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Association of different bioimpedanciometry estimations of muscle mass with functional measures

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Aim: To investigate the muscle mass adjustment technique that best correlates with functional measures.

Methods: A cross-sectional study was designed. Community-dwelling older adults aged ≥60 years were assessed for body composition and functional measures between November 2012 and July 2017 in the geriatric outpatient clinic of a university hospital. Body composition was assessed with bioimpedance analysis. Skeletal muscle mass (SMM) was adjusted by height^2, weight or body mass index (BMI). Functional and disability measures included handgrip strength assessed by a Jamar hydraulic hand dynamometer, gait speed by 4-m usual gait speed, frailty by the Fatigue, Resistance, Ambulation, Illnesses and Loss of Weight scale score, activities of daily living (ADL) and instrumental ADL scores. Nutrition was evaluated by the Mini Nutritional Assessment – Short Form.

Results: A total of 1437 older adults (458 men, 979 women) with a mean age of 74.6 ± 7.0 years were included. The prevalences of low muscle mass were 2.4%, 47.8% and 20.3% when SMM was adjusted by height^2, weight and BMI, respectively. Multivariate analyses adjusted for age, number of diseases, drugs and the Mini Nutritional Assessment – Short Form score revealed that when the SMM was adjusted by BMI, low muscle mass showed better associations with grip strength, gait speed, ADL, instrumental ADL and frailty than the height^2 or the weight-adjusted SMM.

Conclusions: SMM adjustment by BMI to designate low muscle mass was better associated with functional and disability measures than adjustment by height^2 and weight. The present results put forward the SMM index (by BMI) as the best adjustment method for SMM. These findings might be relevant for defining both sarcopenia and malnutrition. **Geriatr Gerontol Int 2019; ••: ••–••.**

Keywords: adjustment, functionality, muscle mass, sarcopenia.

Introduction

Functionality is the focus of concern in geriatric care. Disability causes dependency of older adults, with significant medical, social and economical consequences for both the affected individual and their caregivers. Sarcopenia is defined as the loss of muscle mass and muscle strength/physical performance.[1–5] The low muscle mass (MM) component of sarcopenia is identified as one of the major diagnostic criteria for malnutrition in the European Society for Clinical Nutrition and Metabolism consensus and the very recent Global Leadership Initiative on Malnutrition criteria.[6,7] Sarcopenia is a well-known consequence of aging, constituting one of the major causes of age-related disability. Globally, as the population becomes older, age-related disability draws a great deal of attention to preventive and therapeutic care. Many studies have focused on sarcopenia in relation to its association with functional outcomes. The aim is to detect individuals at risk and those with prevalent sarcopenia as early as possible. Then, preventive and therapeutic measures can be applied.

Low MM is a prerequisite to define sarcopenia according to consensus reports.[1–5] Accordingly, studies have concentrated on the means of exact MM measurement. The MM assessment technique constitutes one arm of exact measurement, the other arm being the adjustment technique. The approach is almost clear for the assessment technique. Dual energy X-ray absorptiometry and bioimpedance analysis are the widely and successfully applied modalities in both clinical practice and research, followed by computed tomography, magnetic resonance imaging and total/partial body potassium per fat-free soft tissue, which might, generally, only be used in research.[1] In contrast, there is no global consensus on the MM adjustment technique. It is obvious that MM and its evaluation for adequacy are affected by height^2 and weight. Accordingly, different approaches are suggested to adjust MM to the body size. These include MM indices adjusted for height^2 (m^2),[8] bodyweight[9] or the body mass index (BMI).[10] All of these indices were reported as correlated with functional measures; for example, physical disability, muscle strength or performance.[8–11] It is apparent that the prevalence of low MM and sarcopenia differs by differences in the MM adjustment techniques.[12] Skeletal MM indexed to height^2 is the most commonly used MM adjustment technique; however, this index is highly correlated with BMI and primarily identifies thin people as sarcopenic, but does not identify most obese individuals as sarcopenic.[13] Obese individuals who have both higher lean and fat mass might not appear to be sarcopenic, even though their MM might be inadequate for their size and their physical functioning.[13] Furthermore, the association of low MM and sarcopenia with the functional measures might well be different between the different MM adjustment techniques. To our knowledge, among studies examining the association of low MM with functional measures comparatively between different MM adjustment methods, only one study included MM adjustment by BMI,[12] and this was carried out specifically in a hemodialysis patient population. The diagnosis of sarcopenia and malnutrition would be more accurate and valuable, as its relationship with functional measures increases. Identification of the MM adjustment technique that is best related to functional outcomes, hence, is important. Hereby, we aimed to compare the MM adjustment methods by height^2, weight and BMI for their efficacy in relation to the functional outcomes (i.e. muscle strength, walking speed, activities of daily living, instrumental activities of daily living and frailty) of low MM among the community-dwelling older adult population that were admitted to the geriatric outpatient clinic.

Methods

Community-dwelling older adults were recruited at the geriatric outpatient clinic of Istanbul University, Istanbul Medical School Hospital, Istanbul, Turkey, between November 2012 and July 2017. This outpatient clinic is accessible to all older adults that are aged ≥60 years. A total of 3729 geriatric outpatients were assessed medically in this time period. Among them, 1702 patients were not offered inclusion because of staffing issues, 201 patients did not give informed consent and 389 had poor medical condition for acute problems, hence 2292 patients were excluded from the study. Therefore, the final study population was composed of 1437 participants. The flowchart outlining the enrolment of study participants is shown in Figure S1.

Assessment of MM with different adjustment methods

Body composition was evaluated with bioimpedance analysis (Tanita BC 532 model).[14] Fat-free mass was measured and the skeletal MM (SMM) was calculated using the formula: SMM (kg) = 0.566 × fat-free mass (kg). This formula had been validated among individual and group data compared with SMM data calculated by using 24-h creatinine excretion.[15] BMI was calculated by weight (kg)/height^2 (m^2). SMM was adjusted by three alternative adjustment techniques: by height^2, weight and BMI. SMM index (SMMI) adjusted for height^2 (SMMI [height^2]) was calculated as SMM (kg)/height^2 (m^2);[8] SMMI adjusted for weight (SMMI [weight]) was calculated as SMM (kg) × 100/weight,[9] SMMI adjusted for BMI (SMMI [BMI]) was calculated as SMM (kg) / BMI (kg/m^2).[10]

Low MM was defined using cut-off points based on a national representative population, using a mean 2 SD of a previously reported healthy young adult group for SMMI (height^2) [low MM (height^2)][16] and for SMMI (weight) [low MM(weight)].[17] Accordingly, participants were classified as having a low MM (height^2) and low MM (weight) if SMMI (height^2): women <7.4 kg/m^2 and men <9.2 kg/m^2,16 or if SMMI (weight): women <33.6% and men <37.4%.[17] Cut-off points for SMMI (BMI) were defined as having a SMMI (BMI) lower than the value that discriminates the muscle weakness as suggested by the Foundation for the National Institutes of Health group.[10] Local reference muscle weakness cut-off points (i.e. <22 kg in women and <32 kg in men) were used in this calculation.[16] The corresponding local cut-off points for SMMI (BMI) were <0.677 kg/BMI in women and <1.017 kg/BMI in men.[17]

Assessment of functional parameters and nutrition

Muscle strength was evaluated by handgrip strength (HGS) with a Jamar hydraulic hand dynamometer. Maximum grip strength was measured three times from bilateral hands, and resting intervals of a minimum of 30 s were supplied. The maximum recorded grip strength was noted as the HGS. Cut-off points based on population-specific national data were <22 kg in women and <32 kg in men.[16]

Physical performance was assessed by usual gait speed (UGS). It was measured as the participants walked 4 m at their usual pace, and slow walking speed was noted when UGS was <0.8 m/s.

We assessed functionality with six-item Katz activities-of-daily-living (ADL) scores and eight-item Lawton instrumental ADL (IADL) scores.[18,19] The scores were modified to document intermediate functional scores (i.e. independent, partially dependent and dependent).[20] For each item, the participant was asked whether they carried out the activity without help (3 points), with some help (2 points), or they did not carry out the activity at all or they were completely dependent on someone to carry out the activity for them (1 point).[20] The participants were classified as independent in ADL or IADL if they carried out the activity without help in all items of the test corresponding to 18 points for ADL and 24 points for IADL.

Frailty was assessed by the Fatigue, Resistance, Ambulation, Illnesses and Loss of Weight (FRAIL) scale.[21,22] The presence of frailty was regarded positive if the FRAIL score was ≥3 and negative if the FRAIL score was <3. Nutrition was screened by the Mini Nutritional Assessment – Short Form (MNA-SF).[23]

The relationship of low MM with use of different MM adjustment techniques (low MM [height^2], low MM [weight], low MM [BMI]) with the functional measures – that is, HGS, low UGS, ADL, IADL and frailty – were examined.

The study was carried out in accordance with the guidelines in the Declaration of Helsinki. Informed consent was signed by all participants. The study was approved by the Istanbul University Istanbul Medical Faculty Ethics Committee.

Statistical analysis

Variables were investigated for normal distribution. Numerical variables were given as mean ± SD or median, as appropriate. Categorical variables were represented as frequencies. Two groups were compared with independent samples *t*-test or Mann–Whitney *U*-test when necessary. The χ^2-test with Yates correction and Fisher's exact test were used for 2 × 2 contingency tables, when appropriate for non-numerical data. Correlations between numerical parameters were analyzed with Pearson's or Spearman's correlation test, as necessary. After univariate analysis, multicollinearity was checked among the parameters significantly related to functional parameters. Then factors related to HGS, UGS, ADL, IADL and frailty were analyzed with linear or logistic regression analysis, as appropriate. Accordingly, HGS, ADL and IADL scores were analyzed with linear regression analyses. Because UGS and FRAIL scores were non-parametric variables, logistic regression analyses were carried out for the presence of low UGS and frailty. The results were evaluated at $P < 0.05$ level. SPSS for Windows version 21.0 (SPSS, Chicago, IL) was used for analysis.

Results

A total of 1437 older adults (458 men, 979 women) with a mean age of 74.6 ± 7.0 years (median age 74 years, range 60–99 years) were included in the study. The characteristics of the study population including MM, functional, frailty and nutritional measures by sex are given in Table S1. The prevalences of low MM were 2.4%, 47.8% and 20.3% when SMM was adjusted by height^2, weight and BMI, respectively. A total of 40.8% had low HGS, 35.2% had low UGS and 54.9% had low muscle performance (low HGS and/or low UGS).

Univariate analyses between functional parameters and low MM in men and women

We calculated the differences in functional measures depending on the presence of low MM using the three definitions (Table S2). Here, major differences were found. Low MM (weight) was hardly associated with functional measures, and when an association was documented, low MM (weight) was conversely associated with better functional measures. In contrast, the other two measures (low MM [height^2] and low MM [BMI]) showed associations with worse functional measures in most of them. There were some differences between sexes, in favor of low MM (height^2) for men and low MM (BMI) for women. The negative and positive predictive values of low MM with different adjustment methods to predict low muscle function (i.e. low HGS and low UGS) are given in

Table 1 Results of the regression analysis for handgrip strength regarding low muscle mass with use of different muscle mass adjustment techniques in men and women (all models)

Variables	Beta	*P*
Men		
†Low MM (height^2)	−0.174	0.005
‡Low MM (weight)	−0.042	0.5
§Low MM (BMI)	−0.219	<0.001
Women		
‡Low MM (height^2)	−0.055	0.16
†Low MM (weight)	0.087	0.03
¶Low MM (BMI)	−0.052	0.18

Dependent variable: handgrip strength; independent variables: age, low muscle mass (Low MM), number of chronic diseases and number of chronic drugs. †Disappeared after inclusion of the Mini Nutritional Assessment – Short Form (MNA-SF) score in regression analysis for Low MM (height^2) (beta = −0.097, $P = 0.15$) in men and Low MM (weight) (beta = 0.067, $P = 0.09$) in women. ‡An insignificant association remained when the MNA-SF score was included, for Low MM (height^2) in women (beta = −0.040, $P = 0.31$); for LOW MM (weight) in men (beta = −0.083, $P = 0.19$). §Association remained after inclusion of MNA-SF score in regression analysis for Low MM (body mass index [BMI]) in men (beta = −0.234, $P < 0.001$). ¶Became significant after inclusion of MNA-SF score in regression analysis for Low MM (BMI) in women (beta = −0.088, $P = 0.027$).

Table 3 Results of the regression analysis for the activities of daily living regarding low muscle mass with use of different muscle mass adjustment techniques in men and women (all models)

Variables	Beta	*P*
Men		
†Low MM (height^2)	−0.278	<0.001
‡Low MM (weight)	−0.013	0.85
‡Low MM (BMI)	−0.049	0.48
Women		
‡Low MM (height^2)	0.035	0.43
§Low MM (weight)	−0.056	0.21
¶Low MM (BMI)	−0.094	0.035

Dependent variable: activities of daily living; independent variables: age, low muscle mass (Low MM), number of chronic diseases and number of chronic drugs. †Disappeared after inclusion of the Mini Nutritional Assessment – Short Form (MNA-SF) score in regression analysis for Low MM (height^2) in men ($P = 0.19$). ‡An insignificant association remained when the MNA-SF score was included, for Low MM (height^2) in women ($P = 0.11$); for Low MM (body mass index [BMI]) in men (beta = −0.072, $P = 0.24$); for Low MM (weight) in men (beta = −0.083, $P = 0.190$). §Became significant after inclusion of MNA-SF score in regression analysis for Low MM (weight) in women (beta = −0.103, $P = 0.02$). ¶Association remained after inclusion of MNA-SF score in regression analysis for Low MM (BMI) in women (beta = −0.116, $P = 0.007$).

Table S3. The negative predictive values were highest for low MM (BMI) for low HGS and UGS (~65%). The positive predictive values were highest for low MM (BMI) for low UGS (42.1%) and highest for low MM (height^2) for low HGS.

The MNA-SF score correlated positively with all functional scores, and negatively with the FRAIL score ($r = 0.30–0.60$, $P < 0.001$ for all). The MNA-SF score was correlated positively with SMMI (height^2), and negatively with SMMI (weight) and SMMI (BMI) ($r = 0.312$, $r = −0.339$, $r = −0.128$ in men, and $r = 0.186$, $r = −0.253$, $r = −0.167$ in women, respectively, $P < 0.001$ for all). The negative correlation of MNA was more prominent with SMMI (weight) than SMMI (BMI).

Multivariate analyses for functional parameters including low MM in men and women

Dependent variables were functional measures (HGS, UGS, ADL, IADL or FRAIL score), independent variables were age, the presence of low MM, number of chronic diseases and number of chronic drugs. Three models were generated in regression analyses for each functional measure regarding the three different types of MM adjustment techniques. In model 1, low MM (height^2); in model 2, low MM (weight); and in model 3, low MM (BMI) were included in the analysis. Here, when the MNA-SF score was included in regression analysis, low MM (BMI) was related to all functional measures; low MM (weight) was related to two functional measures (i.e. UGS and ADL), and low MM (height^2) was related only to IADL. Again, there were some differences between the sexes. The associations of low MM with functional measures were all in favor of better functional status with normal MM measures. The results are detailed in Tables 1–5.

Table 2 Results of the regression analysis for the low usual gait speed regarding low muscle mass with use of different muscle mass adjustment techniques in men and women (all models)

Variables	*P*	OR
Men		
†Low MM (height^2)	0.882	1.087
‡Low MM (weight)	0.165	0.565
Low MM (BMI)	0.001	0.284
Women		
†Low MM (height^2)	0.309	3.42
‡Low MM (weight)	0.01	0.534
‡Low MM (BMI)	0.579	0.065

Dependent variable: usual gait speed; independent variables: age, low muscle mass (Low MM), number of chronic diseases and number of chronic drugs. †An insignificant association remained when the Mini Nutritional Assessment – Short Form (MNA-SF) was added in analyses for Low MM (height^2) ($P = 0.27$ and $P = 0.9$ in men and women, respectively). ‡Became significant when MNA-SF was added in analyses for Low MM (weight) ($P = 0.001$ and OR 0.405, and $P = 0.04$ and OR 0.403 in men and women, respectively); for Low MM (BMI) ($P = 0.02$ and OR 0.260, and $P = 0.02$ and OR 0.456 in men and women, respectively).

Discussion

In the present study, we found that low MM (BMI) was related to all functional measures; low MM (weight) was related to two functional measures (i.e. UGS and ADL), and low MM (height^2) was

Table 4 Results of the regression analysis for the instrumental activities of daily living regarding low muscle mass with use of different muscle mass adjustment techniques in men and women (all models)

Variables	Beta	*P*
Men		
†Low MM (height^2)	−0.147	0.021
‡Low MM (weight)	−0.014	0.82
‡Low MM (BMI)	−0.033	0.6
Women		
§Low MM (height^2)	0.037	0.36
‡Low MM (weight)	0.003	0.94
§Low MM (BMI)	−0.045	0.20

†Disappeared after inclusion of the Mini Nutritional Assessment – Short Form (MNA-SF) score in regression analysis for Low MM (height^2) in men ($P = 0.11$). ‡An insignificant association remained for Low MM (weight) ($P = 0.25$ and $P = 0.17$ in men and women, respectively) and for Low MM (body mass index [BMI]) in men ($P = 0.42$). §Became significant after inclusion of MNA-SF score in regression analysis for Low MM (BMI) in women (beta = −0.076, $P = 0.04$) and for Low MM (height^2) in women (beta = 0.079, $P = 0.034$).

Table 5 Results of the regression analysis for frailty regarding low muscle mass with use of different muscle mass adjustment techniques in men and women (all models)

Variables	*P*	OR
Men		
†Low MM (height^2)	0.006	0.205
‡Low MM (weight)	0.13	
‡Low MM (BMI)	0.63	
Women		
‡Low MM (height^2)	0.52	
‡Low MM (weight)	0.49	
§Low MM (BMI)	0.086	

†Disappeared after inclusion of the Mini Nutritional Assessment – Short Form (MNA-SF) score in regression analysis (P = 0.8) for Low MM (height^2) in men. ‡An insignificant association remained after inclusion of the MNA-SF score in regression analysis for Low MM (height^2) in women, P = 0.81); for Low MM (weight) (P = 0.76 and 0.08, in men and women, respectively) and for Low MM (body mass index [BMI]) in men (P = 0.24). §Became significant after inclusion of the MNA-SF score in regression analysis for Low MM (BMI) in men (OR 0.474, P = 0.02).

related only to IADL. There were some differences between the sexes.

In univariate analyses, low MM (height^2) and low MM (BMI) were the low MM measures that were more related to the functional and frailty measures. In women, low MM (weight) was related to higher HGS and IADL scores, which was surprising. At this point, importantly, the MNA-SF score was correlated positively with all functional scores, and negatively with FRAIL score. Additionally, MNA-SF score was correlated positively with SMMI (height^2), and negatively with SMMI (weight) and SMMI (BMI). This is due to the fact that as the weight increases, the participants are more likely to have lower SMMI (weight) and SMMI (BMI). Therefore, the opposite association of low MM (weight) with some functional measures was due to the effect of malnutrition, which could naturally not be considered in univariate analyses. As expected, in the multivariate analyses including the MNA-SF score, the documented associations of low MM (weight) with functional measures were in the way of better functional status with normal MM (weight) measures.

A few studies addressed the question of which MM adjustment method shows better efficacy for the association with functional measures.[12,24–27] In these studies, the association of SMMI with functional measures was analyzed between different adjustment methods in all studies,[24–27] except one that studied the association of low MM between different adjustment methods.[12] SMMI (height^2) has been compared with SMMI (weight) for different measures in five studies showing conflicting outcomes. SMMI (height^2) showed a better association for some measures in three studies,[24–26] and SMMI (weight) showed a better association for some measures in three studies.[12,26,27] In their studies, Han *et al.*[24] and Liu *et al.*[25] reported that SMMI (height^2) correlated with HGS and gait speed (GS) better than SMMI (weight). Han *et al.* also reported that SMMI (height^2) was correlated with more muscular functions than the SMMI (weight).[24] Estrada *et al.* studied leg strength and power, and showed that SMMI (height^2) was better associated than the SMMI (weight). In contrast, in that study they found that SMMI (weight) was better associated with the GS than SMMI (height^2).[26] Similarly, in the very recent 2017 study carried out with hemodialysis patients, Kittiskulnam *et al.* reported low MM (weight) as being better associated with GS than low MM (height^2).[12] In a 2015 study, Meng *et al.* studied a different measure – "falls" – and reported that SMMI (weight) was better associated with "falls" than the SMMI (height^2).[27]

Adjustment of SMM by BMI is a recent suggestion proposed by the Foundation for the National Institutes of Health group in 2014.[10] Hence, only one study that was reported by Kittiskulnam *et al.* was carried out before the present study.[12] Kittiskulnam *et al.* investigated hemodialysis patients with a mean age of 56.7 ± 14.5 years. Another difference was they defined low MM adjusted by each adjustment strategy, including low MM adjusted by BMI, as MM of ≥2 SD below sex-specific means of healthy young adults. In this only study reported so far by Kittiskulnam *et al*, low MM (BMI) correlated better with HGS, GS and with more muscular functions than the SMMI (height^2) and SMMI (weight). In the present study, MM adjustment by BMI emerged as the best adjustment method in terms of the relationship between low MM and functional measures. It showed a relationship with HGS, UGS, ADL, IADL and frailty measures in women or in both sexes. Furthermore, the prevalence of low MM was approximately 10-fold more when SMM was adjusted by BMI than it was by height^2 (20.3% *vs* 2.4%). Hence, SMMI (BMI) identified more participants with low MM accompanied by its better functional associations than the SMMI (height^2). Although it identified fewer participants with low MM than the adjustment by weight, its far better efficacy in relation to functional measures put SMMI (BMI) forward as the best adjustment method for SMM.

The present study had some limitations and strengths. The participants were not drawn from a population-based sample of older community-dwelling older adults, but from the outpatients admitted to a geriatric outpatient clinic in Istanbul. However, Istanbul is the most populous and cosmopolitan city in Turkey, and it takes a great deal of immigration from other cities. This was a cross-sectional study, therefore a cause–effect relationship could not be documented. We adjusted the analyses for potential confounders, but as with any study, there might be unmeasured confounding factors that could influence the relationship between low MM and functional measures. We evaluated nutrition by the MNA-SF, which is a screening tool rather than assessment, and our participants were ≥aged 60 years. However, the MNA-SF is reported to have good consistency with the full MNA assessment tool, and has quite comparable abilities in rating the nutritional status of older adults.[28] It is suggested as appropriate for functioning as stand-alone units for rating the nutritional status of older adults in community-dwelling settings or the general population.[28] Compared with the full MNA, the MNA-SF is easier to use and has been used in previous studies.[29,30] The MNA-SF is applied to participants aged ≥60 years in a number of studies, including mortality studies in older adults undergoing orthopedic surgery[29] and nutritional assessment of community-dwelling older adults[30] with confidential conclusions. Also, the present study population was aged >60 years, with a much higher mean age of 74.6 years. Other strengths of the present study are that we included a relatively high number of participants. We considered low MM adjusted by BMI as SMMI (BMI) lower than the value that discriminates the muscle weakness, as suggested by the Foundation for the National Institutes of Health group for the first time in a comparative study of MM adjustment techniques.[10]

In conclusion, the present study showed that low MM (BMI) was related to all of the functional measures. Our results suggest that MM reveals a better association with functional and frailty measures when adjusted by BMI than by the height^2 and weight. These findings might be relevant for defining both sarcopenia and malnutrition.

Disclosure statement

The authors declare no conflict of interest.

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Supporting information

Additional supporting information may be found in the online version of this article at the publisher's website:

Figure S1 Flowchart outlining the enrolment of study participants.
Table S1 Characteristics of the study population by sex.
Table S2 Association of low muscle mass with functional and frailty measures (univariate analysis).
Table S3 Positive and negative predictive values of low muscle mass with different adjustment methods to predict low handgrip strength and usual gait speed.

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