**Relevance to assess and preserve muscle strength in aging field**

F. Buckinx1&2, M. Aubertin-Leheudre1&2\*

*1Département des Sciences de l’activité physique, Groupe de Recherche en Activité Physique Adaptée (GRAPA), Université du Québec à Montréal, Montréal, Canada*

*2Centre de Recherche de l’Institut Universitaire de Gériatrie de Montréal (CRIUGM), Montréal, Canada*

**\*** ***Corresponding Author:***

Aubertin-Leheudre Mylene,

Département des Sciences de l’activité physique,

Faculté des Sciences, UQAM,

Pavillon Sciences Biologiques, SB-4615,

141, Avenue du Président Kennedy,

Montréal, Québec, Canada, H2X 1Y4.

Email: aubertin-leheudre.mylene@uqam.ca

**Abstract**

According to the revised European consensus on sarcopenia, muscle strength is the primary parameter of sarcopenia and is associated with adverse outcomes or physical limitation. This literature review aims to clarify how and why to measure and preserve muscle strength in older population. Overall, the relationship between muscle strength and physical function is impacted by level of muscle mass, the degree of obesity (BMI), age and physical activity. Therefore, these factors are to be considered in the evaluation of muscle strength. It is necessary to have objective, reliable and sensitive tools to assess muscle strength, in different populations to detect and quantify weakness, to adapt physical exercises to patients’ capacity and to evaluate the effects of treatment. Handgrip strength measurement might be reasonable for clinical practice while the measurement of knee flexors/extensors strength with both 1RM and dynamometers is increasingly important yet restricted by the requirement ofspecial equipment. Physical activity and nutrition are two important behavioral factors to maintain muscle strength. Combined exercise and nutrition interventions improved muscle strength to a more prominent degree than exercise or nutrition alone.

**Key words:** muscle; strength; dynapenia; assessment; management

**Highlights**

* Overall, the relationship between muscle strength and physical function is impacted by level of muscle mass, the degree of obesity (BMI), age and physical activity.
* It is necessary to have objective, reliable and sensitive tools to assess muscle strength.
* Handgrip strength measurement might be reasonable for clinical practice while the measurement of knee flexors/extensors strength with both 1RM and dynamometers is increasingly important yet restricted by the requirement of special equipment.Physical activity and nutrition are two important behavioral factors to maintain muscle strength

# **Introduction**

Aging process is associated with a progressive loss in muscle function, a downward spiral that may lead to functionality decline and frailty. The strong association between muscle strength and functional capacities has sparked growing interest in these associated factors. In addition to muscle mass, many other factors are associated with muscle strength, such as body weight, gender, physical activity. These factors will be developed in the present review. Moreover, according to the aim or the design of the study, there are different ways to measure and express muscle strength (i.e. absolute or relative muscle strength, muscle quality) which have advantages and disadvantages that are described below. Overall, this literature review therefore aims to clarify how and why to measure and preserve muscle strength in older population.

# **Why is it important to assess muscle strength?**

A standout amongst the most critical consequencesof the loss in physical performance was a noteworthyprognostic indicator for the development of physical disability, frailty, loss of physical autonomy, nursing home admission, hospitalization, and even mortality. In recent years, it has been appeared that larger muscle mass only is not adequate to keep up functional capacity in more established age [1, 2]. Despite the fact that sarcopenia is related with expanded risk of physical disability and poor quality of life, various investigations to date demonstrated that muscle composition (i.e. muscle quality) instead of muscle mass is related to better physical function[1, 2].

# According to the revised European consensus on sarcopenia, muscle strength is the primary parameter of sarcopenia [3] which is an Independent Condition by an International Classification of Disease, Tenth Revision, Clinical Modification (ICD-10-CM) Code. In fact, it is well recognized that strength is better than mass in predicting adverse outcomes or physical limitation [4-9]. Altogether, the progressive inadequacy between muscle mass and strength and power suggests a progressive deterioration of muscle “quality” that also could be illustrative as being representative of the age-related decreased ability of muscle to adapt to its environment, as for example following a bed rest or during a training program. Muscle quality, referring both to micro- and macroscopic changes in muscle architecture and composition, and to muscle function delivered per unit of muscle mass, is also impaired with aging [3]. Indeed, several studies demonstrated that muscle quality rather than muscle mass is linked to better physical function [10]. More evidence has shown that muscle strength would be a better indicator of functional capacity, risks of hospitalization, and mortality than muscle mass [2, 11]. In light of this, low muscle quality (defined as the ratio of strength to muscle mass) and low muscle strength have been suggested as potential indexes for identifying individuals at risk of functional impairments [12, 13]. **Factors influencing muscle strength?**

Different factors potentially influencingmuscle strength decline and its relation with functional capacities have been identified in the literature. The most important factors are described in the present section.

### ***Age***

Aging process is accompanied by adistinct loss of muscle mass and strength[14]. Maximum strength is between 20th and 30th life years [15, 16]. Changes marked with aging process occur after 50th life year. From this age, we observe a loss of muscle strength of 1.5–5%/year [17, 18]. According to Leblanc et al., age would explain 6-44% of the variability of muscle strength [19]. The loss of muscle strength with age comes along with a decrease in muscle quality [12]. This is more greater in lower limbs than in upper limbs [20]. Moreover, the decrease in muscle quality is observed when muscle strength is measured using a concentric approach [21, 22] whereas the findings are more contradictory when muscle strength is assessed using isometric [21, 23] or eccentric approaches [24, 25]. Furthermore, the way muscle mass is estimated influences the relationship between muscle quality and age.***3.2. Sex***

Evidence suggests that sex differences may exists in muscle strength and muscle quality. Lebland et al. highlighted a strong association between muscle strength and sex (explaining 40–74 % of the variance) [19]. Men and women have a similarmuscle strength/muscle mass ratio at the level of the legs, but it is higher in men than in women for the arms [18]. Previous work had already shown that, compared to men, the women were approximately 52% and 66% as strong in the upper and lower body respectively. Based on lean body mass, the men were also stronger[26]. A sex difference in muscle strength decline is also reported in the literature. Longitudinal studies [27, 28] highlighted a larger decrease over time for muscle strength (i.e. knee extensors) in men compared to women.

### ***3.3. Cognition and education***

In the literature, poor cognitive function is a predisposing factor for low muscle strength [29]. Longitudinal and cross-sectional studies showed that poor cognitive function was related toa faster decrease in handgrip strength in community-dwelling older people [30] or hospitalized older patients [31]. The level of education is also another factor positively associated with muscle strength. [32]

### ***3.4. BMI/Obesity***

### Compelling evidence suggeststhat overweight or obesity may increase the risk of functional decline and mobility disability in older adult [33]. In this sense, it is recognized that BMI could explain 2-16% % of the variability of muscle strength [19]. Published data imply that higher BMI in adults over 70 years is positively correlated with higher grip strength [34, 35]. However, Stenholm et al. highlighted that there is an association between long-term exposure to obesity and poor hand grip strength later in life in persons aged 55 years and older [36]. Similarly, increasing fatty infiltration of muscle tissue is associated with decreasing muscle strength [28]. Higher fat mass content may also speed up the alteration of muscle quality. Then, Rolland et al. reported that muscle quality (i.e. muscle strength adjusted for muscle mass) did not differ significantly between obese, normal-weight and lean subjects [37]. It has been also observed that abdominal obesity does not necessarily lead to a reduction of functional capacity among active older women, if lower limb muscle strength is maintained [9]. Nevertheless, the extent to which the increase in body fat contente (obesity) worsens the relationship between the metabolic, mechanical properties of skeletal muscle and poses higher risk on functional capacity and future disability in older adults cannot be said with certainty since age, sex and history of obesity can influenced these conclusions. ***3.5. Physical activity***

Physical activity is another factor influencing muscle strength since it explains 1-3% of the variability of muscle strength [19]. Cooper et al. highlighted that grip strength and physical activity were linearly and positively associated with each other in cross-sectional analysis including 66 582 men and women [38]. The study of Bartels et al. also reports that the level of daily physical activity during leisure was positively correlated to muscle strength in the lower extremities [32]. In addition, Barbat-Artigas et al. observed that voluntary long-term engagement in physical activity (either in resistance or aerobic exercises) beyond 60 years old is beneficial for muscle quality and should be encouraged [39]. Given these findings, physical activity is a modifiable lifestyle variable that could be interesting in the prevention and the management of muscle strength decline. Consequently, this aspect will be developed in the appropriate section below (i.e. how to manage or treat loss of muscle strength).

Overall, the relationship between muscle strength and physical function is impacted by level of muscle mass, the degree of obesity (BMI), age [39] and physical activity [40].

# **How to assess muscle strength?**

It is necessary to have objective, reliable and sensitive tools to assess muscle strength, in different populations (especially in intensive care, geriatrics, pediatrics, athletes) to detect and quantify weakness, to adapt physical exercises to patients’ capacity and to evaluate the effects of treatment [41]. Although muscle strength of several muscle groups can be assessed, the most frequently evaluated are handgrip and knee flexors and extensors. Two methods are mainly used to measure muscle strength: one-repetition maximum and dynamometry. One repetition maximum (1RM) is a measure of the maximum weight a subjects can lift in a single repetition for a given exercise and it is the reflect ofindividual’s maximum strength. Dynamometers are devices that generally allow isometric and isokinetic measurements of strength such as concentric or eccentric torque at various velocities. Thus, this chapter aims to describe and discuss the different ways of expressing (muscle groups) and measuring muscle strength according to clinical and research purposes.

## ***Handgrip strength***

Handgrip strength measurement is extensively used as a measure of overall strength in many areas of medicine and sport science[42]. Indeed, handgrip strength shows a good correlation with leg strength [43]. Handgrip strength is also used as an indicator of general health [44], nutritional status [45], and all-cause mortality [6]. A recent international survey indicated that clinicians, both from the fields of geriatric medicine and rheumatology, generally used grip strength to assess muscle strength in their daily practice [46]. Widespread use of the grip strength test results from its high reliability [47] and its easy access [48]. Indeed, the method is inexpensive, and does not require a specialist trained staff [49]. Moreover, it is non-invasive [50].

Hydraulic dynamometer, such as the Jamar dynamometer, is the gold standard for this measurement. However,the design of this dynamometer is not suitablefor patients with advanced arthritis [51]. In this case, a good alternative is the pneumatic dynamometer, such as the Martin vigorimeter.. This flexible pear-shaped vigorimeter is available in three sizes, will facilitate the measurement of grip strength in these special cases. Roberts et al. have developed a standardized protocol to assess grip strength, in order to make the studies comparable to each other [52]. During the standardized evaluation, the subject need to be sitting on a standard chair with their forearms resting flat on the armchairs. Clinicians should demonstrate the use of the dynamometer and encourage the patients to squeeze the dynamometer as hard and as tightly as possible during 3–5 seconds. Three measures of each arm should be performed and, usually, the highest reading of the 6 measurements is reported as the final result [53]. A variety of thresholds of grip strength have been proposed to characterize low muscle strength, ranging from 16 to 20 kg for women and 26–30 kg for men [54-57]. A limitation of grip strength may not overall strength of the body [58] and a measurement of isometric strength whereas most daily activities require dynamic muscle contractions.

## ***Lower limb muscle strength***

Lower limb muscle strength (i.e. knee flexors and extensors) is also often studied, since it may be better associated with functional activities in comparison to handgrip strength [59, 60]. An age-related decline in isometric is observed in both men and women. This is true for concentric and eccentric strength but it is less marked with eccentric strength [61, 62]. Thus, lower limb muscle strength (i.e. usually strength of the knee extensors), is generally measured in isometric and/or isokinetic condition.

*Isometric strength* method consists in measuring the isometric maximum voluntary strength during contractions performed at constant angular position against resistance. The result is specific to the fixed angular position and reflects the ability of the muscle group to generate a force during isometric contraction (without variation in overall muscle length); it is therefore a measure of the static strength (as opposed to dynamic strength). A portable dynamometer could have a potential interest in clinical practice, especially outside medical centers, if it is simple to use, reliable and reproducible. However, it also has limitations in its measurement position, depending on the joint angle, the measurement site, the type of measurement, the type of muscle contraction and the speed of the movement. Standardization of measurement is therefore necessary and a protocol has been proposed recently [63]. In addition, bias in the assessment, such as the skill and strength of the evaluators, may affect the test results [64]. In 2011, Stark and his team synthesized the results of validation studies of portable dynamometers available in the scientific literature [65]. According to the authors, the reproducibility of portable dynamometers varies from "moderate" to "good". Other portable dynamometers are sometimes used without having been subject to any validation. It is therefore recommended to use tools that have been validated in quality scientific studies. The measurement of the isometric strength allows the establishment of bilateral differences and an agonist / antagonist ratio. However, this technique has a poor specificity for the evaluation of dynamic strength. In some cases, the clinician cannot be satisfied with an isometric evaluation and must access the dynamic strength (i.e. eccentric and concentric torque).

*Dynamic muscle strength* can be precisely measured by the isokinetic method, which proposes a unidirectional analytical motion, performed at a constant angular velocity imposed by the experimenter [66]. These characteristics result from the intervention of a variable resistance, constantly enslaved to the subject's capacity for effort. The isokinetic technique guarantees maximum muscle contraction during the entire exercise, and for each degree of joint movement. The measured isokinetic strength is, therefore, the closest reflection of the physiological reality of muscle contraction. This technique is commonly used in athletes to characterize their muscle performance [67] but also to detect bilateral asymmetries between homologous muscles or imbalances between agonist and antagonist muscles [68]. It is also a technique that has demonstrated its usefulness in clinical practice, for example in revalidation, in orthopedic patients [69]. However, isokinetic evaluation requires the use of sophisticated, expensive and non-portable measuring devices, which limits its feasibility in some environments. It should be noted that the use of the tools presented above may differ depending on the clinical context and measurement objectives. For example, if it seems worthwhile to recommend assessing grip strength in daily clinical practice, isokinetic therapy has added value in more specific clinical situations (e.g. muscle atrophy or unfavorable biomechanical conditions).

## ***Functional tests***

The sit-to-stand test as well as the walking speed test are also widely used to assess lower limb muscle strength, mainly among older adults [70, 71].

The sit-to stand-test involves asking the subjects to stand up from a sitting position and to sit down 10 times as quickly as possible, with arms crossed, and the time required to complete the task is recorded. [72]. Variations of the sit-to-stand test include the maximum number of times a subject can stand up and sit down on a regular chair in a given period of time, usually 30-seconds or 1-minute [73]. Getting up and sitting in a chair involves activiation of lower limb muscles, this is why the sit-to-stand test represents a good alternative for measuring muscle strength of the lower limbs.[73, 74]. This tests is simple and quick to perform. It has the advantage of requiring minimal equipement (i.e. conventional chair with armrests and chronometer) and not requiring highly qualified personnel [73].

According to the recent systematic review of Graham, there is great variation in the methodology of walking speed measurement [75]. In the field of sarcopenia, gait speed is usually assessed in accordance with the instruction in Short [Physical Performance](https://www.sciencedirect.com/topics/medicine-and-dentistry/physical-performance" \o "Learn more about Physical Performance) Battery [76]. In brief, subjects are asked to walk at their usual speed for 4 m and the time required to perform the task is recorded. Walking speed is positively associated with muscle strength and, because walking speed is a quick and easy test to administer, not limited to a specific health care discipline, and is a reliable, valid and sensitive measure [77], it is often included in clinical and epidemiological research studies [78, 79] to estimate lower limb muscle strength.In conclusion, Handgrip strength measurement might be reasonable for clinical practice while the measurement of knee flexors/extensors strength with both 1RM and dynamometers is increasingly important yet restricted by the requirement of special equipment. Functional tests can be an alternative to this limit by allowing an estimate of lower limb muscle strength.

# **How to express muscle strength?**

Muscle strength is defined as the force-producing capacity of muscle. Literature suggests different ways to express muscle strength, each of these way presents advantages and limitations, mainly depending on the aim and the design of the study. From a clinical and public health point of view, it is important to determine a clinical index to identify individuals at risk of impairments. Such an index could help clinicians to provide appropriate treatment for prevention of these negative outcomes in order to limit the society and families of this burden. Because, it does not require other measurements, absolute muscle strength is the simplest way to express muscle strength. However, relative muscle strength may be increasingly applicable to understandfunctional impairments. As described, in daily life, muscle strength relies upon other variables such as body weight, muscle mass, BMI etc. [80] Thus, correcting muscle strength for these confounding variables could be relevant. In this sense, Ploutz-Snyder et al. suggest to correct muscle strength for body weight (i.e. relative strength) in order to determine physical function threshold [81]. In a perspective of muscle quality assessment, other teams recommend to control muscle strength for muscle mass [20, 82]. Indeed, expressing muscle strength per unit of muscle mass may allow to estimate the contribution of neuromuscular factors to changes in muscle strength. Strength muscle index (e.g. upper or lower in absolute, divided by body weight or muscle mass), is a predictive value of disabilities. In this sense, subjects with low index are, at least, 3 times more likely to have disabilities than subjects with high index value.[83]. Among these indexes, the lower limber muscle strength divided by body weight index seems to be the most appropriate in clinical setting because it is accessible and integrates two measures (body weight and quadriceps muscle strength). The predominant role of lower extremities in performing ADL has previously been emphasized [84, 85]. Misic et al. also highlighted that relative muscle strength was the best predictor of lower-extremity physical function in healthy older people [86].The ability of muscle quality indicator to discriminate individuals at risk of disability or functional performance decline appears to be lower than the ability of relative lower limb muscle strength. However, the choice of the tasks itself engaging or not lower limb to evaluate the accuracy of the method used to assess muscle strength may be biased. Thus, handgrip strength [87, 88] and mostly divided by body weight [89] is considered as a strong predictor of disability and mortality. More specifically, muscle function (e.g. quality) or body composition alone (e.g. muscle mass or fat mass percentage) are of little importance for performing the tasks of daily living (i.e. walking, rising from a chair, or climbing stairs), as long as enough strength is generated to move the entire body.

In conclusion, lower limbs are more relevant than upper limbs for gait and physical functions. However, relative handgrip strength (expressed as handgrip strength divided by body weight) should not be overlooked and used since it is a simple and accurate tool to predict physical disabilities in older population.

***Proposed clinical cut point to identify older adults at risk:***

Table 1 summarizes the various clinical muscle strength or quality cut-points validated in various studies: absolute [90] or relative [63] muscle strength; Upper [12] and lower [12] muscle quality.

Clinical muscle strength cut-point was assessed as previously described [91], with type I corresponding to a value ranging from 1 to 2 standard deviations and type II corresponds to a value 2 SDs below the mean value of the reference population (i.e. healthy men and women aged 18 to 30 years) [91].

Muscle power was estimated using the 10 repetitions sit to stand equation [92] muscle mass and body weight using a bio-impedancemeter, and handgrip strength using a Lafayette dynamometer. All these tests were chosen since it is clinically feasible.

Table 1: various clinical muscle strength or quality cut-points

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Absolute handgrip**  **strength (kg)** | **Relative handgrip**  **strength (HS/BW; kg/kg)** | **Upper muscle quality**  **(HS/MM; kg/kg)** | **Lower muscle quality**  **(MP/MM; W/kg)** |
| **Normal** | W: >20  M: > 32 | W: >0.44  M: >0.61 | W: > 1.53  M: > 1.53 | W: > 5.50  M: > 5.50 |
| **Type I** | W: 20 ≥ **X** > 16  M: 32 ≥ **X** > 26 | W: 0.44 ≥ **X** > 0.35  M: 0.61 ≥ **X** > 0.50 | W: 1.53 ≥ **X** > 1.35  M: 1.53 ≥ **X** > 1.36 | W: 5.50 ≥ **X** > 4.08  M: 5.50 ≥ **X** > 4.33 |
| **Type II** | W: ≤ 16  M: ≤ 26 | W: ≤ 0.35  M: ≤ 0.50 | W: ≤ 1.35  M: ≤ 1.36 | W: ≤ 4.08  M: ≤ 4.33 |

W= women, M = men; MM= muscle mass; MP = muscle power

# **How to manage the loss of muscle strength in older adult?**

A recent systematic review, including 34 articles, highlighted that exercise has moderate-to-large effects on muscle strength among older adults [93]. There is growing evidence suggesting that the best way to improve muscle function [94] and physical performance [95-97] is resistance training. Several studies reported positive effects of resistance training on muscle strength [98] and muscle quality [99-101] in older subjects. In addition, mixed power training (power velocity training combined to functional exercise) is also efficient to counteract HS loss in dynapenic-obese older men [102]. Body and mind exercise could also be considered as another potential intervention to fight against loss of muscle function in dynapenic older adults [8]. More importantly, it has been shown that cardiovascular training is as beneficial as resistance training to maintain muscle quality and to mitigate the decline in functional capacities in voluntary active individuals over the age of 60 [39]. Lack of time is the main barrier to be engage in physical activity. Thus, high-intensity interval training (HIIT), a subtype of cardiovascular training but shorter has been recently shown to be particularly effective in triggering beneficial muscle adaptations compared to continuous aerobic exercise [103].

Accordingly, given that physical activity and nutrition are two important behavioral factors to maintain muscle strength, it is not surprising that combined exercise and nutrition interventions improved muscle strength to a greater extent than exercise or nutrition alone. First, a review concluded that protein intake plays a role in muscle health and recommends an intake of 1.0–1.2 g/kg of body weight per day for older adults [104]. Few months earlier, Dulac and colleagues had already highlighted that a higher daily protein intake (i.e. at least 1.2 g·kg-1·d-1 of protein) optimized the effects of mixed power training on muscle function, specifically on muscle quality [105]. A recent meta-analysis suggested that protein or amino acid supplementation without concomitant nutritional or exercise interventions increases muscle mass or strength in predominantly healthy elderly people [106]. A meta-analysis also reported a small but significant positive effect of vitamin D supplementation on global muscle strength with a standardized mean difference (SMD) of 0.17 (P = .02) [107]. *n*-3 PUFA supplement can brings added benefits in the prevention of sarcopenia and functional decline [108]. In addition, it has been suggested that Long-chain n-3 PUFA supplementation augments increases in muscle function and quality in older women but not in older men after resistance exercise training [109].

In addition, it has been recently found that citrulline supplementation (i.e. an amino-acid) when combined with HIIT lead to better improvements on upper limbs muscle strength in dynapenic-obese older adults [110]. Moreover, adding a caloric restriction to a resistance training can be especially useful to potentiate improvements in physical capacity in dynapenic-obese older adults [111].

# **Conclusion**

Loss of muscle strength is a predictor of functional capacities and adverse health outcomes and is therefore considered as a real public health problem. Indeed, this phenomenon alters the quality of life and generates costs for the society. It is therefore essential to assess accurately muscle strength in an aging population. The choice of the methods used to assess muscle strength depends on several criteria, such as accessibility, cost, specificity, etc. Nevertheless, it seems essential to use validated assessment tests, supported by high quality scientific studies. At present, exercise and nutrition seems beneficial non-pharmacological treatment to counteract dynapenia even if no specific dose/time efficiency established. Based on the prevalence of older adults in the society and its consequences, more and more studies are nowadays interested in understanding, identifying and managing the loss of muscle strength. Further studies are needed to established international consensus on How to assess and manage muscle strength decline in older adults with or without obesity.

*Funding*

*This research did not receive specific grant from funding agencies in the public, commercial or not-for-profit sectors.*

**References**

1. McGregor, R.A., D. Cameron-Smith, and S.D. Poppitt, *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): p. 9.

2. Cawthon, P.M., et al., *Do muscle mass, muscle density, strength, and physical function similarly influence risk of hospitalization in older adults?* J Am Geriatr Soc, 2009. **57**(8): p. 1411-9.

3. Cruz-Jentoft, A.J., et al., *Sarcopenia: revised European consensus on definition and diagnosis.* Age Ageing, 2018.

4. Schaap, L.A., et al., *Associations of Sarcopenia Definitions, and Their Components, With the Incidence of Recurrent Falling and Fractures: The Longitudinal Aging Study Amsterdam.* J Gerontol A Biol Sci Med Sci, 2018. **73**(9): p. 1199-1204.

5. Ibrahim, K., et al., *A feasibility study of implementing grip strength measurement into routine hospital practice (GRImP): study protocol.* Pilot Feasibility Stud, 2016. **2**: p. 27.

6. Leong, D.P., et al., *Prognostic value of grip strength: findings from the Prospective Urban Rural Epidemiology (PURE) study.* Lancet, 2015. **386**(9990): p. 266-73.

7. Schaap, L.A., A. Koster, and M. Visser, *Adiposity, muscle mass, and muscle strength in relation to functional decline in older persons.* Epidemiol Rev, 2013. **35**: p. 51-65.

8. Barbat-Artigas, S., et al., *Relationship between dynapenia and cardiorespiratory functions in healthy postmenopausal women: novel clinical criteria.* Menopause, 2011. **18**(4): p. 400-5.

9. Dulac, M.C., L.P. Carvalho, and M. Aubertin-Leheudre, *Functional capacity depends on lower limb muscle strength rather than on abdominal obesity in active postmenopausal women.* Menopause, 2018. **25**(2): p. 176-181.

10. Barbat-Artigas, S., et al., *Muscle quantity is not synonymous with muscle quality.* J Am Med Dir Assoc, 2013. **14**(11): p. 852.e1-7.

11. Newman, A.B., et al., *Strength, but not muscle mass, is associated with mortality in the health, aging and body composition study cohort.* J Gerontol A Biol Sci Med Sci, 2006. **61**(1): p. 72-7.

12. Barbat-Artigas, S., et al., *How to assess functional status: a new muscle quality index.* J Nutr Health Aging, 2012. **16**(1): p. 67-77.

13. Clark, B.C. and T.M. Manini, *Sarcopenia =/= dynapenia.* J Gerontol A Biol Sci Med Sci, 2008. **63**(8): p. 829-34.

14. Keller, K. and M. Engelhardt, *Strength and muscle mass loss with aging process. Age and strength loss.* Muscles Ligaments Tendons J, 2013. **3**(4): p. 346-50.

15. Baumgartner, R.N., et al., *Sarcopenic obesity predicts instrumental activities of daily living disability in the elderly.* Obes Res, 2004. **12**(12): p. 1995-2004.

16. Doherty, T.J., *The influence of aging and sex on skeletal muscle mass and strength.* Curr Opin Clin Nutr Metab Care, 2001. **4**(6): p. 503-8.

17. Goodpaster, B.H., et al., *The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study.* J Gerontol A Biol Sci Med Sci, 2006. **61**(10): p. 1059-64.

18. Frontera, W.R., et al., *A cross-sectional study of muscle strength and mass in 45- to 78-yr-old men and women.* J Appl Physiol (1985), 1991. **71**(2): p. 644-50.

19. Leblanc, A., et al., *Relationships between physical activity and muscular strength among healthy adults across the lifespan.* Springerplus, 2015. **4**: p. 557.

20. Lynch, N.A., et al., *Muscle quality. I. Age-associated differences between arm and leg muscle groups.* J Appl Physiol (1985), 1999. **86**(1): p. 188-94.

21. Overend, T.J., et al., *Knee extensor and knee flexor strength: cross-sectional area ratios in young and elderly men.* J Gerontol, 1992. **47**(6): p. M204-10.

22. Young, A., M. Stokes, and M. Crowe, *The size and strength of the quadriceps muscles of old and young men.* Clin Physiol, 1985. **5**(2): p. 145-54.

23. Alway, S.E., et al., *Muscle torque in young and older untrained and endurance-trained men.* J Gerontol A Biol Sci Med Sci, 1996. **51**(3): p. B195-201.

24. Lindle, R.S., 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): p. 1581-7.

25. Hortobagyi, T., et al., *Low- or high-intensity strength training partially restores impaired quadriceps force accuracy and steadiness in aged adults.* J Gerontol A Biol Sci Med Sci, 2001. **56**(1): p. B38-47.

26. Miller, A.E., et al., *Gender differences in strength and muscle fiber characteristics.* Eur J Appl Physiol Occup Physiol, 1993. **66**(3): p. 254-62.

27. Charlier, R., et al., *Age-related decline in muscle mass and muscle function in Flemish Caucasians: a 10-year follow-up.* Age (Dordr), 2016. **38**(2): p. 36.

28. Goodpaster, B.H., et al., *Attenuation of skeletal muscle and strength in the elderly: The Health ABC Study.* J Appl Physiol (1985), 2001. **90**(6): p. 2157-65.

29. Christensen, H., et al., *The "common cause hypothesis" of cognitive aging: evidence for not only a common factor but also specific associations of age with vision and grip strength in a cross-sectional analysis.* Psychol Aging, 2001. **16**(4): p. 588-99.

30. Raji, M.A., et al., *Cognitive status, muscle strength, and subsequent disability in older Mexican Americans.* J Am Geriatr Soc, 2005. **53**(9): p. 1462-8.

31. Maeda, K. and J. Akagi, *Cognitive impairment is independently associated with definitive and possible sarcopenia in hospitalized older adults: The prevalence and impact of comorbidities.* Geriatr Gerontol Int, 2017. **17**(7): p. 1048-1056.

32. Bartels, E.M., et al., *Effects of Lifestyle on Muscle Strength in a Healthy Danish Population.* J Lifestyle Med, 2018. **8**(1): p. 16-22.

33. Robert T, M.R., Anton SD, Aubertin-Leheudre M., *The Role of Muscle Mass, Muscle Quality, and Body Composition in Risk for the Metabolic Syndrome and Functional Decline in Older Adults.* Curr Geri Rep, 2015.

34. Massy-Westropp, N.M., et al., *Hand Grip Strength: age and gender stratified normative data in a population-based study.* BMC Res Notes, 2011. **4**: p. 127.

35. Hardy, R., et al., *Body mass index, muscle strength and physical performance in older adults from eight cohort studies: the HALCyon programme.* PLoS One, 2013. **8**(2): p. e56483.

36. Stenholm, S., et al., *Association between obesity history and hand grip strength in older adults--exploring the roles of inflammation and insulin resistance as mediating factors.* J Gerontol A Biol Sci Med Sci, 2011. **66**(3): p. 341-8.

37. Rolland, Y., et al., *Muscle strength in obese elderly women: effect of recreational physical activity in a cross-sectional study.* Am J Clin Nutr, 2004. **79**(4): p. 552-7.

38. Cooper, A., et al., *Bidirectional association between physical activity and muscular strength in older adults: Results from the UK Biobank study.* Int J Epidemiol, 2017. **46**(1): p. 141-148.

39. Barbat-Artigas, S., et al., *Identifying recreational physical activities associated with muscle quality in men and women aged 50 years and over.* J Cachexia Sarcopenia Muscle, 2014. **5**(3): p. 221-8.

40. Barbat-Artigas, S., et al., *Muscle Strength and Body Weight Mediate the Relationship Between Physical Activity and Usual Gait Speed.* J Am Med Dir Assoc, 2016. **17**(11): p. 1031-1036.

41. Morris, M.G., et al., *Relationships between muscle fatigue characteristics and markers of endurance performance.* J Sports Sci Med, 2008. **7**(4): p. 431-6.

42. Wind, A.E., et al., *Is grip strength a predictor for total muscle strength in healthy children, adolescents, and young adults?* Eur J Pediatr, 2010. **169**(3): p. 281-7.

43. Stevens, P.J., et al., *Is grip strength a good marker of physical performance among community-dwelling older people?* J Nutr Health Aging, 2012. **16**(9): p. 769-74.

44. Bohannon, R.W., *Hand-grip dynamometry predicts future outcomes in aging adults.* J Geriatr Phys Ther, 2008. **31**(1): p. 3-10.

45. Norman, K., et al., *Hand grip strength: outcome predictor and marker of nutritional status.* Clin Nutr, 2011. **30**(2): p. 135-42.

46. O.Bruyère, C.B., J.-Y.Reginster, F.Buckinx, D.Schoene, V.Hirani, C.Cooper, J.A.Kanis, R.Rizzoli, E.McCloskey, T.Cederholm, A.Cruz-Jentoft, E.Freiberger, *Assessment of muscle mass, muscle strength and physical performance in clinical practice: An international survey.* European Geriatric Medicine, 2016. **7**(3): p. 243-246.

47. Hamilton, G.F., C. McDonald, and T.C. Chenier, *Measurement of grip strength: validity and reliability of the sphygmomanometer and jamar grip dynamometer.* J Orthop Sports Phys Ther, 1992. **16**(5): p. 215-9.

48. Mathiowetz, V., *Comparison of Rolyan and Jamar dynamometers for measuring grip strength.* Occup Ther Int, 2002. **9**(3): p. 201-9.

49. Ploegmakers, J.J., et al., *Grip strength is strongly associated with height, weight and gender in childhood: a cross sectional study of 2241 children and adolescents providing reference values.* J Physiother, 2013. **59**(4): p. 255-61.

50. Taekema, D.G., et al., *Handgrip strength as a predictor of functional, psychological and social health. A prospective population-based study among the oldest old.* Age Ageing, 2010. **39**(3): p. 331-7.

51. Bean, J.F., et al., *The relationship between leg power and physical performance in mobility-limited older people.* J Am Geriatr Soc, 2002. **50**(3): p. 461-7.

52. Roberts, H.C., et al., *A review of the measurement of grip strength in clinical and epidemiological studies: towards a standardised approach.* Age Ageing, 2011. **40**(4): p. 423-9.

53. Waak, K., S. Zaremba, and M. Eikermann, *Muscle strength measurement in the intensive care unit: not everything that can be counted counts.* J Crit Care, 2013. **28**(1): p. 96-8.

54. Cruz-Jentoft, A.J., et al., *Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People.* Age Ageing, 2010. **39**(4): p. 412-23.

55. Studenski, S.A., et al., *The FNIH sarcopenia project: rationale, study description, conference recommendations, and final estimates.* J Gerontol A Biol Sci Med Sci, 2014. **69**(5): p. 547-58.

56. Lauretani, F., 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): p. 1851-60.

57. Dodds, R.M., et al., *Grip strength across the life course: normative data from twelve British studies.* PLoS One, 2014. **9**(12): p. e113637.

58. Buckley, C., M. Stokes, and D. Samuel, *Muscle strength, functional endurance, and health-related quality of life in active older female golfers.* Aging Clin Exp Res, 2018. **30**(7): p. 811-818.

59. Buckinx, F., et al., *Relationship between Isometric Strength of Six Lower Limb Muscle Groups and Motor Skills among Nursing Home Residents.* J Frailty Aging, 2015. **4**(4): p. 184-7.

60. Harris-Love, M.O., et al., *The Influence of Upper and Lower Extremity Strength on Performance-Based Sarcopenia Assessment Tests.* J Funct Morphol Kinesiol, 2018. **3**(4).

61. Hortobagyi, T., et al., *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): p. B399-406.

62. Porter, M.M., et al., *Concentric and eccentric knee extension strength in older and younger men and women.* Can J Appl Physiol, 1995. **20**(4): p. 429-39.

63. Buckinx, F., et al., *Reliability of muscle strength measures obtained with a hand-held dynamometer in an elderly population.* Clin Physiol Funct Imaging, 2017. **37**(3): p. 332-340.

64. Keating, J.L. and T.A. Matyas, *The influence of subject and test design on dynamometric measurements of extremity muscles.* Phys Ther, 1996. **76**(8): p. 866-89.

65. Stark, T., et al., *Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: a systematic review.* Pm r, 2011. **3**(5): p. 472-9.

66. Croisier, J.L. and J.M. Crielaard, *[Isokinetic exercise and sports injuries].* Rev Med Liege, 2001. **56**(5): p. 360-8.

67. Amaral, G.M., et al., *Muscular performance characterization in athletes: a new perspective on isokinetic variables.* Braz J Phys Ther, 2014. **18**(6): p. 521-9.

68. Croisier, J.L., et al., *Strength imbalances and prevention of hamstring injury in professional soccer players: a prospective study.* Am J Sports Med, 2008. **36**(8): p. 1469-75.

69. Almekinders, L.C. and J. Oman, *Isokinetic Muscle Testing: Is It Clinically Useful?* J Am Acad Orthop Surg, 1994. **2**(4): p. 221-225.

70. McCarthy, E.K., et al., *Repeated chair stands as a measure of lower limb strength in sexagenarian women.* J Gerontol A Biol Sci Med Sci, 2004. **59**(11): p. 1207-12.

71. Rantanen, T., et al., *Association of muscle strength with maximum walking speed in disabled older women.* Am J Phys Med Rehabil, 1998. **77**(4): p. 299-305.

72. Yanagawa, N., et al., *Relationship between performances of 10-time-repeated sit-to-stand and maximal walking tests in non-disabled older women.* J Physiol Anthropol, 2016. **36**(1): p. 2.

73. Zanini, A., et al., *The one repetition maximum test and the sit-to-stand test in the assessment of a specific pulmonary rehabilitation program on peripheral muscle strength in COPD patients.* Int J Chron Obstruct Pulmon Dis, 2015. **10**: p. 2423-30.

74. Bohannon, R.W., et al., *Sit-to-stand test: Performance and determinants across the age-span.* Isokinet Exerc Sci, 2010. **18**(4): p. 235-240.

75. Graham, J.E., et al., *Assessing walking speed in clinical research: a systematic review.* J Eval Clin Pract, 2008. **14**(4): p. 552-62.

76. Guralnik, J.M., et al., *A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission.* J Gerontol, 1994. **49**(2): p. M85-94.

77. Green, J., A. Forster, and J. Young, *Reliability of gait speed measured by a timed walking test in patients one year after stroke.* Clin Rehabil, 2002. **16**(3): p. 306-14.

78. Buckinx, F., et al., *Relationship between frailty, physical performance and quality of life among nursing home residents: the SENIOR cohort.* Aging Clin Exp Res, 2016. **28**(6): p. 1149-1157.

79. Cesari, M., et al., *Prognostic value of usual gait speed in well-functioning older people--results from the Health, Aging and Body Composition Study.* J Am Geriatr Soc, 2005. **53**(10): p. 1675-80.

80. Reed, R.L., et al., *The relationship between muscle mass and muscle strength in the elderly.* J Am Geriatr Soc, 1991. **39**(6): p. 555-61.

81. Ploutz-Snyder, L.L., et al., *Functionally relevant thresholds of quadriceps femoris strength.* J Gerontol A Biol Sci Med Sci, 2002. **57**(4): p. B144-52.

82. Metter, E.J., et al., *Muscle quality and age: cross-sectional and longitudinal comparisons.* J Gerontol A Biol Sci Med Sci, 1999. **54**(5): p. B207-18.

83. Barbat-Artigas, S., et al., *Clinical relevance of different muscle strength indexes and functional impairment in women aged 75 years and older.* J Gerontol A Biol Sci Med Sci, 2013. **68**(7): p. 811-9.

84. Brown, M., D.R. Sinacore, and H.H. Host, *The relationship of strength to function in the older adult.* J Gerontol A Biol Sci Med Sci, 1995. **50 Spec No**: p. 55-9.

85. Reid, K.F., et al., *Lower extremity muscle mass predicts functional performance in mobility-limited elders.* J Nutr Health Aging, 2008. **12**(7): p. 493-8.

86. Misic, M.M., et al., *Muscle quality, aerobic fitness and fat mass predict lower-extremity physical function in community-dwelling older adults.* Gerontology, 2007. **53**(5): p. 260-6.

87. Al Snih, S., et al., *Handgrip strength and mortality in older Mexican Americans.* J Am Geriatr Soc, 2002. **50**(7): p. 1250-6.

88. Al Snih, S., et al., *Hand grip strength and incident ADL disability in elderly Mexican Americans over a seven-year period.* Aging Clin Exp Res, 2004. **16**(6): p. 481-6.

89. Dulac, M., et al., *Is handgrip strength normalized to body weight a useful tool to identify dynapenia and functional incapacity in post-menopausal women?* Braz J Phys Ther, 2016. **20**(6): p. 510-516.

90. Alley, D.E., et al., *Grip strength cutpoints for the identification of clinically relevant weakness.* J Gerontol A Biol Sci Med Sci, 2014. **69**(5): p. 559-66.

91. Lauze, M., D.D. Martel, and M. Aubertin-Leheudre, *Feasibility and Effects of a Physical Activity Program Using Gerontechnology in Assisted Living Communities for Older Adults.* J Am Med Dir Assoc, 2017. **18**(12): p. 1069-1075.

92. Takai, Y., et al., *Sit-to-stand test to evaluate knee extensor muscle size and strength in the elderly: a novel approach.* J Physiol Anthropol, 2009. **28**(3): p. 123-8.

93. Liberman, K., et al., *The effects of exercise on muscle strength, body composition, physical functioning and the inflammatory profile of older adults: a systematic review.* Curr Opin Clin Nutr Metab Care, 2017. **20**(1): p. 30-53.

94. Law, T.D., L.A. Clark, and B.C. Clark, *Resistance Exercise to Prevent and Manage Sarcopenia and Dynapenia.* Annu Rev Gerontol Geriatr, 2016. **36**(1): p. 205-228.

95. Fiatarone, M.A., et al., *Exercise training and nutritional supplementation for physical frailty in very elderly people.* N Engl J Med, 1994. **330**(25): p. 1769-75.

96. Bemben, D.A., et al., *Effects of combined whole-body vibration and resistance training on muscular strength and bone metabolism in postmenopausal women.* Bone, 2010. **47**(3): p. 650-6.

97. Candow, D.G., *The impact of nutritional and exercise strategies for aging bone and muscle.* Appl Physiol Nutr Metab, 2008. **33**(1): p. 181-3.

98. Peterson, M.D., A. Sen, and P.M. Gordon, *Influence of resistance exercise on lean body mass in aging adults: a meta-analysis.* Med Sci Sports Exerc, 2011. **43**(2): p. 249-58.

99. Welle, S., S. Totterman, and C. Thornton, *Effect of age on muscle hypertrophy induced by resistance training.* J Gerontol A Biol Sci Med Sci, 1996. **51**(6): p. M270-5.

100. Ivey, F.M., et al., *Effects of strength training and detraining on muscle quality: age and gender comparisons.* J Gerontol A Biol Sci Med Sci, 2000. **55**(3): p. B152-7; discussion B158-9.

101. Tracy, B.L., et al., *Muscle quality. II. Effects Of strength training in 65- to 75-yr-old men and women.* J Appl Physiol (1985), 1999. **86**(1): p. 195-201.

102. Carvalho, L.P., et al., *Effect of a 12-week mixed power training on physical function in dynapenic-obese older men: does severity of dynapenia matter?* Aging Clin Exp Res, 2018.

103. Garcia-Pinillos, F., et al., *Effects of 12-week concurrent high-intensity interval strength and endurance training programme on physical performance in healthy older people.* J Strength Cond Res, 2017.

104. Mithal, A., et al., *Impact of nutrition on muscle mass, strength, and performance in older adults.* Osteoporos Int, 2013. **24**(5): p. 1555-66.

105. Dulac, M.C., et al., *Differences in muscle adaptation to a 12-week mixed power training in elderly men, depending on usual protein intake.* Exp Gerontol, 2018. **104**: p. 78-85.

106. Tieland, M., et al., *The Impact of Dietary Protein or Amino Acid Supplementation on Muscle Mass and Strength in Elderly People: Individual Participant Data and Meta-Analysis of RCT's.* J Nutr Health Aging, 2017. **21**(9): p. 994-1001.

107. Beaudart, C., et al., *The effects of vitamin D on skeletal muscle strength, muscle mass, and muscle power: a systematic review and meta-analysis of randomized controlled trials.* J Clin Endocrinol Metab, 2014. **99**(11): p. 4336-45.

108. Tessier, A.J. and S. Chevalier, *An Update on Protein, Leucine, Omega-3 Fatty Acids, and Vitamin D in the Prevention and Treatment of Sarcopenia and Functional Decline.* Nutrients, 2018. **10**(8).

109. Da Boit, M., et al., *Sex differences in the effect of fish-oil supplementation on the adaptive response to resistance exercise training in older people: a randomized controlled trial.* Am J Clin Nutr, 2017. **105**(1): p. 151-158.

110. Buckinx, F., et al., *Effect of High-Intensity Interval Training Combined with L-Citrulline Supplementation on Functional Capacities and Muscle Function in Dynapenic-Obese Older Adults.* J Clin Med, 2018. **7**(12).

111. Senechal, M., et al., *The effects of lifestyle interventions in dynapenic-obese postmenopausal women.* Menopause, 2012. **19**(9): p. 1015-21.