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Review

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Assessment of Muscle Quantity, Quality and Function

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Sarcopenia is a syndrome characterized by loss of skeletal muscle mass and strength that can increase the risk of physical disability, chronic conditions such as diabetes mellitus and cardiovascular diseases, and long-term mortality. Sarcopenia adversely affects not only the elderly population, but also young adults. This review provides updated definitions of sarcopenia and recommendations for the assessment of muscle quantity and quality.

Key words: Sarcopenia, Muscle strength, Skeletal muscle, Muscle weakness, Guidelines

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INTRODUCTION

The importance of maintaining muscle mass among the elderly population has been emphasized since the late 1980s,[1] and research has also explored the role of muscle quality in overall health.[2] Sarcopenia is a syndrome characterized by loss of skeletal muscle mass and strength that can increase the risk of physical disability, chronic diseases such as diabetes mellitus,[3,4] cardiovascular diseases,[5] and long-term mortality.[6,7] Additionally, it adversely affects not only the elderly population but also young adults.[8]

Muscle quality and mass are important factors in clinical outcomes,[9-11] and measurement of muscle strength is a widely used method for evaluating muscle quality.[7,12] Muscle strength has been reported to be significantly associated with metabolic health,[10,11] risk of cardiovascular events,[13,14] and overall mortality.[9,13] Furthermore, a prospective study in a community-based elderly cohort demonstrated that muscle strength is more important for predicting mortality than muscle mass.[9]

This review provides updated definitions for sarcopenia and recommendations for the assessment of muscle quantity and quality.

DIVERSE DEFINITIONS OF SARCOPENIA

Currently, the most frequently used definitions for sarcopenia are the revised European Working Group on Sarcopenia in Older People 2 (EWGSOP2) in 2019,[7] Asian Working Group for Sarcopenia (AWGS) 2019 update,[15] Foundation for the National Institute of Health (FNIH),[12] and International Working Group on Sarcopenia (IWGS)[16] definitions (Table 1).

The EWGSOP published a consensus on sarcopenia in 2010[17] and that was updated in 2019 (EWGSOP2).[7] In the 2019 definition of EWGSOP2, low muscle strength was the primary parameter of sarcopenia;[7] based on this definition, the prevalence of sarcopenia in the nationwide Korean Frailty and Aging Cohort Study (mean

Table 1. Definition of sarcopenia

Variable	EWGSOP2[7]	AWGS update 2019[15]	FNIH[12]	IWGS[16]
Year	2019	2019	2014	2011
Definition of sarcopenia				
Case finding	SARC-F or clinical suspicion	Calf circumference or SARC-F ≥ 4 or SARC-CalF ≥ 11	Poor physical function with weakness	
Sarcopenia, probable	Low muscle strength: - HGS: (M) < 27 kg, (F) < 16 kg - 5× STS test: > 15 sec	Low muscle strength ± reduced physical performance - HGS: (M) < 28 kg, (F) < 18 kg - 5× STS test: > 12 sec		
Sarcopenia, confirmed	Low muscle strength with low muscle mass: - ASM: (M) < 20 kg, (F) < 15 kg - ASM/ht^2: (M) < 7.0 kg/m^2, (F) < 5.5 kg/m^2	(1) Low muscle strength with low ASM: - ASM/ht^2 DXA: (M) < 7.0 kg/m^2, (F) < 5.4 kg/m^2 BIA: (M) < 7.0 kg/m^2, (F) < 5.7 kg/m^2 or (2) Low physical performance - 6-m walking < 1.0 m/sec - 5× STS test: ≥ 12 sec - SPPB: ≤ 9	Weakness with low muscle mass - HGS: (M) < 26 kg, (F) < 16 kg* - ASM/BMI: (M) < 0.789, (F) < 0.512†	Low physical performance with low muscle mass (1) Physical performance - Gait speed < 1 m/sec (2) Low whole-body mass or low ASM - ASM/ht^2: (M) < 7.23 kg/m^2, (F) < 5.67 kg/m^2
Sarcopenia, severe	Low physical performance: - Gait speed ≤ 0.8 m/sec - SPPB ≤ 8 - TUG ≥ 20 sec - 400-m walk test: ≥ 6 min	Low muscle strength with low ASM+low physical performance		

*Alternate, HGS/BMI: (M) < 1.0, (F) < 0.56; †Alternate, ASM: (M) < 19.75 kg, (F) < 15.02 kg.
EWGSOP, European Working Group on Sarcopenia in Older People 2; AWGS, Asian Working Group for Sarcopenia; FNIH, Foundation for the National Institute of Health; IWGS, International Working Group on Sarcopenia; SARC-F, strength, assistance with walking, rising from a chair, climbing stairs, and falls; SARC-CalF, SARC-F combined with calf circumference; HGS, handgrip strength; M, male; F, female; 5× STS test, the 5-time sit-to-stand test; ASM, appendicular skeletal muscle mass; ht^2, height squared; DXA, dual-energy X-ray absorptiometry; BIA, bioelectrical impedance analysis; SPPB, short physical performance battery; BMI, body mass index; TUG, timed up and go test.

age, 75.9 ± 4.0 years) was 4.6%–14.5% and 6.7%–14.4% in males and females, respectivley.[18]

The AWGS proposed a diagnostic algorithm with a specific cutoff for sarcopenia based on Asian data in 2014,[19] which was updated in 2019.[15] The AWGS 2019 defined sarcopenia as "age-related" loss of skeletal muscle mass with loss of muscle strength and/or reduced physical performance, and retained the age cutoffs at either 60 or 65 years.[15] Sarcopenia associated with uncontrolled acute or chronic clinical conditions is excluded from the AWGS 2019 definition of sarcopenia.[15]

The EWGSOP2 and AWGS 2019 update recommended the use of "strength, assistance with walking, rising from a chair, climbing stairs, and falls (SARC-F)" questionnaire for case finding. The SARC-F questionnaire is the most frequently used tool in the screening for sarcopenia,[20] and the SARC-F combined with calf circumference (SARC-CalF) questionnaire, a modified version of SARC-F incorporating calf circumference (Table 2),[21] improves the SARC-F's diagnostic accuracy, especially its sensitivity.[22,23] The SARC-F comprises five assessment items: strength, assistance with walking, rising from a chair, climbing stairs, and falls (Table 2).[24] The Korean version of the SARC-F questionnaire has been validated.[25] For cases with positive findings in SARC-F or SARC-CalF, assessment of muscle mass and quality should be performed.[7,15]

In both the EWGSOP2 and AWGS 2019 update, the diagnostic flow for sarcopenia was "case finding"→"sarcopenia, probable"→"sarcopenia, confirmed"→"sarcopenia, severe." Severe sarcopenia is defined as low physical performance combined with low muscle strength and low muscle mass. Low physical performance was emphasized more in recent guidelines compared to those in the FNIH 2014[12] and IWGS 2011.[16] The FNIH in 2014[12] and IWGS 2011 defined sarcopenia based on muscle mass, handgrip strength (HGS), and gait speed (Table 1).

MEASUREMENT OF SKELETAL MUSCLE MASS

Dual-energy X-ray absorptiometry (DXA) and bioelectrical impedance analysis (BIA) are the most frequently used tools for as-

Table 2. The SARC-F[20] and SARC-CalF questionnaire[21]

Component	Question	SARC-F	SARC-CalF
Strength	How much difficulty do you have in lifting and carrying 10 pounds?	None=0 Some=1 A lot or unable=2	None=0 Some=1 A lot or unable=2
Assistance in walking	How much difficulty do you have walking across a room?	None=0 Some=1 A lot, use aids, or unable=2	None=0 Some=1 A lot, use aids, or unable=2
Rise from a chair	How much difficulty do you have transferring from a chair or bed?	None=0 Some=1 A lot or unable=2	None=0 Some=1 A lot or unable=2
Climb stairs	How much difficulty do you have climbing a flight of 10 stairs?	None=0 Some=1 A lot or unable without help= 2	None=0 Some=1 A lot or unable without help= 2
Falls	How many times have you fallen in the past year?	None=0 1–3 falls=1 ≥4 falls=2	None=0 1–3 falls=1 ≥4 falls=2
Calf circumference	(Measurement of the right calf in standing position at the point of greatest circumference)	-	M: >34 cm=0, ≤34 cm=10 F: >33 cm=0, ≤33 cm=10

SARC-F, strength, assistance with walking, rising from a chair, climbing stairs, and falls; SARC-CalF, SARC-F combined with calf circumference; M, male; F, female.

sessing skeletal muscle mass. DXA measures the attenuation of X-rays passing through the body, which can estimate bone mineral, fat, and lean soft tissue.[26] DXA is considered a reference tool for assessing skeletal muscle mass.[27] BIA measures the electrical properties of body tissue and estimates body composition: total body water and fat-free mass (FFM).[26] Although the accuracy of BIA is limited due to inter- and intra-individual variability in the chemical composition of FFM (i.e., water, minerals, and proteins), BIA, especially when performed with a multifrequency device, correlates closely with DXA-measured muscle mass.[28]

Appendicular skeletal muscle mass (ASM), which is the sum of the muscle mass of the arms and legs, is generally used as the skeletal muscle mass index (Fig. 1). As ASM is naturally affected by body size, most muscle mass indices for assessing the risk of sarcopenia are adjusted for various anthropometric parameters: ASM/height squared (ASM/ht^2), weight (ASM/wt), or body mass index (ASM/BMI). Differences among various skeletal muscle mass indices have been reported.[29,30] Due to age-related changes in body weight, the ASM/wt might underestimate the risk of sarcopenia in the elderly population.[29] Additionally, sex and ethnic differences in height may affect the association between ASM/ht^2 and sarcopenia.[29] Although ASM/ht^2, ASM/wt and ASM/BMI all significantly predict death or hospitalization, when adjusted for age and sex, only ASM/ht^2 was significantly associated with major adverse health outcomes.[30] Currently, the EWGSOP2[7] and AWGS 2019 update[15] recommended ASM/ht^2 for muscle mass assessment in the diagnosis of sarcopenia.

The skeletal muscle cross-sectional area (SMA) derived from clinical computed tomography (CT) scans or magnetic resonance imaging (MRI) is another commonly used tool in the assessments of sarcopenia.[31] Muscle area at the level of the third lumbar vertebra (L3) is most commonly used, which is significantly correlated with whole-body muscle mass and most accurately predicts muscle mass compared to other levels.[32] To adjust for body size, the skeletal muscle index at L3 (L3-SMI) is defined as SMA/ht^2 (cm^2/m^2); a reference value of L3-SMI has been suggested in diverse populations.[33,34] Recently, psoas muscle SMA alone has been of interest as a marker of muscle mass; however, inter-individual variation in the relative proportion of SMA between the psoas muscle and other paravertebral muscles or anterior abdominal wall muscles at the L3 level has been reported.[35,36]

ASSESSMENT OF MUSCLE QUALITY: MUSCLE STRENGTH AND PERFORMANCE

Although muscle mass is correlated closely with muscle function, a prospective study showed that functional decline was prominent compared to concomitant loss of muscle mass during the follow-up

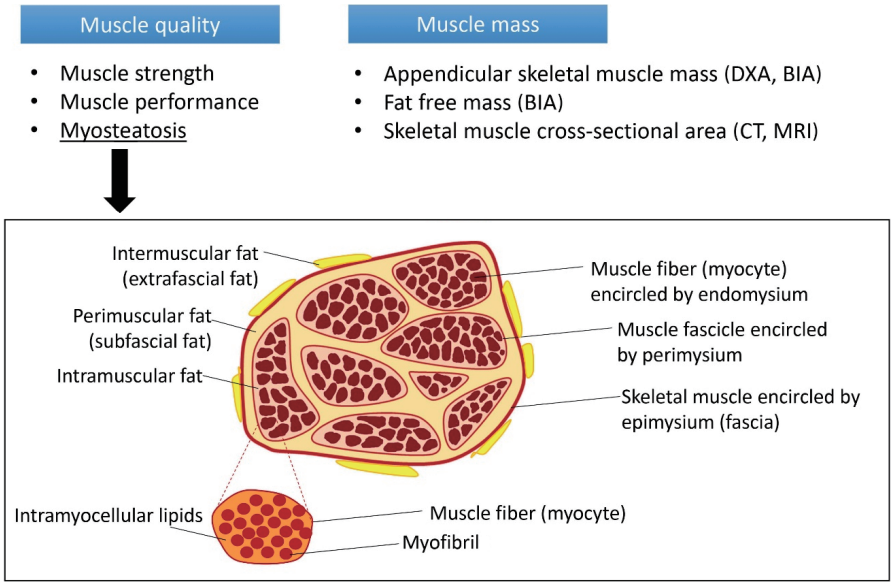

Figure 1. Items for assessing muscle quality and quantity. DXA, dual-energy X-ray absorptiometry; BIA, bioelectrical impedance analysis; CT, computed tomography; MRI, magnetic resonance imaging.

period.[37] This suggests a role of muscle quality apart from muscle mass in its function.[38] Muscle quality is a broad term referring to muscle function, including force production, contraction and relaxation, and metabolism,[39] which is quantified as muscle strength or intramuscular fat content.[39]

Measurement of muscle strength is categorized as (1) manual muscle testing, (2) field testing, and (3) dynamometry.[40] Manual muscle testing determines muscle strength through observation, palpation, and force application by an examiner, and strength is graded from 0 to 5; grade 3 corresponds to "movement observed through full range and test position held against gravity but not against moderate break force."[40] Field tests use body weight as a primary means of quantification for resistance and time or repetitions. Sit-to-stand test (STS) and heel-raise test belong to field tests. The 5-time STS (5×STS) is widely used as a component of the short physical performance battery (SPPB), which is recommended for sarcopenia case finding in the EWGSOP2[7] and AWGS 2019 update (Table 1).[15] The protocol for 5×STS is five repetitions of sitting on an armless chair of standard height (48 cm) and full standing up, as fast as possible without using the upper limbs.[41] The time from the initial stand to the completed fifth stand was recorded as the examinee's score. The heel-raise test measures the strength of the ankle plantar flexor muscles.[42] The examinees stand facing a wall with their hands lightly resting on the wall for balance. They perform a unilateral heel-raise at a rate of one every second while non-weight-bearing on the other lower limb. The tested lower limb knee remains fully extended. The scoring for the test ranges from 0 (no evidence of contraction) to 5 (full range of motion, ≥20 times).

Dynamometry is used to measure HGS. An examinee exerts maximal force against the dynamometer over a period of several seconds.[43] A HGS male <27 kg, female <16 kg or HGS male <28 kg, female <18 kg was adopted as a cutoff for probable sarcopenia in the EWGSOP2[7] and AWGS 2019 update,[15] respectively (Table 1).

The EWGSOP2[7] and AWGS 2019 update[15] defined sarcopenia with low physical performance as "severe sarcopenia." Physical performance can be evaluated using the timed up and go test (TUG), SPPB, or gait speed. The TUG is a simple, quick, and widely used performance-based assessment of lower extremity function.[44] The TUG measures the time from sitting on a chair–standing up–walking for 3 m (10 feet)—walking back to the chair—sitting again on the chair. A TUG ≥20 seconds reflects low physical performance.[7] For the gait speed test, a 1-m zone for acceleration followed by a central 4 m (or 6 m) "testing" zone and a subsequent 1-m zone for deceleration is needed. The walking speed in a central "testing" zone ≤0.8 m/sec or <1.0 m/sec is considered as low physical performance in the EWGSOP2[7] and AWGS 2019 update,[15] respectively.

The SPPB is composed of (1) gait speed test, (2) 5×STS, and (3) standing balance test;[45] SPPB scores range from 0 to 12 possible points. An SPPB ≤8 and ≤9 are considered cutoffs for low physical performance in the EWGSOP2[7] and AWGS 2019,[15] respectively (Table 1).

ASSESSMENT OF MUSCLE QUALITY: MYOSTEATOSIS

Obesity and aging are independent risk factors of poor muscle strength,[46] and meta-analysis confirmed that obesity, but not low muscle mass, is a major determining factor for functional decline.[47] Myosteatosis, which is excessive fat deposition in muscles, is ectopic fat deposit due to positive energy balance that affects muscle quality (Fig. 1).[48] Aside from excessive energy intake, muscle injury, disuse, chronic inflammation, insulin resistance, mitochondrial dysfunction, defective leptin signaling, sex steroid deficiency, or increased glucocorticoid levels can also cause myosteatosis.[48-51] Myosteatosis adversely affects not only muscle strength and mobility but also overall survival and prognosis related to underlying diseases.[48] Myosteatosis can also occur in the absence of sarcopenia and can independently affect clinical outcomes of sarcopenia.[52]

A recent systematic review showed significant heterogeneity in the diagnostic methods and cutoff values used to diagnose myosteatosis.[48] The most common method for assessing myosteatosis is measuring the Hounsfield units (HUs) of muscles on CT. Not only the mean HU of muscle but also the muscle area in a specific range of HU can reflect the severity of myosteatosis.[53] Muscle area can be divided according to HU as follows: (1) normal attenuation muscle area (NAMA; +30 to +150 HU), reflecting healthy muscle with little intramuscular fat; (2) low attenuation muscle area (LAMA; −29 to +29 HU), reflecting unhealthy muscle with intramuscular lipid pools; and (3) intramuscular adipose tissue (IMAT; −190 to −30 HU), reflecting fat tissue between the muscle fibers.[53] Total muscle area (−190 to +150 HU) was defined as the whole area including all skeletal muscles and fat tissues (NAMA+LAMA+IMAT).[53] Each proportion of NAMA and LAMA rather than total muscle area itself are precisely associated with adverse clinical outcomes.[54]

MRI can also quantify macroscopic regions of intermuscular adipose tissue; however, the signal intensity of MRI may differ between protocols and machines. In contrast, CT density or attenuation is standardized across CT protocols and machines; therefore, CT might be optimal for myosteatosis evaluation.[53] Magnetic resonance spectroscopy can uniquely quantify microscopic intramyocellular lipid droplets. Ultrasonography (US) has been used in a limited capacity to evaluate muscle quantity and quality, and a protocol has not been standardized; however, thickness and echogenicity of muscle measurement on US reflect muscle quantity and quality.[55]

CONCLUSION

Considering the rapidly growing aged population in Korea, and the strong association between sarcopenia and morbidities, the assessment and prevention of sarcopenia is critical. Sarcopenia adversely affects not only the elderly population but also young adults.[8,56] Simple screening tools for sarcopenia and well-validated methods for assessing muscle mass and quality are available; in addition, resistance training can prevent sarcopenia.[57] Therefore, clinicians should prioritize active surveillance for sarcopenia.

CONFLICTS OF INTEREST

Bo Kyung Koo is an Associate Editor. However, she was not involved in the peer reviewer selection, evaluation, or decision process of this article. Otherwise, no other potential conflicts of interest relevant to this article were reported.

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