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Proposal for a Simple Equation for Limb Muscle Weight Calculation

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Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: Although body mass index (BMI) is currently being utilized frequently as an indicator of obesity, it provides little information concerning body composition; key components such as fat and muscle cannot be differentiated. It is especially non-sensitive in identifying muscle mass, which can be challenging to examine without the use of radiologic methods. We sought to identify whether biometric values such as upper arm subcutaneous fat thickness/circumference could provide an adequate indicator of muscle mass.





Material/Methods: Patients admitted to our clinic for various causes were retrospectively studied in 95 consecutive cases. Physical parameters including upper arm subcutaneous fat thickness, upper arm circumference, weight, and height were measured. Then, values such as limb muscle weight (LMW^{DXA}) and total fat weight (FW^{DXA}) were obtained from dual-energy X-ray absorptiometry. Pearson's correlation coefficients were calculated and linear regression analysis was conducted.

Results: Neither upper arm subcutaneous fat thickness nor upper arm circumference was correlated with LMW^{DXA}. FW^{DXA} also showed a correlation with BMI ($r=0.823$, $P<0.001$). LMW^{DXA} also significantly correlated with measured body weight (BW^m)-BMI ($r=0.719$, $P<0.001$).

Conclusions: From our analytic data we propose an equation for calculating muscle mass, designated the Simple Muscle Weight (SMW): $SMW=289.2 \times (BW^m - BMI) + 3631$. SMW calculation has potential for use as an easy and simple first-line diagnostic tool to identify diminished muscle mass.

Keywords: **Body Mass Index • Sarcopenia**

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Background

Overall health in older patients is influenced by the degree of decrease in muscle mass [1]. Despite the fact that methods of diagnosis vary, from measuring walking speeds and grip strength to radiological investigations, the majority of these methods have faced difficulties, due to the myriad of tests or parameters required [2,3].

Theoretically, diminished muscle volume can be diagnosed easily by radiological modalities such as computed tomography, magnetic resonance imaging, and/or dual-energy X-ray absorptiometry (DXA). These methods are practically not available in the majority of smaller clinics, and the demand for a simple method is high.

We aimed to assess the statistical correlations between biometric values such as weight, height, upper arm subcutaneous fat thickness, and upper arm circumference to find a combination of parameters that correlates with the values obtained by DXA scans such as total fat weight (FW^{DXA}) and limb muscle weight (LMW^{DXA}).

Material and Methods

This study was conducted in accordance with the principles of the Helsinki Declaration. The protocol was approved by the Ethics Review Board of Ebetsu Tanifuji Hospital (Ethical Number R2-0910).

In our cross-sectional study, 109 patients were retrospectively examined by our hospital's Nutrition Support Team (NST) for a duration of 33 months from July 2019 to April 2022. Of the original 109, 14 patients were excluded due to a lack of DXA data, yielding a final sample size of 95 patients. The NST consists of 10 members including medical doctors, registered nutritionists, nurses, laboratory technicians, pharmacists, speech therapists, physical trainers, and administrative staff. All patients gave informed consent, and the study has been approved by the hospital's ethical council. Data from 95 patients were utilized to test for a correlation between physical parameters and the values obtained by DXA. The most common causes of admission were fractures of the extremities, fractures of the vertebrae, and pneumonia, as is summarized in **Table 1**.

The physical parameters of body weight (kg), height (cm), upper arm subcutaneous fat thickness (mm), and upper arm circumference (cm) were measured by a nutritionist using caliper tools. Biometric data were measured according to protocols from the National Institute for Health Research to minimize personal bias [4]. The general patient status was examined by the NST. All new inpatients were screened for signs of

Table 1. Primary reasons for hospitalization.

Diagnosis	Case number
Fractures	
Extremities	41
Vertebrae	19
Pelvis	3
Spinal cord injury	1
Lumbar spinal canal stenosis	4
Cervical spondylosis	1
Pneumonia	12
Pyothorax	2
Congestive heart failure	1
Ischemic heart disease	1
Cerebral ischemia	3
Alcoholism	1
Cholelithiasis	1
Heat stroke	1
Rhabdomyolysis	1
Infectious arthritis of knees	1
Urinary tract infection	1
Deep venous thrombosis	1
Total	95

malnutrition such as recent weight loss, loss of appetite, and low serum sodium and albumin levels.

Limb Muscle Weight Measurement

FW^{DXA} and LMW^{DXA} of all 4 limbs were measured by DXA [5] using a PRODIGY Fuga Advance system (GE Healthcare, Chicago, Illinois, USA) with enCORE: Ver. 17 SP1 software.

Statistical Analysis

Statistical analysis was performed using JSTAT: Ver. 22.0E [6]. The Pearson's correlation coefficient and probability values were determined for each of the physical parameters compared with the values obtained using DXA. Probability less than 0.01 was regarded as significant.

Results

Patient Background and Measured Parameters

The gender distribution in the 95 cases was 27: 68 for Men: Women, respectively. BMI, upper arm subcutaneous fat

Table 2. Measured physical parameters and radiological values for the patients.

Total case number: 95 patients	
M: F = 27: 68	
Age (years old)	
47-102 (85±8.3)	
M: 47-95 (82±11)	
F: 68-102 (87±6.3)	
BMI: body mass index (kg/m ²)	
11.6-28.1 (18.4±3.18)	
M: 13.3-23.2 (17.9±3.02)	
F: 11.6-28.1 (18.6±3.26)	
Upper arm subcutaneous fat thickness (mm)	
0.6-18 (7.9±4.0)	
M: 1.1-16 (6.5±3.5)	
F: 0.6-18 (8.4±4.1)	
Upper arm circumference (cm)	
12-27 (20±3.0)	
M: 17-27 (21±2.6)	
F: 17-27 (20±3.1)	
Total fat weight (g) obtained by DXA (FW ^{DXA})	
3563-25 823 (11 823±5203.9)	
M: 4301.0-20 997 (11 051±4739.8)	
F: 3563-25 823 (12 130±5417.0)	
Limb muscle weight (g) obtained by DXA (LMW ^{DXA})	
6951-17 595 (10 772±2388.2)	
M: 8272-17 413 (12 433±2398.9)	
F: 6951-15 864 (10 114±2074.0)	

Values are expressed in range (mean±standard deviation).
M – men; F – women; DXA – dual-energy X-ray absorptiometry.

thickness, and upper arm circumference were measured (mean±standard deviation) as seen in **Table 2**.

Age ranged from 47 to 102 years of age (85±8.3). Measured body weight (BW^m) ranged from 26.8 to 64.0 kg (43.1±8.17). Height ranged from 134 to 175 cm (153±8.85). BMI ranged from 11.6 to 28.1 kg/m² (18.4±3.18). Upper arm subcutaneous fat thickness ranged from 0.6 to 18 mm (7.9±4.0). Upper arm circumference ranged from 12 to 27 cm (20±3.0).

The mean values as measured by DXA were as follows: FW^{DXA} was 3563-25 823 g (11 823±5203.9) and LMW^{DXA} was 6951-17 595 g (10 772±2388.2).

Table 3. Statistical analysis for correlation of measured physical and radiological factors.

	Upper arm subcutaneous fat thickness	Upper arm circumference
BMI		
r	0.558	0.629
P	<0.001*	<0.001*
FW ^{DXA}		
r	0.666	0.743
P	<0.001*	<0.001*
LMW ^{DXA}		
r	0.163	0.458
P	0.114	<0.001*
Body mass index		
FW ^{DXA}		
r	0.823	
P	<0.001*	

r – correlation coefficient; P – probability; BMI – body mass index; FW^{DXA} – total fat weight obtained by DXA; LMW^{DXA} – limb muscle weight obtained by DXA; DXA – dual-energy X-ray absorptiometry. * Statistically significant.

Statistical Analyses for Correlation Between Physical Parameters and DXA Values

Upper arm subcutaneous fat thickness was significantly correlated with BMI (r=0.558, P<0.001) and FW^{DXA} (r=0.666, P<0.001). Upper arm circumference was also significantly correlated with BMI (r=0.629, P<0.001) and FW^{DXA} (r=0.743, P<0.001) (**Table 3**).

In contrast, upper arm subcutaneous fat thickness had no correlation with LMW^{DXA} (r=0.163, P=0.114). A moderate correlation, however, was suggested between upper arm circumference and LMW^{DXA} (r=0.458, P<0.001).

Relationship Between FW^{DXA} and BMI

Since upper arm subcutaneous fat thickness and circumference did not significantly correlate with LMW^{DXA} but did correlate with FW^{DXA}, we tested the correlation between BMI and FW^{DXA}. As a result, we found that BMI does correlate significantly with FW^{DXA} (r=0.823, P<0.001) (**Figure 1**). The linear correlation suggests that BMI can mathematically substitute for FW^{DXA} in the studied population. Therefore, we additionally hypothesized that there may be a correlation between LMW^{DXA} and the difference between BW^m and BMI (BW^m-BMI) (**Appendix 1**).

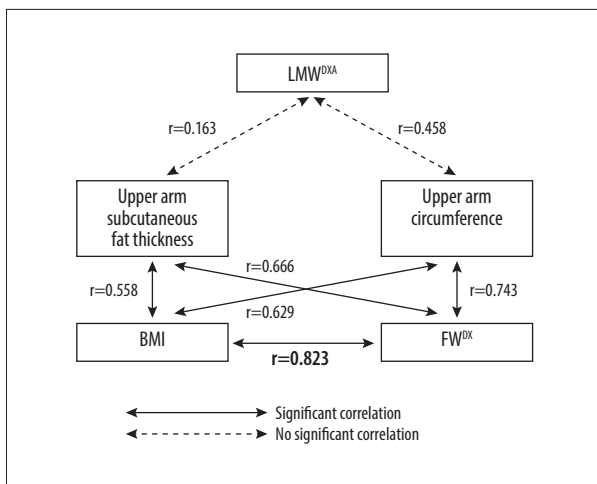


Figure 1. Statistical analysis for each correlation. Total fat weight (FW^{DXA}) obtained by DXA strongly correlates with BMI. BMI – body mass index; DXA – dual-energy X-ray absorptiometry; FW^{DXA} – total fat weight obtained by DXA; LMW^{DXA} – limb muscle weight obtained by DXA; r – correlation coefficient.

Since LMW^{DXA} correlated significantly with (BW^m-BMI) (r=0.719, P<0.001), in our subjects, we can regard (BW^m-BMI) as muscle mass, which might help to predict sarcopenia (Figure 2).

In conclusion, we propose the Simple Muscle Weight (SMW) equation [SMW=289.2×(BW^m-BMI)+3631] as a possible first-step indicator of muscle mass.

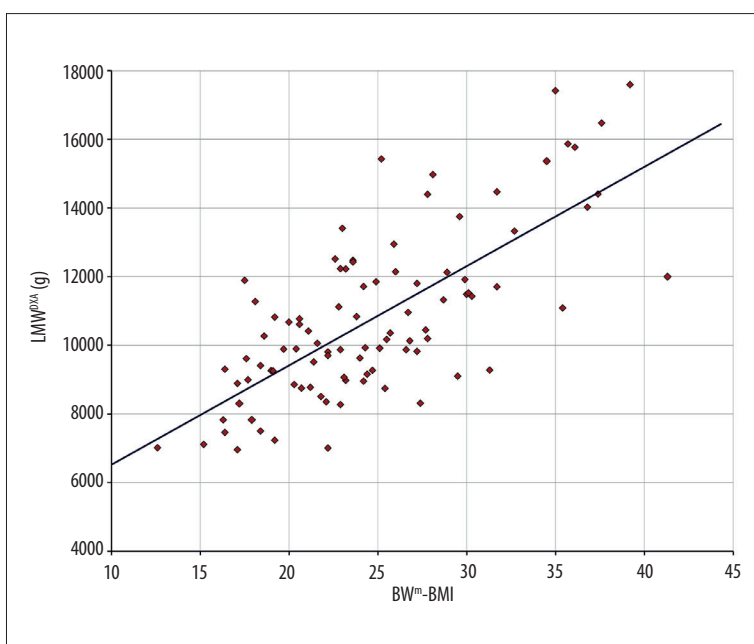


Figure 2. Scatter diagram and regression line of limb muscle weight (LMW^{DXA}) and the difference between BW^m and BMI. A strong linear correlation between LMW^{DXA} and (BW^m-BMI) can be seen (r=0.719, P<0.001, y=289.2×(BW^m-BMI)+3631). This enables us to approximate muscle mass simply by using BW^m and height. BMI – body mass index; BW^m – measured body weight; DXA – dual-energy X-ray absorptiometry; LMW^{DXA} – limb muscle weight obtained by DXA.

Discussion

BMI was originally considered to define the “l’homme moyen=average person or ordinary man” by Quételet [7]. The human body is heterogeneous, consisting of many different constituents, such as water-rich muscle, heavy minerals, and fat, which is relatively light but present in large amounts. Keys et al [8] proposed that the amount of body fat in a patient could be correlated with the patient’s BMI. In spite of its wide use, BMI has been criticized for not containing relevant information about the patient, such as fat mass [9]. BMI also does not take into consideration a wide variety of factors such as ethnicity, sex, and age, giving only a poor idea of the individual’s body composition, and with it, the underlying comorbidities [10]. As Karasu [11] states, “Despite all the progress we have made in science since Quételet’s 19th century index, we are still far from being able to measure our body’s fat conveniently and accurately in a physician’s office”.

Current Strategies for Measuring Muscle Mass: Radiological Methods

While DXA remains unchallenged as the criterion standard for measuring muscle mass, emerging modalities have been identified to be useful in the identification of sarcopenia, but with certain difficulties [12]. Although ethnic and disease-specific modifications apply, the accuracy of DXA has been backed by numerous research studies in the literature [13].

The use of radiological measurement to obtain accurate values requires special equipment and qualifications, compared with the cheaper and lighter devices used for impedance adipometry [14] and ultrasonic measurement of muscle thickness [15].

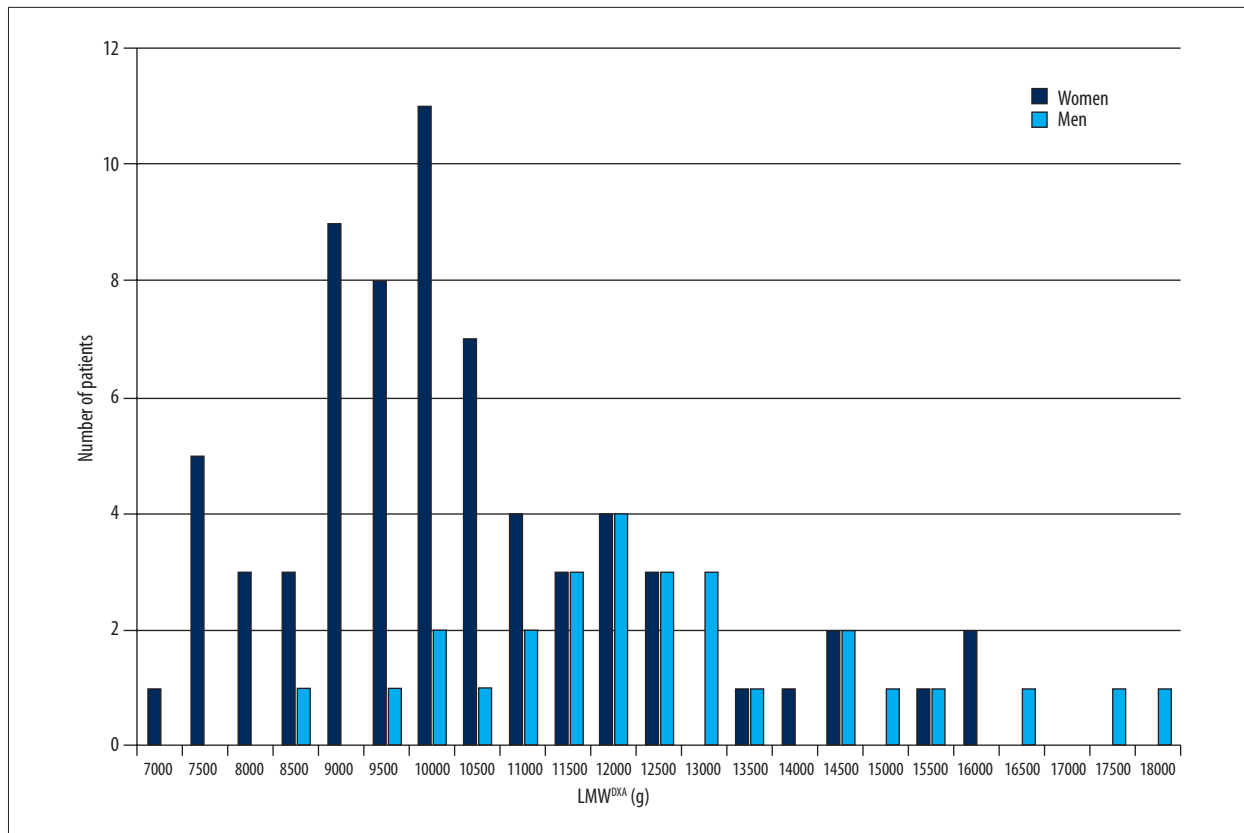


Figure 3. Distribution of limb muscle weight (LMW) in 95 cases. DXA – dual-energy X-ray absorptiometry; LMW^{DXA} – limb muscle weight obtained by DXA.

Current Strategies for Measuring Muscle Mass: Functional Testing

A common way to start the initial investigation for sarcopenia is measurement of the patient's calf circumference, grip strength, and ambulatory abilities, which can be inaccurate and inconsistent in patients with physical disabilities. Functional tests such as the Sit to Stand test, 30-second Chair Stand Test, muscle strength, physical performance, and physical functioning have also been examined to determine the loss of muscle mass in the elderly [16]. These functional tests give quantitative and descriptive analyses of the patient population, with numerous modifications requiring adjustment for different populations [17].

Biochemical Markers

The lack of availability of a way to easily measure muscle mass has resulted in increased use of non-radiological methods. Fayh et al [18] and Evans et al [19] have proposed methods using biochemical markers. Other markers, such as blood albumin levels and molecular markers, have been speculated to reflect the existence of diminished muscle mass. Although these biomarkers have the potential to aid in the diagnosis

of decreased muscle mass, difficulties remain, including coverage of the costs, difficulty/lack of accessibility, and patient cooperation.

Understanding the Correlation Between BMI and Fat Weight

While there is a substantial body of literature examining the relationship between BMI and fat weight, the estimation of body composition without the use of radiological or biochemical methods seems to be challenging.

Our study showed significant correlations between FW^{DXA} and upper arm subcutaneous fat thickness and/or circumference. More importantly, BMI was significantly correlated with FW^{DXA}. These findings are in accord with the international literature, especially when measured by impedance adipometry or DXA [20].

To better understand the dynamic relationship between FW^{DXA} and BMI, we re-examined the correlations between these parameters, and found that LMW^{DXA} is also significantly correlated with (BW^m-BMI). From this correlation and the linear regression, the equation $SMW=289.2 \times (BW^m - BMI) + 3631$ was devised. This equation serves as a way, by applying it as a relative index,

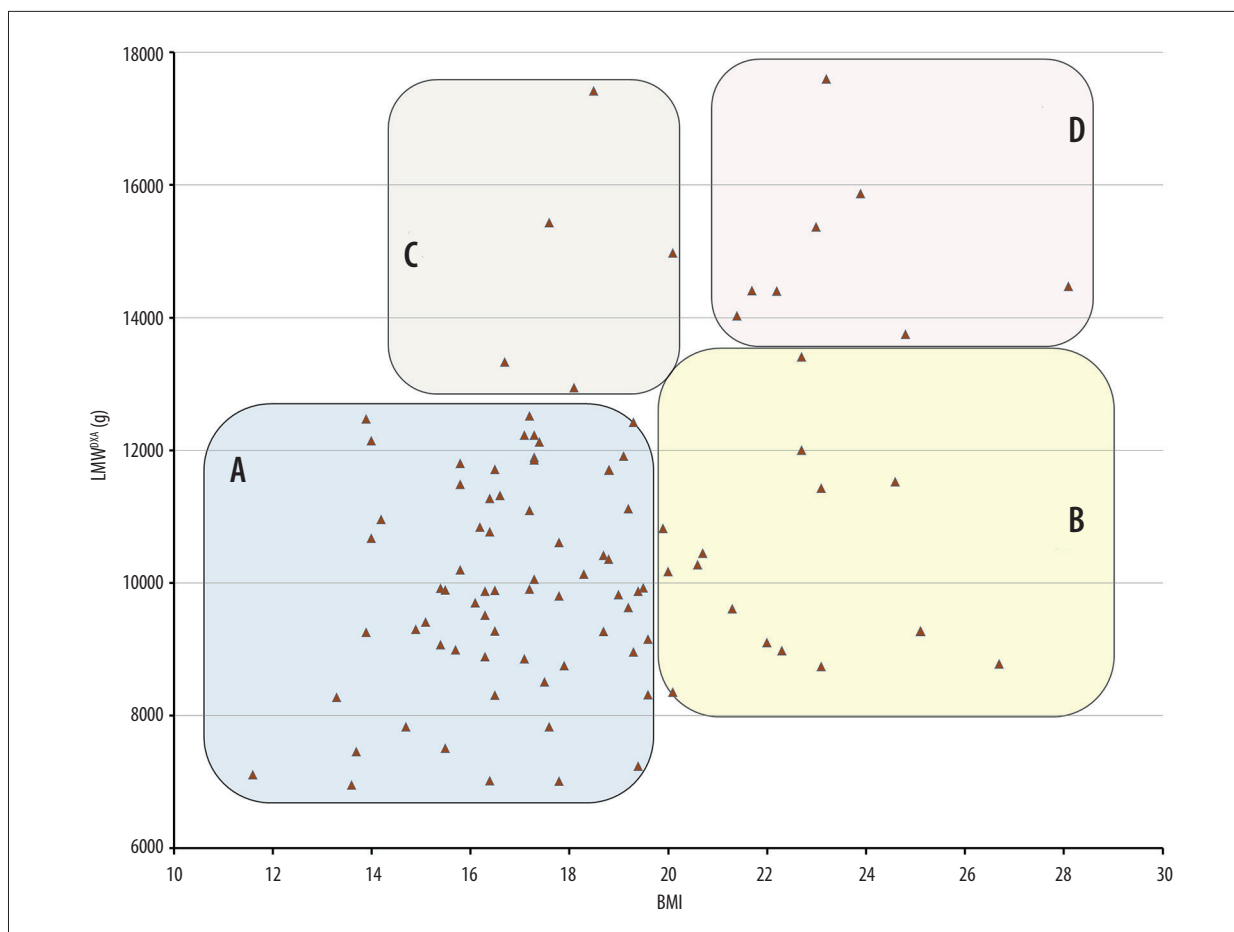


Figure 4. Distribution and relationship of limb muscle weight (LMW^{DXA}) versus BMI. **A:** Low BMI and low LMW^{DXA} , representing possible sarcopenia. **B:** High BMI and low LMW^{DXA} , representing possible sarcopenic obesity. **C:** Low BMI and high LMW^{DXA} , representing muscular body type seen in athletes. **D:** High BMI and high LMW^{DXA} , representing a large body type. BMI – body mass index; DXA – dual-energy X-ray absorptiometry; LMW^{DXA} – limb muscle weight obtained by DXA.

to identify underlying muscle mass. In **Figure 3** we see a large portion of patients' LMW^{DXA} indicating low muscle mass. Even when BMI offered no information on sarcopenia in these patients, the results of the SMW calculation showed that most patients were sarcopenic. Indeed, the majority of the patients in our study were admitted with limb fractures caused by falls, and pneumonia – conditions which are highly associated with sarcopenia [21,22].

On the other hand, patients with low BMI did not necessarily show low LMW^{DXA} , as can be seen in **Figure 4**. High BMI did not necessarily mean that the patients did not have diminished muscle mass; some patients with relatively high BMI even presented with low LMW^{DXA} . This is important, since obesity coexisting with sarcopenia, known as sarcopenic obesity, can lead to especially high morbidity in the elderly [23].

Limitations and Further Prospects

Although our study suggested that muscle weight could be roughly calculated without radiographic, biochemical, or functional data, there were a few factors that it did not take into consideration. While SMW appears to be able to be calculated on the basis of body weight and BMI for a homogenous population, we have yet to understand modifying factors, as well as the accuracy of SMW in different ethnicities. Our subject population was mostly elderly patients, but it would be interesting to observe whether the same principles apply in younger, healthier patients as well. Male and female differences should also be considered, and modifying factors must be addressed and identified.

Clinical pictures based on multiple parameters are of the utmost importance, and assessment for risk of falls, debilitation, and ambulatory function should also be considered if SMW is to be applied in a realistic clinical situation, where indication of therapy would be determined on its basis.

Conclusions

From our analytic data we propose the possibility of calculating muscle mass as a variable called the Simple Muscle Weight. The equation is: $SMW=289.2 \times (BW^m - BMI) + 3631$. SMW calculation has the potential to be used as an easy and simple first-line diagnostic tool to identify diminished muscle mass.

Appendix

Statistical analyses resulted in a simple equation for simple muscle weight.

The equation is derived as follows:

Body Weight (BW) is expressed as the sum of Muscle Weight (MW) + Fat Weight (FW) + others (w):

w: weights of internal organs and bone

$$BW = MW + FW + w$$

$$MW = BW - FW - w$$

It is important to address these points:

1) The weight of internal organs is only minimally affected by nutritional state.

2) Bone weight is trivial (3% of BW).

Therefore, w is small and constant, and is subsequently ignorable in the equation.

The following can be derived:

$$MW // (BW - FW) \quad (1)$$

According to our data analysis, there was a significant correlation between FW^{DXA} and BMI ($r = 0.823$); therefore:

$$FW^{DXA} // BMI$$

Because there is a linear relationship between FW^{DXA} and BMI:

$$FW^{DXA} = a \cdot BMI \quad (a: \text{constant})$$

FW can be substituted by aBMI in equation (1), resulting in the following:

$$MW // (BW - FW) = (BW - a \cdot BMI)$$

$$MW // (BW^m - BMI)$$

A strong correlation was observed between LMW^{DXA} and $(BW^m - BMI)$, consequently leading to the following regression line:

$$y = 289.2 \times (BW^m - BMI) + 3631 \quad (r = 0.719; P = 0.001)$$

BW – body weight; BW^m – measured body weight; MW – muscle weight; FW – fat weight; FW^{DXA} – total fat weight obtained by DXA; BMI – body mass index; LMW^{DXA} – limb muscle weight obtained by DXA; // – proportional relationship; DXA – dual-energy X-ray absorptiometry.

Declaration of Figures' Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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