20.8 ± 3.7 kg. Therefore, the cut-off levels were 20.1/13.3 in men and women, respectively, according to the sum of extremities; 21.47/13.45 according to the equation that we created. The means of SMM were found to be 34.5 kg/24.9 kg, and 2-SD lower of the means were determined 22.7 kg/16.8 kg as cut-off points in males and females, respectively. The averages of other muscle mass estimates and 2-SD low levels are shown in Table 1 comparatively.

Estimation equation which gives the closest result to ASMM (except for the equation created by us) was calculated with ASMM (Yoshida); the lowest ASMM estimate was obtained by Kim equation. Peniche predicts a higher ASMM in men than Sergi, while it is the opposite in women. This is probably due to the difference in sex multiplier, the same for the h^2-, w-, and BMI-adjusted muscle mass *indices*. The cut-off levels of ASMM/h^2, which is one of the most commonly used *indices* in the diagnosis of sarcopenia, are 6.97/5.41 in males and females, respectively. In addition, the cut-off levels of SMM/w, which is another most frequently used *indices* in the diagnosis of sarcopenia, are 27.5%/23.3% in men and women, respectively, in our study. All other *indices* and adjusted models proposed or not proposed yet in the literature are summarized in Table 1.

Correlations Between Muscle Strength and Muscle Mass Indices

The correlation between these measured and calculated *indices* with muscle strength was demonstrated in Table 2. The strongest correlation between muscle mass and muscle strength was determined by ASMM calculated according to the equation developed by Kim

Table 1. Differences Among Muscle Mass and Muscle Strength *Indices* Derived from Height-, Weight-, and Body Mass Index-Adjusted Models and Cut-Off Points of the Young Healthy Adult Reference Group in Assessing Sarcopenia

		Male			Female		
		Mean	SD	2 SD	Mean	SD	2 SD
	Age (years)	28.9	5.8		27.9	5.8	
	Height (cm)	176.1	7.4		161.5	6.7	
	Weight (kg)	80.1	16.6		68.0	18.3	
	Body mass index (kg/	25.7	4.6		26.0	6.6	
	Hand grip strength	43.5	7.7	28.1	24.8	4.3	16.1
Muscle mass	Muscle mass (kg)	59.76	8.90	41.95	43.03	6.54	29.96
	Fat free mass (kg)	63.37	9.37	44.63	46.40	7.37	31.65
	ASMM (kg)	28.59	4.27	20.1	20.28	3.48	13.3
	SMM (Janssen)	34.50	5.92	22.66	24.93	4.04	16.84
	ASMM (Kyle)	26.07	4.53	17.00	19.30	3.72	11.85
	ASMM (Peniche)	24.35	4.22	15.91	17.38	3.38	10.62
	ASMM (Sergi)	23.66	3.95	15.77	18.00	3.32	11.35
	ASMM (Kim)	19.50	2.27	14.95	14.26	1.94	10.38
	ASMM (Yoshida)	27.82	5.12	17.58	20.79	4.04	12.72
	ASMM (Ours)	29.06	3.80	21.47	20.76	3.65	13.45
h^2 adjusted (kg/m^2)	Muscle mass (kg)	19.22	2.17	14.88	16.47	2.08	12.31
	Fat free mass (kg)	20.37	2.25	15.88	17.76	2.45	12.87
	ASMM (kg)	9.27	1.15	6.97	7.93	1.26	5.41
	SMM (Janssen)	11.09	1.60	7.90	9.55	1.43	6.70
	ASMM (Kyle)	8.37	1.15	6.07	7.38	1.30	4.79
	ASMM (Peniche)	7.82	1.10	5.62	6.66	1.21	4.23
	ASMM (Sergi)	7.60	0.99	5.63	6.89	1.16	4.58
	ASMM (Kim)	6.28	0.59	5.11	5.47	0.70	4.07
	ASMM (Yoshida)	8.93	1.33	6.28	7.96	1.45	5.06
	ASMM (Ours)	9.40	.98	7.43	7.92	1.29	5.33
w adjusted (%)	Muscle mass (kg)	75.62	6.45	62.72	65.36	8.84	47.67
	Fat free mass (kg)	80.18	6.70	66.78	70.28	8.63	53.03
	ASMM (kg)	36.13	3.24	29.65	30.00	3.61	22.79
	SMM (Janssen)	44.10	8.29	27.53	38.14	7.44	23.26
	ASMM (Kyle)	33.03	4.49	24.06	29.07	3.75	21.57
	ASMM (Peniche)	30.92	4.68	21.56	26.22	3.74	18.73
	ASMM (Sergi)	29.98	3.77	22.43	27.14	3.34	20.47
	ASMM (Kim)	24.92	3.46	18.00	21.76	3.42	14.92
	ASMM (Yoshida)	35.05	3.56	27.92	31.27	3.68	23.91
	ASMM (Ours)	36.78	3.55	29.68	31.12	2.84	25.44

Table 1. Differences Among Muscle Mass and Muscle Strength Indices Derived from Height-, Weight-, and Body Mass Index-Adjusted Models and Cut-Off Points of the Young Healthy Adult Reference Group in Assessing Sarcopenia (*Continued*)

		Male			Female		
		Mean	SD	2 SD	Mean	SD	2 SD
BMI adjusted	Muscle mass (kg)	2.35	0.28	1.80	1.71	0.26	1.18
	Fat free mass (kg)	2.49	0.29	1.91	1.84	0.26	1.32
	ASMM (kg)	1.12	0.15	0.81	0.77	0.10	0.56
	SMM (Janssen)	1.37	0.28	0.82	1.00	0.21	0.58
	ASMM (Kyle)	1.03	0.17	0.69	0.76	0.12	0.52
	ASMM (Peniche)	0.96	0.17	0.63	0.68	0.12	0.45
	ASMM (Sergi)	0.93	0.14	0.65	0.71	0.11	0.50
	ASMM (Kim)	0.77	0.11	0.55	0.57	0.09	0.38
	ASMM (Yoshida)	1.09	0.15	0.79	0.82	0.12	0.58
	ASMM (Ours)	1.14	0.13	0.88	0.81	0.09	0.63

ASMM, appendicular skeletal muscle mass; BMI, body mass index; h^2, height square; HGS, hand grip strength, FFM, fat free mass; MM, total muscle mass; SMM, skeletal muscle mass; SD, standard deviation; w, weight.

et al[7] (*r*: 0.762, *P*: < .001). The highest correlation coefficient was determined between ASMM (Kim) and HGS (r^2: 0.57).

The strongest correlation between muscle mass *indices* and HGS was seen in BMI-adjusted models as shown in Table 2. Among the BMI-indexed models, the strongest correlation with HGS was observed with our equation (*r*: 0.757; *P* <.001). Between HGS, the strongest correlation was with MM/h^2 in height-indexed models; and with ASMM/w (ours) in weight-indexed models.

DISCUSSION

In the meta-analyses, although it was detected more common in Asian individuals (around 20%), the prevalence of

Table 2. Spearman Rho Correlation Coefficient Between Hand Grip Strength and Muscle Mass *Indices*

Hand Grip Strength	Muscle Masses	Height Square-Adjusted Models	Weight-Adjusted Models	Body Mass Index-Adjusted Models
Muscle mass	0.750	0.582	0.467	0.754
Fat free mass	0.747	0.529	0.451	0.753
Appendicular skeletal muscle mass	0.725	0.421	0.466	0.735
Skeletal muscle mass (Janssen)	0.708	0.442	0.298	0.593
Appendicular skeletal muscle mass (Kyle)	0.684	0.429	0.386	0.680
Appendicular skeletal muscle mass (Peniche)	0.703	0.473	0.426	0.691
Appendicular skeletal muscle mass (Sergi)	0.669	0.382	0.319	0.670
Appendicular skeletal muscle mass (Kim)	0.762	0.493	0.316	0.662
Appendicular skeletal muscle mass (Yoshida)	0.656	0.385	0.421	0.711
Appendicular skeletal muscle mass*	0.719	0.461	0.539	0.757

All correlations are significant at the 0.01 level.
*Calculated by the formula in this study.

sarcopenia in the world was 10% on average.[11] This is very valuable in terms of recognizing sarcopenia and taking the necessary precautions early, predicting the aging generation and the problems to be encountered.

These *indices*, which were used in the definition of sarcopenia, were originally published in the study by Baumgartner et al[12] developed for the estimation of ASMM in magnetic resonance imaging (MRI)/computed tomography-verified DEXA measurement.[12] This study has been the reference for many future studies. However, because this index is positively correlated with BMI, it has the limitation that subjects with a greater BMI due to a larger amount of fat are less likely to be classified as having sarcopenia. Since it was developed for DEXA, we could not include the formula that he developed.

Then in 2000, Janssen et al[5,13] developed the SMM equation for MRI-validated BIA measurement. The difference between this formula and other formulas was that they did not include weight variable but suggested the weight-adjusted SMM/w index. Another difference was that the mean of young healthy adult population was defined as 1 SD low in class 1 sarcopenia and 2 SD low in class 2 sarcopenia. The recommended cut-off levels in men and women, respectively, were 37%/28% for class 1 sarcopenia; the same order as 31%/22% in class 2 sarcopenia. Accordingly, in our study, cut-off levels were 3% lower in men; 1% higher in women. The reason for this can be explained by the fact that the body weights of men in our population are in a wider range and the SD values are high and the cut-off point is 2 SD lower.

In 2010, according to EWGSOP consensus, muscle mass cut-off points on diagnosis of sarcopenia were recommended as 8.87/6.42 kg/m^2 for SMM/h^2; severe sarcopenia <8.5/5.75 kg/m^2; moderate sarcopenia 8.51-10.75/5.76-6.75; normal muscle >10.76/6.76 kg/m^2 for absolute muscle mass/height^2 in men and women, respectively, by using BIA. While there was a natural difference of 2 kg/m^2 between skeletal muscle loss and absolute muscle mass loss for men at these recommended threshold levels, this difference of 0.3 kg/m^2 in women caused some confusion. In our study, *EWGSOP* first reported that SMM/h^2 was 1 kg/m^2 lower in men and 0.3 kg/m^2 higher in women (7.9/6.7 kg/m^2 for men and women). For MM/h^2, the difference was 4 kg/m^2 for men and 5.6 kg/m^2 for women. This consensus led to serious confusion in the diagnosis of sarcopenia.

Fortunately, the cut-off levels proposed in the EWGSOP 2018 revision were further simplified and only ASMM terminology was used. Cut-off levels were clearly defined as 20/15 kg for ASMM; as 7/6 kg/m^2 for ASMM/h^2. Prior to that, in 2014, the Asian Working Group for Sarcopenia (AWGS) was much closer to these levels, have recommended cut-off values for ASMM/h^2 measurements 7.0 kg/m^2/5.7 kg/m^2 for men and women, respectively. In our study, the values of 20.1/13.3 kg for ASMM and 7.0/5.4 kg/m^2 for ASMM/h^2 in men and women, respectively, were determined and this difference between the sexes and between each other was minimized according to both the 2nd revision of the EWGSOP and the AWGS report. Even with the prediction equation we have created, we have reached much closer levels, especially in men (21.47/13.45 for ASMM; 7.43/5.33 for ASMM/h^2 in men and women, respectively). The reason for this difference in women can be explained by the fact that the weight of women in our study is higher than in the current studies.

By the way, another muscle mass index, the ASM/BMI index, was introduced by the Foundation for the National Institutes of Health (FNIH) Sarcopenia Project in 2014.[14] According to this study, ALM/BMI cut-off levels were recommended as 0.789 for males and 0.512 for females which were very close to our accounts (0.81 and 0.56, respectively, in men and women). A slight difference of 0.06 was found in our cut-off levels calculated by the estimation equation.

In our country, a recent study by Bahat et al.[15] involving 301 healthy young and 992 elderly, is perhaps the only study to determine BIA-based cut-off levels in the Turkish population. According to this study, the cut-off points of SMI/h^2 were 9.2/7.4 kg/m^2 in males and females, respectively. In another study by the same authors, the reference cut-off thresholds for SMMI/w were proposed as 37.4% and 33.6% for men and women, respectively, using the Janssen formula. In the same study, SMMI (BMI) cut-off points that best predict the low grip strength for 26 kg/16 kg thresholds were detected as 1.036 kg/BMI and 0.770 kg/BMI for males and females, respectively.[15] In our study, calculated cut-off cutting levels were approximately 1 kg/m^2 low in the length index model; 10% lower in the weight index model; 0.2 units low in the BMI-indexed model. The reason for excess difference in the weight-indexed model was that the weight of the individuals participating in our study was higher than the individuals in Bahat et al's study.[15] We have not included obesity as an exclusion criterion in our study.

In 2010, the EWGSOP consensus recommends the cut-off levels for HGS as 30/20 kg and recommends modification according to BMI; in the 2018 revision, it was determined to be 27/16, very similar to the FNIH study. As a matter of fact, while the AWGS group recommends 26 kg/18 kg respectively in men and women, in the FNIH study, 26/16 was recommended. In our study, the cut-off levels of HGS were found to be 28/16 similar to the recommendations of the European group.

According to all these studies, even if a consensus was obtained in the ASMM and ASMM *indices* measured by BIA method and our study supported these, most of the BIA machines currently used could not perform segmental measurements and could not detect skeletal muscle mass or appendicular muscle mass. Therefore, data that could be diagnosed as sarcopenia could not be obtained with BIA devices that use *foot-to-foot* measurement. The second objective of this study was to compare the estimation equations developed in these countries and to develop a new equation suitable for our society.

Among all, BMI-indexed models were the best and among BMI-indexed models, ASMM/BMI index, developed by us was superior in correlation with HGS (*r*: 0.757).

This study showed us the superiority of the ASMM equation developed by Kim et al[7] (*r*: 0.762) in correlation with HGS for our society. However, the muscle mass volumes predicted in the Kim equation were lower than that of both the other equations and other studies in the literature because of the difference between impedances of the BIAs, suggesting that this formula should be modified slightly more in our society. The Yoshida equation gave the closest result to the ASMM calculated by the sum of the limbs separately.

The reason for this difference was the frequency characteristic of the instrument used. In other words, Yoshida and Kim used a multi-frequency BIA device while the other 4 used a single-frequency BIA device. The machine used in Kim's study was 250 kHz resistance BİA device but the one in Yoshida's study was 50 kHz. Probably for this reason, ASMM (Kim) results remained below the estimates of other equations despite the HGS prediction being the strongest, ASMM (Kim) equation (figure). Perhaps the most powerful estimates could be obtained in our society with a modified equation obtained by increasing the constant coefficient or a new cohort with DEXA/BT/MRI and BIA measurements could be composed to create a new equation specific to our society. But we chose to create a new estimation equation by targeting ASMM. We found that this equation corresponds with the data obtained from segmental BIA device with 96% accuracy and its correlation with HGS is very strong (*r*: 0.719).

Estimation equations developed for BIA measurements were then validated with DEXA for ease of use and cost. In 2003, Kyle developed a new equation by including the "weight" factor in addition to the Janssen equation.[6] In 2014, in 2 separate Yoshida[8] equations specifically for gender and in the Peniche's[9] and Sergi's[10] equations developed in 2015, there is no age factor unlike the others.

Another difference between studies is that there were only young participants in the Janssen and Kyle studies, while others were only elderly individuals. For this reason, the mean muscle mass obtained by the Kyle equation was higher in our study (except Yoshida) than in the others. Similar to our study, Solomon et al[16] from Australia adapted ASMM equations to their populations in individuals aged 18-83 years and showed that the Sergi equation performs best, but the Kyle equation was one step ahead for men and individuals with lower than 25 kg/m^2 of BMI.[16]

In our study, the muscle mass parameter calculated by BIA method in the diagnosis of sarcopenia was examined in various aspects, especially in relation to HGS and in comparison with each other. And with the reference group we established, the suitability of cut-off levels recommended in the literature to our society was tested and very concordant results were obtained. As a result, a new estimation equation that can be used in the estimation of ASMM, which has a strong correlation with HGS, and which can be used for the diagnosis of sarcopenia with non-segmental BIAs, has been created. In addition, there were several limitations of our study. In terms of sample size, it remained well below the literature. And even though the center where the study was conducted encompassed a large and diverse variety of individuals, it was a single-centered study. As a result, it can be thought that the power to represent society may be limited. The other limitation of our study was that the BIA device was a single-frequency machine. Therefore, the adaptation of the equations obtained from the studies performed with the multi-frequency measurement device caused some drawbacks. Since the machine gives only impedance level and does not give R and Xc levels separately, it is calculated manually according to $Z=\sqrt{}(R^2+X^2$ formula (R/Xc≈10).[3]

Ethics Committee Approval: This stud was approved by the University of Health Sciences, Kartal Dr. Lutfi Kirdar City Hospital Ethics committee (Date: April 24, 2018, Decision No: 2018/514/128/12).

Informed Consent: Written informed consent was obtained from volunteers who participated in this study.

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REFERENCES

1. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, et al. Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. *Age Ageing*. 2010;39(4):412-423. [CrossRef]
2. Cruz-Jentoft AJ, Sayer AA, Schneider SM, et al. Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing*. 2018;48(1):16-31.
3. Bioelectrical impedance analysis in body composition measurement: National Institutes of Health Technology Assessment Conference Statement. *Am J Clin Nutr*. 1996;64(3 Suppl):524S-532S. [CrossRef]
4. Clark BC, Manini TM. Sarcopenia $\neq$ Dynapenia. *J Gerontol A Biol Sci Med Sci*. 2008;63(8):829-834.
5. Janssen I, Heymsfield SB, Ross R. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *J Am Geriatr Soc*. 2002;50(5):889-896. [CrossRef]
6. Kyle UG, Genton L, Hans D, Pichard C. Validation of a bioelectrical impedance analysis equation to predict appendicular skeletal muscle mass (ASMM). *Clin Nutr*. 2003;22(6):537-543. [CrossRef]
7. Kim JH, Choi SH, Lim S, et al. Assessment of appendicular skeletal muscle mass by bioimpedance in older community-dwelling Korean adults. *Arch Gerontol Geriatr*. 2014;58(3):303-307. [CrossRef]
8. Yoshida D, Shimada H, Park H, et al. Development of an equation for estimating appendicular skeletal muscle mass in Japanese older adults using bioelectrical impedance analysis. *Geriatr Gerontol Int*. 2014;14(4):851-857. [CrossRef]
9. Rangel Peniche DB, Raya Giorguli G, Alemán-Mateo H. Accuracy of a predictive bioelectrical impedance analysis equation for estimating appendicular skeletal muscle mass in a non-Caucasian sample of older people. *Arch Gerontol Geriatr*. 2015;61(1):39-43. [CrossRef]
10. Sergi G, De Rui M, Veronese N, et al. Assessing appendicular skeletal muscle mass with bioelectrical impedance analysis in free-living Caucasian older adults. *Clin Nutr*. 2015;34(4):667-673. [CrossRef]
11. Shafiee G, Keshtkar A, Soltani A, Ahadi Z, Larijani B, Heshmat R. Prevalence of sarcopenia in the world: a systematic review and meta- analysis of general population studies. *J Diabetes Metab Disord*. 2017;16:21. [CrossRef]
12. Baumgartner RN, Koehler KM, Gallagher D, et al. Epidemiology of sarcopenia among the elderly in New Mexico. *Am J Epidemiol*. 1998;147(8):755-763. [CrossRef]
13. Janssen I, Heymsfield SB, Baumgartner RN, Ross R. Estimation of skeletal muscle mass by bioelectrical impedance analysis. *J Appl Physiol (1985)*. 2000;89(2):465-471. [CrossRef]
14. Studenski SA, Peters KW, Alley DE, et al. The FNIH sarcopenia project: rationale, study description, conference recommendations, and final estimates. *J Gerontol A Biol Sci Med Sci*. 2014;69(5):547-558. [CrossRef]
15. Bahat G, Tufan A, Kilic C, et al. Cut-off points for weight and body mass index adjusted bioimpedance analysis measurements of muscle mass. *Aging Clin Exp Res*. 2019;31(7):935-942. [CrossRef]
16. Solomon C. Y. Yu, Powell A, Khow KSF, Visvanathan R. The performance of five bioelectrical impedance analysis prediction equations against dual X-ray absorptiometry in estimating appendicular skeletal muscle mass in an adult Australian population. *Nutrients*. 2016;8(4):189. [CrossRef]