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Assessment of appendicular lean mass using basic demographic and anthropometric indices

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With age, people experience a gradual loss of muscle mass and strength, known as sarcopenia (SP). The essential criteria for confirming an SP are low appendicular lean mass (ALM) or its index (ALMI), most commonly measured using dual-energy X-ray absorptiometry (DXA). The availability of DXA in Ukraine remains limited, creating an urgent need for simple and accessible screening methods for low ALM. The aim was to develop and cross-validate equations for estimating ALM based on the simple demographic and anthropometric parameters in the Ukrainian population to enhance SP's diagnostic efficiency. This retrospective study analyzed data from 1,710 subjects (1,546 women and 164 men) aged 60 years or older. Skeletal muscle mass was measured using DXA (DISCOVERY Wi, Hologic, Inc., USA). The stepwise multiple linear regression method was used to develop the ALM equations, with ALM as the dependent variable and anthropometric and demographic indices as independent variables. The most optimal formulas for the Ukrainian population aged 60+ were the next: predicted ALM (men) = 0.191 × weight (kg) + 0.141 × height (cm) – 0.077 × age (years) – 9.406 (Coefficient of determination (R^2) = 0.71, standard error of estimate (SEE) = 2.5 kg); ALM (women) = 0.161 × weight (kg) + 0.089 × height (cm) – 0.013 × age (years) – 7.067 (R^2 = 0.71, SEE = 1.68 kg). The developed equations are simple and do not require complicated measurements. They are highly informative and can be effectively used in primary healthcare settings for SP screening to identify patients at risk.

Key words: appendicular lean mass; skeletal muscle mass; sarcopenia; prediction equation.

INTRODUCTION

Skeletal muscles are crucial in ensuring vital body functions, such as breathing and metabolic regulation. They influence metabolism, thermoregulation, and overall energy balance while supporting strength, motor functions, and posture. They are the most extensive tissue by mass in the human body (accounting for about 40% of an adult's total body mass) [1, 2], however, they are one of the most sensitive organs to age-related changes.

Age-related gradual loss of muscle mass and strength leads to a disease termed sarcopenia (SP). Its last definition was modified in the European Working Group on Sarcopenia in Older People (EWGSOP II, 2019) Consensus [3]. Due to the global population's ageing, SP has become one of the major medical concerns among older people, which significantly reduces physical endurance, leads to the loss of independence, and increases the risk of falls and fractures. Additionally, SP is associated with an elevated risk of chronic diseases such as diabetes mellitus, cardiovascular disorders, and cognitive impairments, imposing a substantial burden on healthcare systems and society as a whole [4, 5].

According to current concepts, appendicular lean mass (ALM) and its index (ALMI) are considered essential criteria for confirming the loss of skeletal muscle mass and diagnosing SP [3]. However, determining these parameters requires the use of non-portable and relatively expensive methods, such as dual-energy X-ray absorptiometry (DXA), magnetic resonance imaging (MRI), or computed tomography (CT) [6, 7]. Despite the lack of a universal consensus on approaches for assessing muscle mass in SP diagnosis [4], DXA is most commonly used. Its advantages over other imaging methods include low radiation exposure and relative ease of execution. Furthermore, ALM measurements obtained through DXA demonstrate higher accuracy than MRI and CT results [8]. However, the availability of DXA in Ukraine remains limited compared to other methods for diagnosing SP. Given the significant increase in the ageing population, the demand for timely screening and accurate SP diagnostics is expected to grow. Currently, there is an urgent need for simple and accessible methods to screen for low ALM, particularly in primary healthcare settings, to identify high-risk groups for SP and ensure timely diagnosis.

Nowadays, many studies are devoted to the development of simple and convenient formulas for calculating ALM adapted to the specific characteristics of different populations [6, 7, 9–12]. Over a hundred formulas have been validated compared to the ALM indices measured using DXA [6]. Most of these models incorporate anthropometric measurements (e.g., skinfold thickness, limb length, circumference of the upper limbs, waist, or hips) and handgrip dynamometry, which require specialized measuring instruments [9]. At the same time, alternative equations are based on simple demographic (age, sex) and anthropometric (body mass, height) data. Recent review has demonstrated such formulas' high sensitivity and specificity in determining ALM in healthy subjects and patients with various diseases [6].

It is essential to consider that equations developed in one country are often unsuitable for use in another, mainly when the populations are located on different continents. This discrepancy can be attributed to racial and ethnic differences. For instance, Caucasians are more prone to obesity than Chinese subjects and generally have lower intermuscular fat tissue compared to Europeans. Furthermore, Caucasians typically have longer extremities and a greater height. Similarly, some diseases or physiological conditions can alter body composition. For example, the loss of fat or lean mass due to unbalanced nutrition, cancer, or limb atrophy following prolonged immobilization caused by fractures, injuries, or diseases may render formulas developed for a healthy population unsuitable for subjects with specific medical conditions [13].

Our study aimed to develop and cross-validate equations for calculating ALM based on simple demographic and anthropometric indices for the Ukrainian population to enhance the efficiency of SP diagnosis.

METHODS

We conducted a retrospective study at the Department of Clinical Physiology and Pathology of the Musculoskeletal System, D.F. Chebotarev Institute of Gerontology of the National Academy of Medical Sciences of Ukraine, and the Ukrainian Scientific and Medical Center of Osteoporosis. An analysis was performed on data from 1710 subjects (1546 women and 164 men) aged 60 and older (Table 1). The age of menopause in women was 49.0 ± 6.7 years, and the duration of the postmenopausal period was 19.3 ± 9.0 years. Subsequently, the participants were divided into two groups: the “model” group (n = 1406, 1262 women and 144 men) and the “model validation” group (n = 304, 284 women and 20 men).

The study fully complied with ethical, moral, legal, and legislative standards following the Order of the Ministry of Health of Ukraine No. 281 (01.11.2000) and the Helsinki Declaration of the World Medical Association on Ethical Principles for Medical Research Involving Human Subjects. It was conducted following the decision of the Ethics Committee of the Institute (Protocol No. 2, 16.03.2023).

Demographic, anthropometric indices, and the skeletal muscle mass parameter ALM were evaluated. The demographic data included the participants' age and sex. Anthropometric measurements included body weight and height, measured with scales and a stadiometer. Height was measured barefoot, and body weight was recorded in light clothing. The measurements were rounded to the nearest decimal point in centimeters (cm) and kilograms (kg), respectively. All measurements were conducted by trained researchers in the morning.

Skeletal muscle mass was determined using DXA ("Discovery Wi, Hologic, Inc.", USA), assessing ALM (the lean mass of the upper and lower limbs, in kg) and calculating the ALMI (lean mass of the limbs/height², ALMI, kg/m²). The thresholds indicating low muscle mass and used for SP diagnosis are as follows: for men and women, ALM <20 kg and <15 kg, respectively, and ALMI <7 kg/m² and <5.5 kg/m², respectively.

Statistical analysis was performed using the software packages "Statistika 10.0" Copyright© StatSoft, Inc. 1984-2001, Serial number 31415926535897, and SPSS Statistics 17.0 Copyright© Silver Egg Technology 2001. The distribution of variables (parametric or non-parametric) was assessed using the Shapiro-Wilk W-test. Data were presented according to the nature of their distribution as mean and standard deviation (M ± SD). The Student's t-test was used to test the hypothesis of equality between the means of two groups, and Pearson's correlation analysis (r) was applied to assess the relationships between variables.

To develop an equation for calculating ALM based on simple anthropometric and demographic indices in the "model group," stepwise multiple linear regression was employed. ALM was settled as the dependent variable, and anthropometric and demographic characteristics were chosen as independent variables. To compare the calculated ALM from the equations characterized by low skeletal muscle mass with the ALM measured using DXA, a Chi-Square (χ^2) test was used.

Receiver operating characteristic (ROC) analysis assessed the sensitivity and specificity of the values of the created equations. Sensitivity is the proportion of positive results correctly identified (defined as having a definite condition); specificity is the proportion of negative results correctly identified (defined as not having a definite condition). The null hypothesis was rejected at $P < 0.05$ for all tests used.

RESULTS AND DISCUSSION

The demographic and anthropometric indicators analysis demonstrated that men and women did not differ significantly in age (Table 1); however, females had lower body weight, height, and ALM than males. Table 1 presents the demographic, anthropometric characteristics, and parameters of skeletal muscle mass of the study participants.

It was revealed that there was a significant negative correlation between ALM and age, more pronounced in males, and a strong positive correlation between ALM and key anthropometric parameters (body weight and height) in both women and men (Table 2). These findings are consistent with the conclusions of most researchers [13-15]. Older age is associated

Table 1. The demographic and anthropometric characteristics and indices of skeletal muscle mass of the study participants

Indicators	All subjects	Women	Men
Age, years	68.2 ± 6.4	68.2 ± 6.3	68.4 ± 6.9
Height, cm	162.2 ± 7.8	160.7 ± 6.3*	175.2 ± 7.5
Body weight, kg	75.1 ± 15.2	74.0 ± 14.7*	84.4 ± 16.1
ALM, kg	19.0 ± 4.1	18.2 ± 3.1*	26.3 ± 4.6
IALM, kg/m^2	7.2 ± 1.2	7.0 ± 1.1*	8.5 ± 1.3

Note: *significant differences ($P < 0.001$) in women compared to men.

Table 2. Correlation between ALM and key demographic and anthropometric parameters of the study participants

Indicators	Women		Men	
	r	P	r	P
Age, years	-0.16	<0.001	-0.32	<0.001
Height, cm	0.83	<0.001	0.81	<0.001
Body weight, kg	0.46	<0.001	0.55	<0.001
Age of menopause, years	0.01	0.87	-	-
Duration of postmenopausal period, years	-0.13	<0.001	-	-

with significant changes in body composition, particularly a reduction in skeletal muscle mass [16]. Similarly, the body mass index (BMI) can serve as a predictor of muscle mass [15], with a lower BMI indicating a higher risk of SP [17].

Using regression analysis, we developed equations for ALM for men (Equation 1) and women (Equation 2). These equations included the most significant variables (height, body weight, and age) correlated with the ALM. The results of the regression analysis are presented in Table 3.

Equation 1

ALMc (males) = 0.191× Body weight (kg) + 0.141× Height (cm) – 0.077× Age (years) – 9.406.

Equation 2

ALMc (females) = 0.161× Body weight (kg) + 0.089× Height (cm) – 0.013× Age (years) – 7.067.

Note. ALMc – calculated index of appendicular lean mass, 1 – males, 2 – females.

A recent review presented 122 predictive equations from 18 countries to estimate ALM based on DXA results [6]. Among them, 32 formulas were particularly interesting to our study [15-20], as they excluded such predictive parameters as body circumference measurements, skinfold thickness, or functional test results. Instead, they relied on height, body mass, or its derivative, BMI, age, and/or sex. The coefficient of determination (R^2) ranged from 0.58, with a standard error of the estimate (SEE) of 1.70 in the Tanko et al. study [14] to $R^2 = 0.91$ and SEE = 2.1 in the Hsiao et al. study [16]. In our study, the results also showed high accuracy for men ($R^2 = 0.71$; SEE = 2.50) and women ($R^2 = 0.71$; SEE = 1.68).

Gomes et al. [21] developed predictive models for ALM tailored to the Brazilian popu-

Table 3. Results of regression analysis for calculating ALM in the study cohort

Indicators	b*	Std. Error	b	Std. Error	t	P
Equation 1*						
Intercept			-9.406	5.626	-1.67	0.097
Body weight, kg	0.673	0.052	0.191	0.015	12.74	0.0000001
Height, cm	0.230	0.051	0.141	0.032	4.48	0.00002
Age, years	-0.116	0.047	-0.077	0.031	-2.45	0.016
Equation 2**						
Intercept			-7.067	1.450	-4.87	0.000001
Body weight, kg	0.758	0.016278	0.161	0.003	46.56	0.0000001
Height, cm	0.178	0.016494	0.089	0.008	10.81	0.0000001
Age, years	-0.025	0.015531	-0.013	0.008	-1.63	0.104

Notes: *R = 0.84; $R^2 = 0.71$; Std. Error of estimate: 2.50; F (3.140) = 113.9; P < 0.0001; **R = 0.84; $R^2 = 0.71$; Std. Error of estimate: 1.68; F (3.1258) = 1030.8; P < 0.0001.

lation over 80. Similar to our equation, this one included age, height, and body weight: ALM = 0.138 × height + 0.103 × weight + 3.061 × sex − 12.489. This formula was found to be more practical due to the lower number of predictive variables ($R^2 = 0.75$; SEE = 1.94 kg) compared to an alternative formula that included gender, height, body weight, triceps skinfold thickness, and waist circumference. However, the last one demonstrated a stronger correlation with ALM ($R^2 = 0.82$; SEE = 1.67 kg).

In the study by Kulkarni et al. [22], a model that included age, body weight, and height as predictors demonstrated a strong correlation with ALM in both men and women ($R^2 = 0.90$; SEE = 1.92 kg). However, adding variables such as thigh, calf, and arm circumferences and/or the sum of skinfold thickness at the biceps, triceps, subscapular, and suprailiac regions improved the determination coefficient (R^2) from 0.90 to 0.94 in men and from 0.91 to 0.92 in women. It also reduced the SEE from 1.92 to 1.63 kg in men and from 1.84 to 1.63 kg in women, indicating better predictive performance of the models with additional variables.

Kawakami et al. [9] developed a formula for estimating ALM for men and women based on four anthropometric parameters: body weight, height, waist circumference, and calf circumference. They found that this model demonstrated higher ALM prediction accuracy (men: $R^2 = 0.92$; women: $R^2 = 0.80$; mixed gender: $R^2 = 0.97$) compared to using a single parameter, such as calf circumference alone (men: $R^2 = 0.82$; women: $R^2 = 0.69$; mixed gender: $R^2 = 0.80$). Comparison of the predictive accuracy of the ALM equation by sex revealed more significant predictive indicators for men. It was explained that women generally have a greater volume of peripheral and overall fat tissue, which should be considered when selecting predictor variables.

Table 4 presents the calculated ALM parameter and the DXA ALM. The correlations between the DXA-derived and calculated ALM values using all equations were statistically significant ($r = 0.84$, $P < 0.0001$ for all formulas).

To further confirm the agreement between the calculated low ALM values (for men and women, ALM <20 kg and <15 kg) and the DXA-derived ones, a Chi-square (χ^2) test was performed. The test demonstrated high and statistically significant levels of agreement, with more substantial correspondence when using Equation 2 for women ($\chi^2 = 4.8$; $P = 0.03$ for Equation 1; $\chi^2 = 249.7$; $P < 0.0001$ for Equation 2).

According to ROC analysis, the sensitivity and specificity of the developed equations for identifying low ALM were as follows:

Equation 1: sensitivity 86.4 %, specificity 85.7 %;

Equation 2: sensitivity 83 %, specificity 81.8 %.

Table 4. DXA-derived and calculated ALM and IALM parameters depending on the equation in study groups

Indicators	Model group		Model validation group	
	Women	Men	Women	Men
ALM, kg (DXA)	18.2 ± 3.1	26.3 ± 4.6	17.2 ± 2.8	23.1 ± 2.9
ALMc, kg (calculated):				
Equation 1	-	26.2 ± 3.9	-	25.3 ± 3.4
Equation 2	18.3 ± 2.6	-	18.1 ± 2.7	-
IALM, kg/m^2 (DXA)	7.0 ± 1.1	8.5 ± 1.3	6.9 ± 1.0	8.0 ± 0.8
IALMc, kg/m^2 (calculated):				
Equation 1	-	8.5 ± 1.2	-	8.5 ± 1.2
Equation 2	7.1±0.9	-	7.2 ± 1.0	-

Notes: ALMc – appendicular muscle mass from equations; IALMc – appendicular muscle mass index from equations.

The areas under the ROC-curve (AUC) were 0.75 (95 % Confidence Interval [CI]: 0.72–0.77), and 0.91 (95 % CI: 0.89–0.92), for the Equation 1 and 2, respectively, with $P < 0.0001$ for both equations.

Our results showed that the ALM determined using anthropometric and demographic indices demonstrated a high diagnostic ability similar to DXA parameters. Previous studies corresponded with this result, finding high agreement between ALM using the anthropometric formula and corresponding indices from imaging examinations in different populations [6, 7, 9, 11, 12, 21].

Further analysis was conducted in the "model validation" group (n = 304, 284 women and 20 men) to validate the model. The results of calculated ALM indices using Equations 1 and 2 and ALM obtained using DXA are presented in Table 4.

We found a moderately significant relationship between DXA-derived and calculated ALM indices (Equation 1 (men): $r = 0.55$; $P = 0.02$; Equation 2 (women): $r = 0.70$; $P < 0.001$).

Verification of the diagnostic ability of the calculated low ALM to the indices measured by DXA in the "model validation" group using the χ^2-test established significant results, more pronounced in women (respectively, Equation 1: $\chi^2 = 9.94$; $P = 0.002$; Equation 2: $\chi^2 = 55.88$; $P < 0.0001$).

According to ROC-analysis, the sensitivity and specificity of the Equation 2 for determining low ALM in women were 72.6% and 91.1%, respectively. The sensitivity for Equation 1 (men) was 100, but its specificity was low (46.7%). The areas under the ROC-curve were 0.63; 95 % CI [0.37-0.85] for Equation 1 ($P = 0.50$), and 0.87; 95 % CI [0.83-0.91] for Equation 2, respectively, ($P < 0.0001$).

The study's strengths include the involvement of a large examined population (n = 1,410) in the modelling group, the high informational value of ALM equations, and the possibility of using them in primary healthcare without the need for expensive diagnostic methods. Among the weaknesses is the low specificity of Formula 1 in the "model validation" group, likely due to the small number of men in this group. Additionally, the informational value of the equations in patients with various comorbidities, such as osteoporosis or diabetes, as well as in younger individuals, remains unexplored and requires further research.

CONCLUSIONS

The developed equations for ALM calculation are simple and do not require complex measurements to assess skeletal muscle mass. They are highly informative and can be recommended for SP screening in the primary care setting to identify patients at risk for this disease. Implementing the equations in practical healthcare more widely will improve the management of SP in older people by increasing the effectiveness of its early diagnosis.

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ОЦІНКА АПЕНДИКУЛЯРНОЇ ЗНЕЖИРЕНОЇ МАСИ ЗА ОСНОВНИМИ ДЕМОГРАФІЧНИМИ ТА АНТРОПОМЕТРИЧНИМИ ХАРАКТЕРИСТИКАМИ

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З віком у людини поступово зменшується м'язова маса та сила, що отримало назву саркопенії. Основними критеріями для підтвердження діагнозу є низька апендикулярна знежирена маса (appendicular lean mass, ALM) чи її індекс (ALMI), найчастіше визначені методом двофотонної рентгенівської абсорбціометрії (ДРА). Доступність ДРА в Україні залишається обмеженою, тому існує нагальна потреба в простих та доступних методах скринінгу низької ALM. Метою нашого дослідження було створення та перевірка формул для розрахунку ALM з урахуванням простих демографічних та антропометричних показників для української популяції задля підвищення ефективності діагностики саркопенії. У ретроспективному дослідженні проаналізовано дані 1710 осіб (1546 жінок і 164 чоловіки) віком 60 років і старших. Масу скелетних м'язів визначали за допомогою ДРА («DISCOVERY Wi, Hologic, Inc.», США). Для створення рівнянь розрахунку ALM використовували метод покрокової множинної лінійної регресії, встановивши залежну змінну як ALM, та антропометричні та демографічні показники як незалежні змінні. Найбільш інформативними рівняннями для осіб віком понад 60 років визначено ALM (чоловіки) = 0,191 × маса (кг) + 0,141× зріст (см) – 0,077 × вік (роки) – 9,406 (коефіцієнт детермінації (R^2) = 0,71, стандартна похибка оцінки (SEE) = 2,5 кг); ALM (жінки) = 0,161 × маса (кг) + 0,089 × зріст (см) – 0,013 × вік (роки) – 7,067 (R^2 = 0,71, SEE = 1,68 кг). Розроблені рівняння є простими і не потребують складних вимірювань. Вони є високоінформативними і можуть бути рекомендовані для скринінгу саркопенії на первинній ланці надання медичної допомоги для визначення пацієнтів групи ризику щодо такого захворювання.

Ключові слова: апендикулярна знежирена маса; маса скелетних м'язів; саркопенія; прогностичне рівняння.

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