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Perspective Article

Muscle quality an evolving concept

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Abstract

Muscle quality concept can be analyzed from a morphological and functional perspectives that include relation between these properties. Morphological muscle quality considers muscle composition, architectural and structural properties. Functional muscle quality has been defined as a ratio between muscle strength or power per unit of muscle mass or area. Biological and adaptative changes to ageing must be considered when interpretation of muscle quality assessment is done in a clinical or research context. One of the conditions that requires an adequate homologation in terminology is sarcopenia, to establish definition and cut-off points.

Keywords: Functional, Morphological, Muscle ageing, Muscle quality, Sarcopenia

Introduction

The assessment of muscle in clinical and research settings is complicated, since it involves both the study of muscle function and the integrity of contractile and non-contractile tissue, and the lack of a consensus to establish definitions in the involved concepts.

Primary muscle function can be described by physiological domains that are involved in clinical muscle assessment, these include force production, power, endurance, flexibility, metabolism, thermoregulation, and production/signaling of myokines that determine an individual's physical capacity, consistent with age, sex, and race[1]; different authors have suggested that this evaluation can be through the determination of the "Muscle quality". The term "quality" can have different meanings based on the context it is used, in general it refers to the characteristics or attributes of something; in other words, the "essential character" and its "distinguishing attributes"[1]. In this context there is no clearly accepted definition.

One of the biggest problems related to muscle evaluation in clinical practice is sarcopenia. In 1988, Rosenberg proposed the term sarcopenia to refer to muscle wasting in older people[2]. Initially, the operational definition of sarcopenia was based on the quantification of lean mass assessed by densitometry, defining it as more than two standard deviations (SD) below the mean for young adults[3]. Since there is no instrument that serves as a gold standard, diagnostic integration is carried out through constructs; however, there are different groups that have established regional consensus[4,5] (Table 1) without a universal agreement for its definition, diagnosis and evaluation. For the EWGSOP2 consensus (European Working Group on Sarcopenia in Older people 2019), the diagnosis is established through a clinical construct that is based on the initial suspicion of this condition, followed by confirmation through identification of decreased strength, and quantity or muscle quality; subsequently, the functional compromise can be evaluated to establish the severity[4]. In the same way, the AWGS2019 consensus (Asian Working Group for Sarcopenia) proposes the search for cases through surveys and clinimetry, the identification of possible cases through the evaluation of grip strength or physical execution, and diagnostic confirmation through the construct of strength, execution and quantification of muscle mass[6]. Although they do not indicate the method, they state that the diagnosis of sarcopenia requires the measurement of both: muscle quality and quantity.

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		EWGSOP2[4]		AWGS 2019[6]		FNIH 2014[5]	
		Men	Women	Men	Women	Men	Women
Strength	Grip (kgf)	<27	<16	<28	<18	<26	<16
	Sit-to-stand	>15 s / 5 executions		≥12s / 5 executions			
Quantity	ASM (Kg)	<20	<15				
	ALM (Kg)					<19.75	<15.02
	ASM/height²† (Kg/m²)	<7.0	<5.5	<7.0	<5.4		
	ALM_{BMI}					<0.789	<0.512
	ASM‡ (Kg/m²)			<7.0	<5.7		
Execution	Gait speed (m/s)	≤0.8		<1.0			
	SPPB (points)	≤ 8		≤ 9			
	TUG (s)	≥ 20					
	400 m	Not complete or takes ≥6 min to complete					

†through DXA, ‡ through bioelectrical impedance
EWGSOP2: European Working Group in Older People updated in 2019; AWGS2019: Asian Working Group for Sarcopenia 2019 consensus; FNIH 2014: Foundation for the National Institutes of Health published 2014; ALM: appendicular lean mass; ASM: appendicular skeletal muscle mass; DXA: dual-energy X-ray absorciometry; BMI: body mass index; SPPB: Short Physical Performance Battery; TUG: time up and go.

Table 1. Cut points for diagnosis of sarcopenia according to different consensus.

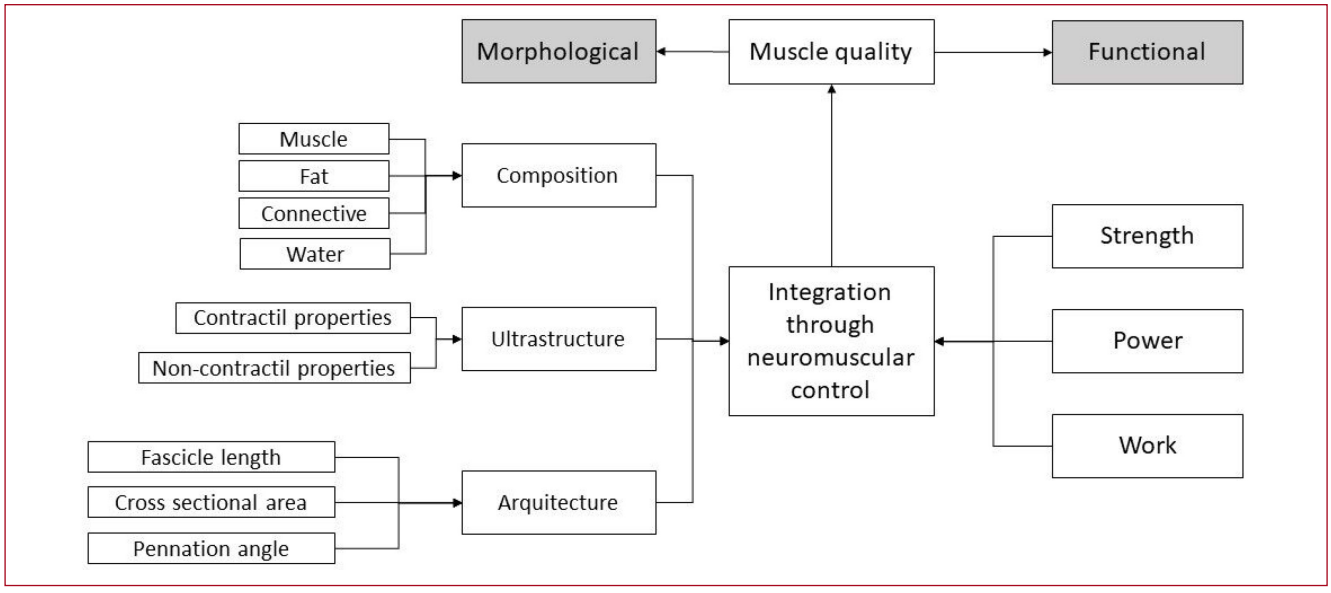

Figure 1. Contractile and non-contractile elements integration with performance to assess muscle quality.

From this perspective, the term muscle quality is ambiguous given the lack of universal definition and the technical difficulty of measuring muscle quantity and quality in a clinical setting, therefore the Global Leadership in Sarcopenia (GLIS)[7] suggests against using this term due to its imprecision.

What has been described as "muscle quality"?

Since 1995[8], there has been a growing interest in the term "muscle quality". Muscle quality is an essential component of human physiology, it refers to the integration of the functional and structural characteristics of the muscle.

Muscle primary function parameters	
Force	Influence that can change the movement of an object. It has magnitude and direction.
Moment (strength)	Rotational effect of the force generated by a muscle or a muscle group around a joint.
Muscle strength	Amount of force a muscle can produce with a single maximal effort.
Muscle power	Ability to exert maximum force in the shortest amount of time, such as accelerating, jumping, or throwing.
Muscle work	Force exerted by a muscle a muscle or group of muscles to perform a physical task.
Muscle contraction type	Two main forms of contraction can be described, when length of the muscle remains without change (isometric) and when length of the muscle changes with contraction (isotonic). Isotonic contraction can be concentric (shortening of muscle length) and eccentric (elongation of muscle length). Isokinetic fixed angular velocity
Muscle quantitative parameters	
Volume	Tridimensional space of a muscle, considering length and shape (through magnetic resonance, ultrasound)
Thickness	Distance between superficial and deep aponeurosis of the muscle (through magnetic resonance, computarized tomography, ultrasound)
Cross sectional area	Anatomic: Bidimensional space of a transversal view of an image Physiologic: ratio of muscle volume between the length of its fibers (through magnetic resonance, computerized tomography, ultrasound
Lean mass	Fat-free and bone mineral–free component that includes muscle and other components such as skin, tendons, and connective tissues (through densitometry, bioimpedance, anthropometry or formulas)
Appendicular lean mass	Is the sum of lean soft tissue from both arms and legs (through densitometry, bioimpedance, anthropometry or formulas)
Skeletal muscle mass	Sum of total muscle mass from the whole body (through magnetic resonance, tomography, indirect by ultrasound and formulas) [20]
Appendicular skeletal muscle mass	Sum of muscle mass from arms and legs (magnetic resonance, computerized tomography)
Muscle qualitative parameters	
Fascicle length	Length of the fascicular path between the insertion of the fascicle to the superficial and deep aponeurosis (magnetic resonance, ultrasound)
Stiffness	Change in force divided by the corresponding change in length, when the length change is imposed by an external agent or by a change in the external load in a muscle (myotonometry, ultrasound, magnetic resonance)
Muscle contraction	Muscle contraction correlated to cross sectional area at rest and maximal contraction (ultrasound)
Microcirculation	Capillary flow in skeletal muscle (ultrasound, magnetic resonance)
Pennation angle	Angle of insertion of the fascicles of muscle fibers in the deep aponeurosis (ultrasound)
Echogenicity	Brightness of the image acquired by ultrasound in gray scale caused by the reflection of soundwaves and is influenced by sound beam characteristics and tissue density (ultrasound)

Table 2. Definition of muscle primary function, quantity and quality components to integrate functional or morphological muscle quality[12-21].

It comprises factors such as strength, power, endurance, and flexibility, which determine individual physical capacity. Quality involves various elements that contribute to efficiency and performance, which can be approached from a functional or morphological perspective; without confusing them with the primary functional characteristics of the muscle (Figure 1).

In a recent comprehensive review on muscle quality, whose objective was to identify the current definitions and assessment methods of "muscle quality" in older adults[9], the authors identified 96 studies (between 2003 and 2022) and found that muscle quality was described in two large domains: functional and morphological. The functional domain is described as assessed muscle function per unit of mass or area; the morphological domain considers changes in architecture, structure, ultrastructure and composition[9-11].

The determination of muscle quality is affected by methodology used to characterize the tissue or measure its performance[1], and the definition used to indicate the results of its evaluation[1,9]. However, despite identifying two ways of approaching muscle quality, it is important to specify that functional quality would involve the ability to generate

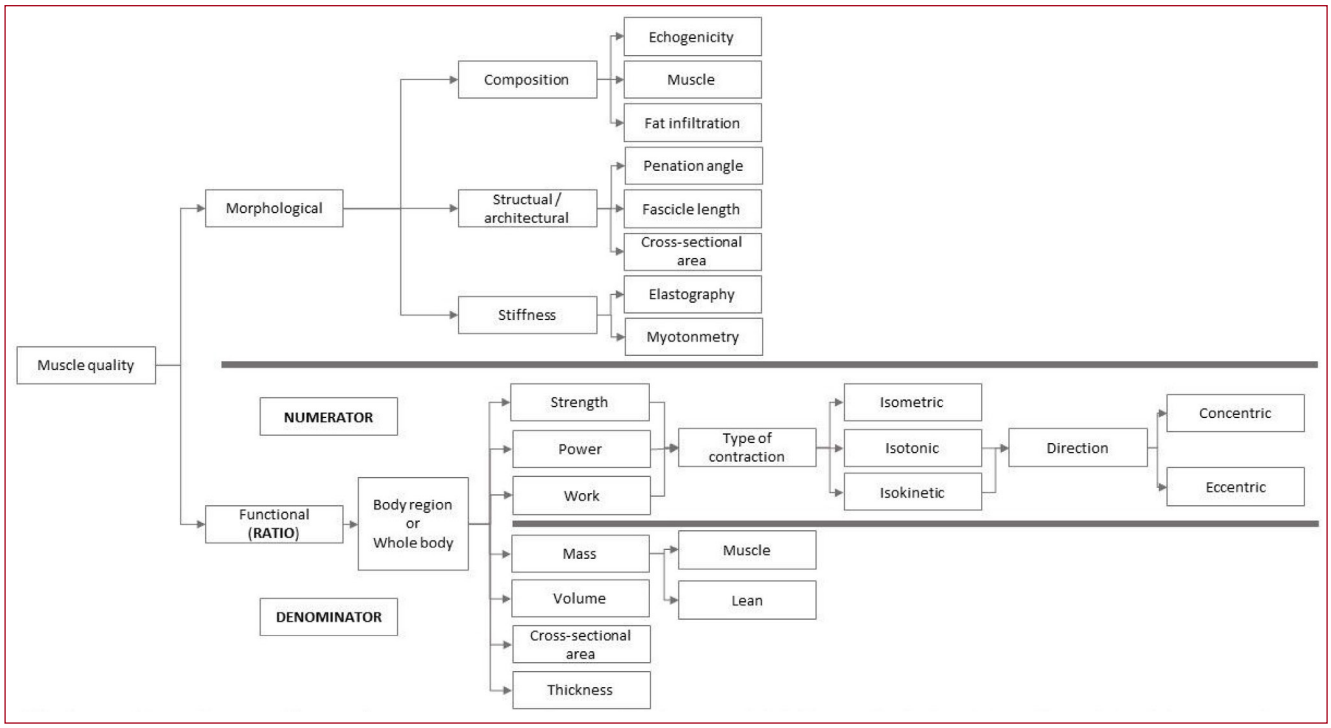

Figure 2. Integration of morphological and functional muscle quality. Muscle composition can be assessed by magnetic resonance or tomography, to establish the amount of fat infiltrate (myosteatosis) or fibrotic tissue. Echogenicity can indirectly demonstrate fat infiltration and fibrosis in muscle without differentiation. Muscle mass and volume can be measured by magnetic resonance. Volume can indirectly be quantified by ultrasound. Cross-sectional area can be measured by ultrasound, magnetic resonance, and tomography. Lean mass can be measured by body composition with densitometry or bioimpedance.

force and power, dependent on qualitative (morphological) characteristics[10].

Concepts and conditions that must be considered when evaluating skeletal muscle quality

The muscular components that are required to integrate functional and morphological muscle quality can be evaluated from the perspective of function, quantitative or qualitative characteristics. Table 2 integrates the concept and considered definition.

Normalization of parameters that integrate muscle quality

The values obtained from muscle performance (strength, power) and muscle quantity (mass) are strongly correlated to body size, so different ways of normalizing them have been proposed for their adjustment. In 2014 the National Institutes of Health (FNIH) within the sarcopenia project proposed adjusting the value of appendicular skeletal muscle mass by body mass index (ASM/BMI) since they report a strong correlation with weakness and slowness of movement[7].

In the same way, since the muscular performance parameters (strength, power and work) are linked to body mass, when comparing a subject against the same subject at two different moments, the absolute value of the implemented test must be considered. And when comparing the results of these variables between subjects, normalization by weight should be considered[5,21].

Cut-off points

There are no cut-off points that can be applied to the values of morphological and functional muscle quality. For sarcopenia, some groups[4,22] recommend the standardization of values with young adults, that is, converting the absolute values in terms of Z score and comparing the number of standard deviations from the mean of the control group. They suggested to consider positive when these values exceed -2 SD[4]; similar to the way that WHO defined osteoporosis[23]. For this, it is necessary to take in account that the behavior of muscle mass is different at distinct ages, as well as among men and women. Total appendicular mass increases until the age of 30 years in men and 40 in women, after which it slowly decreases until 60 years in men and between 50-60 years in women; from this moment it accelerates progressively with increasing age[24]. Therefore, the population of healthy

young adults selected to serve as controls to standardize the values should be around 30 and 40 years of age according to sex and considering a normal body mass index.

Considerations for integration in clinical research

The determination of muscle quality is affected by the function evaluated and by the methodology or technology used to characterize the tissue or measure its performance[1]. In sarcopenia, muscle strength is compromised leading to functional impairment and disability. However, it has been observed that strength and muscle mass are not necessarily linked, since there are conditions in which muscle strength can be diminished without decreasing of muscle mass. As associated to ageing there is a relative increase of non-contractile tissue in relation to contractile tissue of the muscle, this can mislead to overestimate the value of muscle lean mass, when evaluation of skeletal muscle mass is not available[25]. On the other hand, muscle power is strongly associated with gait speed, balance, and functional status[22,26-27]. It has been observed that muscle strength declines by 1 to 2% per year after the age of 50[28], muscle mass is lost by 1 to 2% per year after the age of 50[3,29] but begins to decline since the age of 30 when a loss of 3 to 8% per decade is observed[30]; and muscle power is lost from 3 to 4% per year after age of 60[31]. For this reason, some authors proposed to consider muscle power as the main value to assess muscle performance in older adults[22].

A homologation of definitions to describe muscle quality is necessary since, as GLIS points out, the use of the term without establishing its components can be imprecise or ambiguous[7]. An example of this is relative strength and specific strength, that refer to the same concept, functional muscle quality:

- Relative strength[1]: Ratio of peak force and a measure of body size, regional lean mass or cross-sectional area.
- Specific strength: Strength standardized to muscle size[7].

Another example is that for the integration of the diagnosis of sarcopenia, the assessment of "muscle quantity" cut-off points proposed by EWGSOP2[4] and by AWGS2019[6] refer to "appendicular skeletal muscle mass" (ASM), which gold standard to evaluate would be magnetic resonance. However, they suggest as a more accessible option the use of body composition through dual-energy X-ray absorciometry (DXA), which actually reports lean mass (integrating contractile and non-contractile tissues). It is important to be cautious when applying cut-off points since ASM values are lower than ALM values, as they are different concepts (Table 2). Thus, the recommended cut-off points should consider ALM as it is more available and at a lower cost.

From a morphological point of view, assessment of muscle quality may include assessment of fascicle length, assessment of muscle and tendon stiffness, assessment of muscle contraction, microcirculation, angle of pennation and echogenicity (Figure 2)[1,10,19,22].

From a functional perspective, the assessment of muscle quality should include the quantification of aspects of muscle performance (considering the type and direction of movement), such as power, strength and work, in relation to quantitative parameters of muscle mass, such as muscle mass, lean mass, muscle thickness and physiological or functional cross-sectional area (CSA). These values can be studied from a body region or whole body (Figure 2)[22,32].

Biological and adaptative changes that impact on muscle quality

Muscular ageing involves changes and adaptations of muscular composition of non-contractile and contractile elements, and neuromotor control[33-34]. With ageing, intramuscular and intermuscular fat infiltration increases (myosteatosis)[1,9,35], as well as architectural and structural changes that alter the mechanical and elastic properties of muscle connective tissue[36]. In the same way, the contractile component is affected by changes and adaptations in muscle fibers, with a decrease in the fascicle length, pennation angle, decreased cross-sectional area, predominance of fibers I over II, and a decrease in satellite cells[34,37]. Motor control is affected by changes in the peripheral nervous system, spinal and supraspinal central nervous system, such changes are caused by connective tissue infiltration, decreased myelin and myelination, decreased motor neurons, loss of motor units, generation of large motor units and changes in central motor coordination[34]. These changes and adaptations of the contractile and non-contractile elements and in neuromotor control generally translate into decreased strength (~2% per year)[28], power (~3 a 4% per year)[31], mass (~1 a 2% per year)[3,29] and functional muscle quality (~2.5% per year)[38].

It has been observed during isokinetic tests that comparing young adults (23 to 32 years of age) and older adults (60 to 75 years of age) testing at low speeds, force values (peak torque) were significative lower in older adults[39-40]. However, during high velocity evaluation (180° per sec) the eccentric peak torque of older adults tends to be preserved[41].

In the same way, it has been shown that changes in the mobility of elderly population are linked to the force-velocity relationship, eccentric contractions in a stronger way than concentric contractions[39]. Although the stability of movement control has been shown to be lower in eccentric than in concentric activity, eccentric contraction exhibits stronger activation due to neuromotor control network activation of the primary, secondary, and association cortices.

When compared with young adults, eccentric activity-biased activation shows different patterns. In older adults it was higher in secondary and associations cortices (supplementary, premotor and motor areas) and cingulate cortex; and in young adults in primary motor cortex and sinus sensory cortex[40].

These changes and adaptations have clinical and research

relevance because they translate into a greater loss of concentric than eccentric strength, linked to velocity with age[39]. Muscle mass assessment might be biased by relative preservation due to myosteatosis. It should be integrated as a ratio between muscle strength or power unit, considering eccentric and concentric contraction, per unit of mass or ACT or thickness within functional quality. It reflects a relationship between execution, composition and neuromotor control, that will allow a better understanding of muscle functional behavior.

Conclusion

Considering strength and muscle mass independently, in the assessment of age-associated loss of strength could be misleading. Ageing muscular changes and their functional implications should be considered when evaluating sarcopenia, which should include muscle quality measurement as it refers to the morphological and functional characteristics of skeletal muscle.

Morphological and functional muscular qualities should be considered in clinical practice and research, since they are feasible to estimate and there are different options to do so. Determination of these types of muscle quality will lead to a comprehensive assessment of neuromuscular function and a more targeted treatment.

References

1. Correa-de-Araujo R, Harris-Love MO, Miljkovic I, Fragala MS, Anthony BW, Manini TM. The Need for Standardized Assessment of Muscle Quality in Skeletal Muscle Function Deficit and Other Aging-Related Muscle Dysfunctions: A Symposium Report. Front Physiol 2017;8:87.
2. Rosenberg IH. Sarcopenia: origins and clinical relevance. J Nutr 1997;127(5 Suppl):990S-991S.
3. Baumgartner RN, Koehler KM, Gallagher D, Romero L, Heymsfield SB, Ross RR, et al. Epidemiology of sarcopenia among the elderly in New Mexico. Am J Epidemiol 1998;147(8):755-63. Erratum in: Am J Epidemiol 1999;149(12):1161.
4. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T, et al. Writing Group for the European Working Group on Sarcopenia in Older People 2 (EWGSOP2), and the Extended Group for EWGSOP2. Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing. 2019;48(1):16-31. Erratum in: Age Ageing 2019;48(4):601
5. Studenski SA, Peters KW, Alley DE, Cawthon PM, McLean RR, Harris TB, et al. The FNIH sarcopenia project: rationale, study description, conference recommendations, and final estimates. J Gerontol A Biol Sci Med Sci 2014;69(5):547-58.
6. Chen LK, Woo J, Assantachai P, Auyeung TW, Chou MY, Iijima K, et al. Asian Working Group for Sarcopenia: 2019 Consensus Update on Sarcopenia Diagnosis and Treatment. J Am Med Dir Assoc 2020;21(3):300-307.e2.
7. Cawthon PM, Visser M, Arai H, Ávila-Funes JA, Barazzoni R, Bhasin S, et al. Defining terms commonly used in sarcopenia research: a glossary proposed by the Global Leadership in Sarcopenia (GLIS) Steering Committee. Eur Geriatr Med 2022;13(6):1239-1244.
8. Hortobágyi T, Zheng D, Weidner M, Lambert NJ, Westbrook S, Houmard JA. The influence of aging on muscle strength and muscle fiber characteristics with special reference to eccentric strength. J Gerontol A Biol Sci Med Sci 1995;50(6):B399-406.
9. de Lucena Alves CP, de Almeida SB, Lima DP, Neto PB, Miranda AL, Manini T, et. al. Muscle Quality in Older Adults: A Scoping Review. J Am Med Dir Assoc 2023;24(4):462-467.e12. Epub 2023 Mar 21. Erratum in: J Am Med Dir Assoc. 2023 Apr 27; PMID: 36963436.
10. Fragala MS, Kenny AM, Kuchel GA. Muscle quality in aging: a multi-dimensional approach to muscle functioning with applications for treatment. Sports Medicine (Auckland, N.Z.) 2015;45(5):641-658.
11. Radaelli R, Taaffe DR, Newton RU, Galvão DA, Lopez P. Exercise effects on muscle quality in older adults: a systematic review and meta-analysis. Sci Rep 2021;11(1):21085.
12. Lanza MB, Martins-Costa HC, De Souza CC, Lima FV, Diniz RCR, Chagas MH. Muscle volume vs. anatomical cross-sectional area: Different muscle assessment does not affect the muscle size-strength relationship. J Biomech 2022;132:110956.
13. Jaric S, Radosavljevic-Jaric S, Johansson H. Muscle force and muscle torque in humans require different methods when adjusting for differences in body size. Eur J Appl Physiol 2002;87(3):304-7.
14. Buckinx F, Landi F, Cesari M, Fielding RA, Visser M, Engelke K, et al. Pitfalls in the measurement of muscle mass: a need for a reference standard. J Cachexia Sarcopenia Muscle 2018;9(2):269-278.
15. Beaudart C, Rolland Y, Cruz-Jentoft AJ, Bauer JM, Sieber C, Cooper C, et. al. Assessment of Muscle Function and Physical Performance in Daily Clinical Practice : A position paper endorsed by the European Society for Clinical and Economic Aspects of Osteoporosis, Osteoarthritis and Musculoskeletal Diseases (ESCEO). Calcif Tissue Int 2019;105(1):1-14.
16. Enoka RM, Duchateau J. Muscle fatigue: what, why and how it influences muscle function. J Physiol 2008;586(1):11-23.
17. Wang YC, Bohannon RW, Li X, Sindhu B, Kapellusch J. Hand-Grip Strength: Normative Reference Values and Equations for Individuals 18 to 85 Years of Age Residing in the United States. J Orthop Sports Phys Ther 2018;48(9):685-693.
18. Lindle RS, Metter EJ, Lynch NA, Fleg JL, Fozard JL, Tobin J, et al. Age and gender comparisons of muscle strength in 654 women and men aged 20-93 yr. J Appl Physiol (1985) 1997;83(5):1581-7.
19. Perkisas S, Bastijns S, Baudry S, Bauer J, Beaudart C, Beckwée D, et al. Application of ultrasound for muscle assessment in sarcopenia: 2020 SARCUS update. Eur Geriatr Med 2021;12(1):45-59.
20. Lee RC, Wang Z, Heo M, Ross R, Janssen I, Heymsfield SB. Total-body skeletal muscle mass: development and cross-validation of anthropometric prediction models. Am J Clin Nutr 2000;72(3):796-803. Erratum in: Am J Clin Nutr 2001;73(5):995
21. Dvir Z. Clinical applicability of isokinetics: A review. Clin Biomech (Bristol, Avon) 1991;6(3):133-44.
22. Barbat-Artigas S, Rolland Y, Zamboni M, Aubertin-Leheudre M. How to assess functional status: a new muscle quality index. J Nutr Health Aging 2012;16(1):67-77.
23. Kanis JA. Assessment of osteoporosis at the primary health-care level. Technical Report. http://www. shef. ac. uk/FRAX. 2008.
24. Kim KM, Jang HC, Lim S. Differences among skeletal muscle mass indices derived from, height-, weight-, and body mass index-adjusted models in assessing sarcopenia. Korean J Intern Med 2016;31(4):643-50.
25. Phillips SK, Woledge RC, Bruce SA, Young A, Levy D, Yeo A, Martin FC. A study of force and cross-sectional area of adductor pollicis muscle in female hip fracture patients. J Am Geriatr Soc 1998;46(8):999-1002.
26. Reid KF, Pasha E, Doros G, Clark DJ, Patten C, Phillips EM, et al. Longitudinal decline of lower extremity muscle power in healthy and

mobility-limited older adults: influence of muscle mass, strength, composition, neuromuscular activation, and single fiber contractile properties. Eur J Appl Physiol 2014;114(1):29-39.
27. Alcazar J, Guadalupe-Grau A, García-García FJ, Ara I, Alegre LM. Skeletal Muscle Power Measurement in Older People: A Systematic Review of Testing Protocols and Adverse Events. J Gerontol A Biol Sci Med Sc. 2018;73(7):914-924.
28. Lauretani F, Russo CR, Bandinelli S, Bartali B, Cavazzini C, Di Iorio A, et al. Age-associated changes in skeletal muscles and their effect on mobility: an operational diagnosis of sarcopenia. J Appl Physiol (1985) 2003;95(5):1851-60.
29. Janssen I, Heymsfield SB, Ross R. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. J Am Geriatr Soc 2002;50(5):889-96.
30. Volpi E, Nazemi R, Fujita S. Muscle tissue changes with aging. Curr Opin Clin Nutr Metab Care 2004;7(4):405-10.
31. Bassey EJ, Harries UJ. Normal values for handgrip strength in 920 men and women aged over 65 years, and longitudinal changes over 4 years in 620 survivors. Clin Sci (Lond) 1993;84(3):331-7.
32. Naimo MA, Varanoske AN, Hughes JM, Pasiakos SM. Skeletal Muscle Quality: A Biomarker for Assessing Physical Performance Capabilities in Young Populations. Front Physiol 2021;12:706699.
33. Clark BC, Manini TM. Sarcopenia =/= dynapenia. J Gerontol A Biol Sci Med Sci 2008;63(8):829-34.
34. Hunter SK, Pereira HM, Keenan KG. The aging neuromuscular system and motor performance. J Appl Physiol (1985) 2016;121(4):982-995.
35. Delmonico MJ, Harris TB, Visser M, Park SW, Conroy MB, Velasquez-Mieyer P, et al. Health, Aging, and Body. Longitudinal study of muscle strength, quality, and adipose tissue infiltration. Am J Clin Nutr 2009;90(6):1579-85.
36. Lindle RS, Metter EJ, Lynch NA, Fleg JL, Fozard JL, Tobin J, et al. Age and gender comparisons of muscle strength in 654 women and men aged 20-93 yr. J Appl Physiol (1985) 1997;83(5):1581-7.
37. McGregor RA, Cameron-Smith D, Poppitt SD. It is not just muscle mass: a review of muscle quality, composition and metabolism during ageing as determinants of muscle function and mobility in later life. Longev Healthspan 2014;3(1):9.
38. Russ DW, Gregg-Cornell K, Conaway MJ, Clark BC. Evolving concepts on the age-related changes in "muscle quality". J Cachexia Sarcopenia Muscle 2012;3(2):95-109.
39. Lim JY. Therapeutic potential of eccentric exercises for age-related muscle atrophy. Integrative Medicin Research 2016; 5(3): 176-81.
40. Yao WX, Li J, Jiang Z, Gao JH, Franklin CG, Huang Y, et al. Aging interferes central control mechanism for eccentric muscle contraction. Front Aging Neurosci 2014;6:86.
41. Poulin MJ, Vandervoort AA, Paterson DH, Kramer JF, Cunningham DA. Eccentric and concentric torques of knee and elbow extension in young and older men. Can J Sport Sci 1992;17(1):3-7