Correlation between Low Skeletal Muscle Index and 3D Anthropometric Data of Lower Extremities Measured by 3D Body Scanner

Kyu Wan KIM, Yohan LEE *
Department of Orthopedic Surgery, Seoul National University, College of Medicine,
SMG-SNU Boramae Medical Center, Seoul, South Korea

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1. Introduction

Sarcopenia, characterized by age-related loss of skeletal muscle mass and functional decline, has emerged as a significant health concern in the aging population [1]. Sarcopenia is associated with limitations in independent living, diminished physical performance, and increased risks of acute and chronic diseases, ultimately declining quality of life and health [2].

Early diagnosis of sarcopenia is crucial for appropriate management and treatment [3]. However, the accurate diagnosis of sarcopenia remains challenging, as measurement methods and assessors may vary, allowing sarcopenia to be undiagnosed until the loss of skeletal muscle mass and functional decline have significantly progressed. The core issue lies in the initial stage of detection and screening process. Therefore, various screening tools and diagnostic tests have been developed to aid in the identification and confirmation of sarcopenia.

Screening tools are used as a first-line assessment to quickly identify individuals who are at risk or suspected of having sarcopenia. Appropriate screening tools for detecting diseases require several conditions. Just as in other diseases, in sarcopenia, early detection is important for patients at risk of muscle mass reduction, making high sensitivity essential for the screening tool [4]. Additionally, screening tools should be easy to perform, fast, non-invasive, and cost-effective [5].

For the initial screening of sarcopenia, the length of the calf circumference could be measured, with a cut-off of 34cm or less for males and 33cm or less for females (AWGS guidelines; Asian Working Group for Sarcopenia) [6]. Besides, SARC-F (Strength, Assistance with walking, Rising from a chair, Climbing stairs, Falls) questionnaire and the Short Physical Performance Battery (SPPB) that consists of balance test, gait speed test and chair-stand test assess specific risk factors, symptoms, or functional limitations associated with sarcopenia for screening [7, 8].

While these tools are not invasive, easy to administer and provide a quick initial assessment, helping to determine the need for further diagnostic evaluation, they may not always be sufficiently sensitive or specific, leading to potential false negatives or positives [5]. Therefore, delayed diagnosis of sarcopenia may occur when muscle mass loss and functional decline have already progressed, limiting the effectiveness of interventions and treatments and negatively impacting patients' quality of life and independent function [9].

The measuring calf circumference is simple but has significant the margin of error and low reliability, and it is impossible to evaluate muscle function, making it to be inappropriate to use as the only screening tool [10]. In a survey study conducted in 2022 involving 1,990 healthcare professionals in Asia, there were no questions regarding the use of calf circumference as a screening tool [11].

Currently, screening tools predominantly assess muscle function through such as the SARC-F, grip strength, walking speed, and the five-times sit-to-stand test. However, the superiority of any particular tool remains a topic of debate [5, 11-14]. Diagnoses are based on quantitative muscle measurements with assessments of muscle performance on every-day life. However, the current screening tools predominantly focus on assessing muscle function, having limitation of inadequate assessment of muscle quantity [8].

* Yohan Lee, MD, Ph.D
Department of Orthopaedic Surgery
Seoul National University, College of Medicine
SMG-SNU Boramae Medical Center
20, Boramae-ro 5-gil, Dongjak-gu, Seoul, 07061, South Korea
E-mail: yohanlee@snu.ac.kr

We considered using 3D body scanning alternative to calf circumference measurement as a screening tool for evaluating muscle mass and volume in sarcopenia. With the recent advancements in 3D depth camera technology, cameras have become small enough to be integrated into smartphones, their capture speed has increased, and they have become more common. This has paved the way for the application of 3D depth cameras in various fields. Rapid 3D body measurements have become feasible, enabling 3D reconstruction of the craniofacial skeleton, tooth and teeth atlas, and even forensic applications in the medical field [15].

3D body measurement provides accurate and comprehensive physical measurements, offering values for the volume and surface area of various body parts. To the best of our knowledge, the 3D body scanner has not been previously studied for skeletal muscle mass reduction. In this study, we analyzed the correlation between the SMI value measured in Bio-electrical Impedance Analysis (BIA), with a female sarcopenia cut-off value of 5.7, and the limb volume and surface values measured by the 3D body scanner.

2. Method

This study was approved by Institutional Board in Seoul National University Boramae Hospital (IRB No. 10-2022-114) and the patients' consent was exempted. This is a single-center retrospective analysis of 3D body scanner measurement (Medi Help Line Co., Seoul, South Korea) and BIA analysis of patients who visited our hospital from October 2022 to February 2023.

To identify the screening cut-off values, female patients between the ages of 45 and 85 were included in this study for exclude bias resulting from gender differences. Patients with a history of malignant neoplasia and musculoskeletal disorders, with metal implants in the limbs due to orthopedic surgeries or other reasons were excluded. In addition to these factors, we considered patients' medical histories. Individuals with conditions that could cause lower limb swelling, such as heart or kidney disease, varicose veins, lymphedema, lumbar radiculopathy, or lower extremity trauma within the past six months, and with conditions that could potentially influence the outcomes of the 3D body scanner measurements and BIA were excluded.

The 3D body scanner measured the surface and volume values of both thigh, and calf. During 3D body scan tests, results can vary due to factors such as the patient's posture and clothing. Therefore, we standardized the scanning procedure as follows:

1. Posture: The pose of the patients being scanned can significantly affect the results. Generally, a standard standing pose is adopted, with their feet shoulder-width apart, arms slightly raised, and look forward at a fixed point at eye level. This posture enables a comprehensive 3D body scan, including every aspect of lower extremities (Fig. 1).

Fig. 1. An example of poses for 3D scanner imaging.

2. Clothing: Any clothing or accessories worn by patients being scanned can interfere with the scanner's ability to accurately capture the body's surface. It's typically recommended that minimal clothing be worn and that all accessories, including jewelry, watch and accessories be removed. Patients were asked to wear form-fitting clothing provided by our department to ensure the most accurate body shape capture. For consistency, all patients were scanned wearing the same type of clothing. Any accessories or bulky items were removed prior to the scan (Fig. 2).

Fig. 2. Activewear that adheres to the body worn during the 3D scanner imaging.

3. Body Movement: Body scanning requires the subject to remain completely still throughout the process. Any movement can distort the measurements.

4. Several measurements: If the patient moved during the measurement or the measurement was considered inappropriate for other reasons, the measurement was repeated until it seemed satisfactory.

We calculated the Skeletal Muscle Index (SMI) value using BIA and height. SMI was calculated by dividing the skeletal muscle mass (total muscle mass of four extremities) by the square of the height and the unit is kilograms per square meter (kg/m^2). SMI is commonly used as an indicator of muscle mass relative to body size and used in the assessment of sarcopenia and muscle-related conditions. When the SMI is less than 5.7, it is considered that the patient had low skeletal muscle mass and perhaps indicative of sarcopenia. We classified these patients to "Low SMI" group, and the other patients to control group.

3. Result

Total 6 out of 62 patients were identified with lower SMI than 5.7, classified to "Low SMI" group. Since the number of subjects was small, the normality of the data was conducted with a non-parametric method, Shapiro-Wilk test. We confirmed significant normality in each and mean volumes and surface of both the left and right thigh and calf. We checked for statistical differences in the surface area and volume values of the thighs and calves based on whether the SMI was lower than 5.7. The statistical significance was tested using the Mann-Whitney U test.

The "Low SMI" patients showed statistically significantly lower values of right, left and the mean calf volume than control group (right calf volume 2.62 ℓ vs 3.34 ℓ, p=0.033; left calf volume 2.62 ℓ vs 3.25 ℓ, p=0.044; mean volume of both calf 2.62 ℓ vs 3.29 ℓ, p=0.029). Also, the mean surface of calf showed statistically lower value on Low SMI patients (mean surface of both calf 0.12m^2 vs 0.13m^2, p=0.049). However, there was no statistical difference between two groups in thigh volume and surface (Table 1).

Area Under the Curve-Receiver Operating Characteristic (AUC-ROC) analysis was conducted for four statistically significant values; right and left calf volume, the mean calf volume, and the mean calf surface. The cut-off value for the right calf volume was 2.80 ℓ and the AUC value was 0.768 (specificity=85.7%, sensitivity=66.7%). For the left calf volume, the cut-off value was 2.75 ℓ and the AUC value was 0.753 with the highest specificity and sensitivity (specificity=82.1%, sensitivity=83.3%). For the mean calf volume, the cut-off and AUC values were 3.06 ℓ and 0.774 (specificity=67.9%, sensitivity=83.3%), and for the mean calf surface, the values were 0.12m^2 and 0.747, respectively (specificity=89.3%, sensitivity=66.7%). It was confirmed that mean calf volume of 3.06 ℓ, which had the highest AUC value, as “Fair” value (0.774), could be used as the most significant cut-off value (Fig. 3) and the specificity and sensitivity was highest on the left calf volume.

Table 1. A comparison of anthropometric data between sarcopenic and non-sarcopenic patient

Variables	Group			p-Value§
	Total (n = 62)	Low SMI (n = 6)	Control (n = 56)	
Age (years)	65.85 ± 6.58	66.00 ± 5.18	65.84 ± 6.75	0.9462
Thigh volume (ℓ)				
Right	3.95 (3.46 - 4.66)	4.01 (3.47 - 4.14)	3.92 (3.48 - 4.70)	0.5281
Left	3.68 (3.29 - 4.35)	3.62 (3.30 - 3.86)	3.68 (3.30 - 4.41)	0.4533
Mean	3.78 (3.37 - 4.51)	3.82 (3.37 – 4.00)	3.78 (3.38 - 4.57)	0.4824
Thigh Surface (m2)				
Right	0.11 (0.1 - 0.13)	0.12 (0.10 - 0.12)	0.11 (0.10 - 0.13)	>0.99
Left	0.11 (0.1 - 0.12)	0.11 (0.11 - 0.11)	0.11 (0.10 - 0.12)	0.9336
Mean	0.11 (0.1 - 0.13)	0.11 (0.11 - 0.12)	0.11 (0.10 - 0.13)	0.9525
Calf Volume (ℓ)				
Right	3.29 (2.97 - 3.59)	2.62 (2.52 - 3.01)	3.34 (3.03 - 3.69)	0.0331*
Left	3.16 (2.79 - 3.43)	2.62 (2.49 - 2.72)	3.25 (2.88 - 3.45)	0.0442*
Mean	3.23 (2.88 - 3.55)	2.62 (2.51 - 2.98)	3.29 (2.98 - 3.63)	0.0294*
Calf Surface (m2)				
Right	0.14 (0.13 - 0.15)	0.13 (0.12 - 0.13)	0.14 (0.13 - 0.15)	0.0843
Left	0.13 (0.12 - 0.14)	0.11 (0.11 - 0.12)	0.13 (0.12 - 0.14)	0.0801
Mean	0.13 (0.12 - 0.14)	0.12 (0.11 - 0.13)	0.13 (0.12 - 0.15)	0.0495*

§ Derived with Mann-Whitney U test
** p-Value < 0.05*
Values are expressed as mean ± standard deviation or median (interquartile range).
SMI, Skeletal muscle index.

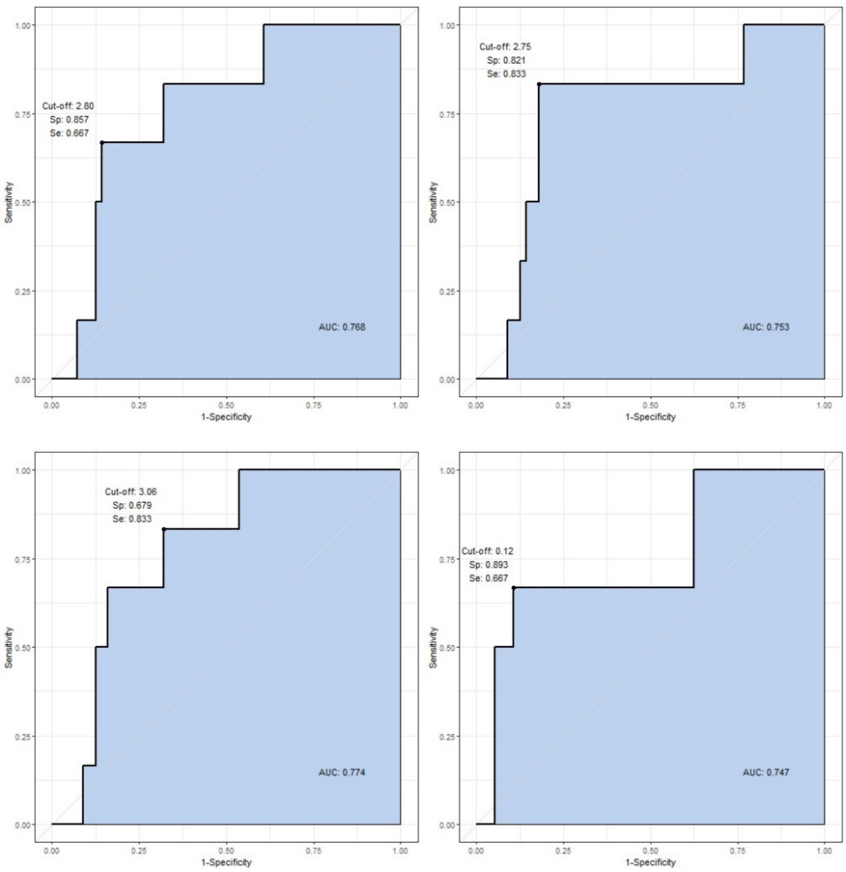

Fig. 3. ROC curve analysis of statistically significant variables. Each four values are Cut-off value, specificity, sensitivity, and AUC, respectively (A) Right calf volume (2.80 ℓ, 0.857, 0.667, 0.768), (B) Left calf volume (2.75 ℓ, 0.821, 0.833, 0.753), (C) Mean calf volume (3.06 ℓ, 0.679, 0.833, 0.774), (D) Mean calf surface (0.12m^2, 0.893, 0.667, 0.747).

4. Discussion

Anthropometry is one of the oldest fields of study, having been researched since the times of ancient Egyptian, Greek, and Roman civilizations. In the ancient era, artists were interested in the depiction of body parts based on reciprocal proportions with anthropometry by length of hands or feet [16]. Leonardo da Vinci studied the proportions between body parts while dissecting cadavers and made his findings known through the "Vitruvian Man."

In the medical field, BMI has been the most widely used anthropometric parameter for the longest time [17]. In particular, anthropometry has played a crucial role in sarcopenia and has been variously associated with it. For example, calf circumference has been used as alternative measure for early identification of sarcopenia [18], and arm circumference has also been used to assess malnutrition in the elderly [19]. However, due to low reliability, using as a screening tool for sarcopenia has become rare in recent literature [10], with assessments now primarily focusing on functional evaluations[11].

Particularly, over the past decade, there has been a rapid advancement in the capabilities of 3D scanning and printing technologies. 3D scanners have advantages on high accuracy, high speed, easy manipulation, low operational costs relative to CT and MRI [20-22]. Moreover, there is minimal risk to human body, such as radiation exposure, resulting in very few limitations on imaging and making it possible to take scan outside the hospital and in everyday space. As a result, researches have been reported about applications on medical field, which apart from areas directly related like engineering and computer science [15]. Especially in fields such as dental, maxillofacial surgery and plastic surgery, there was research on applications of 3D scanning [23, 24]. While these prior studies are conducted with 3D scanning on specific body parts, research on full-body 3D scanning has yet to be conducted.

Full-body scanning data is already being collected as big data by countries. In South Korea, the Ministry of Trade, Industry and Energy has been conducting a Korean anthropometric survey called 'Size Korea' since 1979. Direct measurements using a tape measure have been conducted since 1979 and have accumulated data on 103,254 people, while data on 15,429 people have been collected using a 3D scanner since 2003 and are freely accessible (http://sizekorea.kr). In the United Kingdom, a survey called SizeUK measured 5,500 men and 5,500 women to create a national anthropometric database (Bougourd & Treleaven, 2010). The Centers for Disease Control and Prevention (CDC) periodically compiles and publishes anthropometric data on Americans (Fryar et al., 2021).

Such data collection initiatives were originally commenced due to interests in fields related to body sizing, custom clothing, and virtual shopping. Yet, the potential for medical research based on these data cannot be overlooked. The significance of this study lies in establishing a foundation that associates sarcopenia with whole-body anthropometry data acquired through 3D body scanning. By setting cut-off values for calf volume and surface in cases of low SMI (less than 5.7), this research presents the correlation between sarcopenia and 3D anthropometry.

However, this study has the following limitations. First, this study did not target patients who were definitively diagnosed with sarcopenia. To diagnose sarcopenia, additional tests on grip power, physical activity or DEXA are required, but these tests were impossible due to retrospective study design. Therefore, it is imperative to conduct further research on the 3D anthropometry of patients diagnosed with sarcopenia, especially when integrated with functional assessments such as grip strength, walking speed, and SPPB.

Secondly, this study is based on BIA test results of a small number of patients. BIA test results have high variability. Consequently, when based on a small patient group, the reliability of these values decreases. Therefore, research involving a larger number of patients or based on more reliable tests such as DEXA instead of BIA results is necessary. Lastly, this study targeted a single gender. While it's true that sarcopenia has a higher prevalence in women, research targeting both genders is required for demographic universality.

5. Conclusion

For women aged 45-85, the 3D scanner result that was most useful in distinguishing people with a low SMI was the mean calf volume. The 3D scanner demonstrated its value as a new means for screening sarcopenia.

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Declaration of Competing Interest

The authors declare that they have no competing interests.

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