The association between calf circumference and appendicular skeletal muscle mass index of black urban women in Tlokwe City

PO Ukegbu[a,b]* [ID], HS Kruger[a,c] [ID], JD Meyer[a], C Nienaber-Rousseau[a] [ID], C Botha-Ravyse[a] [ID], SJ Moss[d] and MI Kruger[e] [ID]

[a]Centre of Excellence for Nutrition, North-West University, Potchefstroom, South Africa
[b]Department of Human Nutrition and Dietetics, Michael Okpara University of Agriculture, Umudike, Nigeria
[c]Medical Research Council Hypertension and Cardiovascular Disease Research Unit, North-West University, Potchefstroom, South Africa
[d]Physical Activity, Sport and Recreation Sciences, North-West University, Potchefstroom, South Africa
[e]Africa Unit for Transdisciplinary Health Research, North-West University, Potchefstroom, South Africa
*Corresponding author, email: 30249864@nwu.ac.za

Check for updates

Background: Sarcopenia, the loss of muscle mass and strength, is associated with adverse health outcomes. Calf circumference (CC) has been proposed as a surrogate measure of muscle mass in the elderly; however, ethnic/sex specific cut-off values remain to be established.
Objective: A study was undertaken to investigate the relationship between CC and appendicular skeletal muscle mass (ASM), and the ASM index (ASMI), as well as to determine whether CC could be used to diagnose sarcopenia.
Methods: This was a cross-sectional study of 247 older black women living from Tlokwe, South Africa. ASM was measured using dual-energy X-ray absorptiometry, and the ASMI was calculated. Receiver operator characteristics curves and maximum Youden index were applied to identify a CC cut-off point for sarcopenia according to low gait speed (< 0.8 m/s), low hand-grip strength (< 16 kg) and low ASMI using a South African cut-off point for sarcopenia (ASMI < 4.94 kg/m^2).
Results: A strong positive correlation between CC and ASMI ($r = 0.84$, $p < 0.001$) was observed. The CC to predict low hand-grip strength was 34.3 cm and 37.8 cm for low gait speed. A CC of 29.9 cm was indicative of sarcopenia. The area under the curve for all outcomes was > 0.60.
Conclusion: A CC of 30 cm is proposed as a simple and inexpensive way to predict, screen or diagnose sarcopenia in black women in low-resource health settings. An accessible, inexpensive screening or diagnostic tool could facilitate timely interventions and prevention.

Keywords: gait speed, geriatric, hand-grip strength, muscle strength, sarcopenia

Introduction

Sarcopenia, a progressive and generalised loss of muscle mass and strength that occurs throughout the ageing process, is considered a public health concern in low- and middle-income countries, particularly among geriatric populations.[1,2] Sarcopenia is associated with many adverse outcomes that may impact negatively on the elderly, such as increased incidence of falls, physical dysfunction, reduction in quality of life, and increased morbidity[3] and mortality.[4]

The prevalence of sarcopenia is reported to be between 8% and 50% in people over the age of 50 years, depending on ethnicity, age, setting and diagnostic methodology.[5,6] In 2010, the European Working Group on Sarcopenia in Older People (EWGSOP) released guidelines for the diagnosis of sarcopenia and defined it as the presence of both low muscle mass and low muscle function (strength or performance).[4,7] A South African cut-off point for sarcopenia based on appendicular skeletal muscle mass (ASM) index (ASMI) was recently proposed.[8] According to this cut-off point, 9.1% of the study participants were sarcopenic.[8]

Sarcopenia is recognised as a multi-faceted syndrome caused by various factors. Muscle functionality and physiology can affect muscle performance due to age-related changes in body composition.[9] The ageing process results in a decrease of muscle mass and muscle contractibility. Therefore, a low lean mass to total body mass can reduce functional performance and

muscle strength.[10,11] The decreased contraction of muscle fibres and functionality of older adults could be explained by age-related fat infiltration in muscle tissues.[12] Functional performance can be measured by using grip strength, timed chair stand performance, standing balance, timed get-up-and-go test, stair climb power test and normal walking speed, among others.[4,9] Reduced functional performance is associated with a reduction in physical activity levels, which in turn leads to reduced anabolic stimulus of skeletal muscle, thereby contributing to muscle wasting over time. Other factors that may contribute to a decrease in functional performance and have an impact on the relationship between disability and sarcopenia are inflammation, nutrition, protein turnover and hormonal changes.[13]

Diagnosis of sarcopenia requires measurement of muscle strength as well as body composition. Low skeletal muscle mass can be measured by techniques such as dual-energy X-ray absorptiometry (DXA), computed tomography (CT), magnetic resonance imaging and bio-impedance analysis.[7] Most of these methods are, however, poorly accessible, expensive and some procedures expose subjects to radiation.[14] Various cut-off points for ASM and ASMI together with measures of muscle strength and physical performance have been proposed to identify sarcopenia.[15,16] Baumgartner et al.[15] in the New Mexico Aging Process Study summed up the measurements of the four extremities in the body using a DXA scan. The sum of these four extremities called ASM were used to define cut-off

values for sarcopenia.[15] Sex-specific cut-off points for sarcopenia were defined as an ASMI two standard deviations below the mean ASMI of the male and female reference groups.[15]

Calf circumference (CC) has been proposed as a simple and affordable measure to estimate muscle mass in the elderly.[17] In a Japanese study of 526 participants, CC was positively correlated with ASM and ASMI, and was also associated with the diagnosis of sarcopenia.[18] Correlation between ASM and CC in the New Mexico Aging Process Study was twice as high as the correlation between mid-arm circumference and ASM.[15] People with a high CC rarely present with a poor nutritional status.[19] Evidence also suggests that CC atrophy occurs with physical impairment, functional incapacity or mobility and, therefore, future research is needed to determine whether impairment leads to muscle atrophy or whether physical impairment is followed by atrophy of muscle.[20]

South Africa is a middle-income country and DXA and CT technology are not generally available or accessible as measurement tools to diagnose sarcopenia. The most common method available for the identification of sarcopenia in low- and middle-income countries used by healthcare professionals is anthropometric measurement tools. The purpose of this study was to investigate the relationship between CC and ASMI, and to determine whether CC could be used to diagnose sarcopenia in a group of older black South African women from Tlokwe City.

Materials and methods

Design and setting
Data collected between 2012 and 2013 from the South African arm of the Prospective Urban and Rural Epidemiological (PURE) study were used. The PURE study is aimed at assessing the effects of lifestyle on the development of non-communicable diseases. Sample size was estimated using a pre-determined sensitivity of 70% (0.70), 95% confidence and 80% power to detect a difference of 10% (0.10) between participants with and without the condition, in this case sarcopenia.[21] According to these calculations, 153 participants were needed to determine the diagnostic ability of CC. Our final sample included more, as we had data for 247 individuals. Urban black South African women residing in Tlokwe City of the North West province, older than 45 years with good physical and psychological health and living independently and who were part of the PURE North West study were eligible. Due to participants rarely disclosing their human immunodeficiency virus (HIV) status, healthy persons with HIV could participate, provided that they were not acutely ill and lived independently. Exclusion criteria included being of the male sex, participants with disabilities, taking anabolic steroids or protein supplements, pregnant or lactating women and those with current serious diseases, including acute HIV infection. Approval for the study was given by the Health Research Ethics Committee of North-West University (NWU) in compliance with ethics rules for human experimentation in the Declaration of Helsinki. All volunteers provided written informed consent to participate in the study.

Measures
Anthropometry and body composition
Measurements were carried out by trained anthropometrists using standard calibrated instruments and methods prescribed by the International Society for the Advancement of Kinanthropometry (ISAK).[22] Weight was measured to the nearest 0.1 kg

using an electronic scale (Seca, Birmingham, UK) and height was recorded to the nearest 0.1 m using a stadiometer (Seca, Birmingham, UK) with participants lightly clothed and shoes removed. Body mass index (BMI) was calculated as weight (kg) divided by height in metres squared. CC was measured using a flexible steel tape (Lufkin, Cooper tools, Apex, NC, USA) with participants in a standing position. The tape was placed around the calf at the level of maximal girth without compressing the subcutaneous tissues. Measurement was taken from the lateral side of the body measuring to the nearest 0.1 cm.

A registered radiographer measured body composition (fat-free mass for the whole body, arms and legs) using DXA with default settings (Hologic Discovery W, APEX system software version 2.3.1). ASM was defined as the sum of fat-free muscle mass of the arms and legs, excluding bone mass, while ASMI was calculated as ASM divided by the square of the height (kg/m^2). The South African cut-off point for sarcopenia of ASM < 4.94 kg/m^2 was used to define sarcopenia.[23]

Physical performance and strength tests
Grip strength was assessed using a hand grip dynamometer (Jamar, Bollingbrook, IL, USA) and recorded to the nearest 0.1 kg. Participants were asked to hold the dynamometer in the dominant hand with elbow flexed at a 90° angle and forearm parallel to the floor. The dynamometer was maximally squeezed for 5 seconds. The maximum strength of two repeated measurements was used in this study.[24] Low hand-grip strength was regarded as < 16 kg for women.[24] Gait speed (m/s) was used to assess physical performance. Participants were asked to complete a 6 m walk test. The time taken to complete the test was recorded with a stop watch and the speed (m/s) calculated.[25] A low gait speed was defined as < 0.8 m/s.[25]

Data analysis
Statistical analysis was performed using SPSS version 22 for Windows (SPSS, Chicago, IL, USA). Normality of variables was tested using Kolmogorov–Smirnov and Shapiro–Wilk tests. Normally distributed data were reported as means (SD), and non-normally distributed data as median and interquartile ranges (IQR). Categorical variables were described with frequencies and percentages. Because most variables deviated from the normal distribution, the Mann–Whitney test was used to compare the median values of the characteristics of sarcopenic and non-sarcopenic participants. Pearson's correlation coefficient was used to determine the association between CC and DXA-measured ASM and ASMI. Receiver operating characteristics (ROC) curves were used to determine the optimal Youden index cut-off value of CC in predicting sarcopenia. A p-value of less than 0.05 was regarded as statistically significant.

Results
Table 1 presents the characteristics of the women. The weight, BMI, ASM, ASMI, hand-grip strength, gait speed and CC, respectively, of the sarcopenic women were significantly lower than the same variables of the non-sarcopenic women. A positive correlation was observed between CC and ASMI ($r = 0.84$; $p < 0.001$).

Table 2 represents the ROC analysis for sensitivity and specificity of CC to predict low gait speed, low hand-grip strength and sarcopenia. To predict low gait speed (< 0.8 m), a CC cut-off point of 37.8 cm was established with a sensitivity of 93.8% and specificity of 41.2% (Figure 1a). For low hand-grip strength (< 16 kg), a CC cut-off point of 34.3 cm was calculated with a sensitivity and specificity of 66.7% and 64.4%, respectively (Figure

Table 1: Anthropometric and physical performance characteristics of participants

Variables	Total group ($n = 247$)	Sarcopenic* ($n = 22$)	Non-sarcopenic ($n = 225$)	p-value#
Age (years)	56 (50, 65)	58 (52.5, 62.5)	57 (50, 66)	0.92
Weight (kg)	69.9 (55.3, 84.3)	41.6 (39.4, 45.1)	71.8 (58.1, 84.8)	< 0.0001
Height (cm)	156 (152, 160)	156 (151, 162)	156 (152, 160)	0.97
Body mass index (kg/m^2)	28.3 (22.8, 34.2)	17.7 (16.1, 18.8)	29.2 (24.2, 34.6)	< 0.0001
Calf circumference (cm)	35.7 (31.5, 40.2)	27.5 (25.8, 28.3)	36.4 (32.4, 40.5)	< 0.0001
ASM (kg)	16.2 (13.6, 18.9)	11.4 (9.96, 12.2)	16.6 (14.2, 19.2)	< 0.0001
ASMI (kg/m^2)	6.61 (5.75, 7.72)	4.68 (4.40, 4.84)	6.74 (6.04, 7.81)	< 0.0001
Hand-grip strength (kg)	20.0 (16.0, 25.0)	16.0 (10.5, 20.5)	21.0 (16.0, 26.0)	0.003
Gait speed (m/s)	1.40 (1.18, 1.58)	1.39 (0.96, 1.58)	1.40 (1.18, 1.59)	0.04

Notes: Values are presented as medians (interquartile range, IQR); ASM = appendicular skeletal muscle; ASMI = appendicular skeletal muscle index.
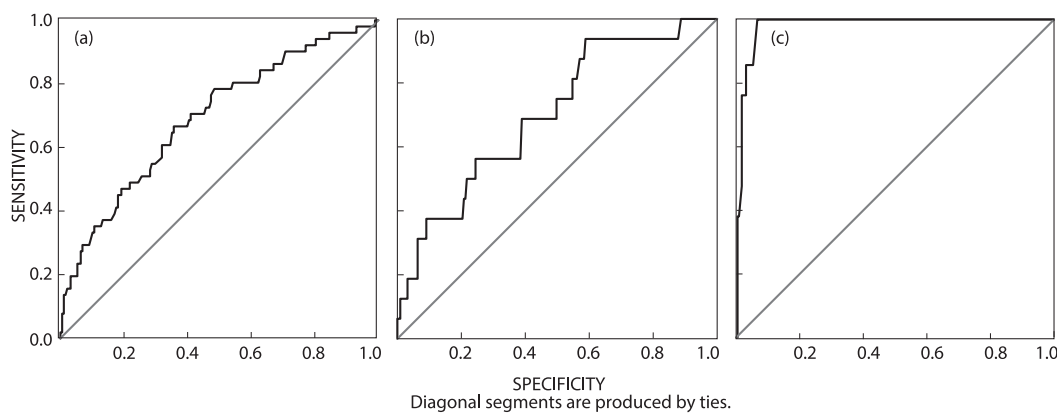*The South African cut-off point for sarcopenia of ASM < 4.94 kg/m^2 was used to define sarcopenia.
#Difference between groups tested using the Mann–Whitney test.

Table 2: Sensitivity and specificity of CC to predict low gait speed, weak hand-grip strength and sarcopenia (ASMI < 4.94 kg/m^2)

Variables	Number of participants identified by each method (%)	AUC (95% CI)	Sensitivity	Specificity	CC (cm) cut-off point
Gait speed < 0.8 m/s	16 (6.5%)	0.70 (0.57, 0.83)	93.8%	41.2%	37.8
Hand-grip strength < 16 kg	51 (20.6%)	0.69 (0.61, 0.78)	66.7%	64.4%	34.3
SA sarcopenia cut-off point	22 (8.9%)	0.94 (0.96, 1.00)	100%	93.3%	29.9

Notes: AUC = area under the curve; ASMI = appendicular skeletal muscle index; CC = calf circumference; CI = confidence interval.

Figure 1: ROC curve of CC to predict the presence of (A) low gait speed (< 0.8 m/s), (B) low hand-grip strength (< 16 kg), and (C) the presence of sarcopenia according to a South African cut-off point.

1b, Table 2). Using the South African sarcopenia cut-off point, i.e. ASMI of 4.94 kg/m^2, to predict sarcopenia, a CC value of 29.9 cm was calculated to have a 100% sensitivity and 93.3% specificity (Figure 1c). The lower limit of the 95% confidence intervals (CI) for the area under the curve (AUC) of gait speed (0.57) was < 0.6, which is considered as the cut-off point for the adequate diagnostic performance of a variable. Hand-grip strength and the South African sarcopenia cut-off points both demonstrated good diagnostic performance (lower limits of the 95% CI of 0.61 and 0.96, respectively). The cut-off point values, 37.8 cm and 34.3 cm, for CC to diagnose low gait speed (< 0.8 m) and low hand-grip strength (< 16 kg), respectively are greater than the CC cut-off point (29.9 cm) to diagnose sarcopenia when using the South African cut-off point. Therefore we propose a CC cut-off point rounded to 30 cm, which is also easier to remember and apply in practice. The prevalence of sarcopenia in the participants using the South African cut-off point (ASMI

< 4.94 kg/m^2) was 8.91% ($n = 22$), whereas when using the newly derived CC cut-off point of 30 cm, 10% more women, i.e. 19.0% ($n = 47$ women), were sarcopenic.

Discussion

This is the first study to investigate a possible surrogate marker for muscle mass in black South African women of Tswana ancestry. We investigated the relationship between CC and ASMI, and evaluated whether CC is a suitable measurement for lean mass to diagnose sarcopenia in black South African women. Non-sarcopenic patients presented with a higher CC than participants diagnosed with sarcopenia. The average CC reported in this study was similar to that reported on French (35 ± 3.1 cm) and Korean (32.4 ± 2.8 cm) elderly women.[20,26] A strong positive correlation ($r = 0.84$; $p < 0.001$) was observed between CC and ASMI in this group of black South African women.

Previous studies in elderly French women, as well as in Japanese and Korean women, also reported that DXA-measured ASM correlated positively with CC ($r = 0.63$, $r = 0.69$, and $r = 0.55$, respectively).[18,20,26] The predictive power of CC to assess lean body mass could be influenced by leg oedema.[18] The relationship between CC and ASM in men has proven a higher correlation than in women. The reason could be that women distribute more fat mass on their lower extremities than men and, therefore, CC is a more sensitive marker for muscle mass in men and lean women than in obese women.[27] However, results of a study conducted in both men and women failed to demonstrate a positive relationship between CC and lower extremity fat.[28] Taking the above-mentioned into consideration, we concluded that CC is a suitable surrogate measurement of muscle mass in adults, except in obese individuals.

In our study, a CC cut-off point of 29.9 cm was determined through ROC curve analysis, and rounded to 30 cm to indicate sarcopenia when using the South African cut-off point. To diagnose low gait speed (< 0.8 m/s) and low grip strength (< 16 kg) respectively, a greater CC was identified to diagnose sarcopenia than when using the South African cut-off point. Authors of two studies[18,26] reported cut-off points for Japanese and Korean women, respectively, at 33 cm (sensitivity 76%, specificity 73%) for type I sarcopenia and a threshold of 34 cm (sensitivity 66%, specificity 74%) for type II sarcopenia,[18] and 33 cm (sensitivity 83%, specificity 50%),[26] respectively. In our ROC analysis, we observed similar cut-off points of 37.8 cm to predict low gait speed with a high sensitivity (93.8%) but with low specificity (41.2%), and 34.3 cm to predict low grip strength (sensitivity 66.7%, specificity 64.4%). However, in the ROC analysis of the CC to predict sarcopenia according to South African sarcopenia cut-off point, we found that 29.9 cm was the value with a high sensitivity (100%) and specificity (93.3%). The rounded CC cut-off point of 30 cm to predict sarcopenia is lower when compared with the cut-off points for CC to predict both low gait speed and low grip strength, as well as lower than those determined in other published studies.[18] Despite the lower CC cut-off point, this CC cut-off point determined in our study still overestimates the prevalence of sarcopenia. When the CC cut-off point (30 cm) is used, women who are sarcopenic as well as pre-sarcopenic according to the South African cut-off values are included. The CC can, therefore, be used as primary prevention screening tool for sarcopenia, which is sensitive to identify pre-sarcopenia as well.

Participants with a low CC also demonstrated decreased physical strength in terms of low hand-grip strength and low gait speed. Hand-grip strength is in itself associated with all-cause mortality.[29] Because of this relationship between CC and physical strength, other health outcomes are also closely associated with CC. Sarcopenic individuals have a greater fall risk in comparison with their healthy counterparts, which also increases their risk for disability or fractures.[30] Cross-sectional studies reported a two to five times greater likelihood of disability or functional impairment in older adults with severe sarcopenia, and sarcopenic obesity was associated with 2.6 times greater risk of developing disability.[15] Women have a higher risk of disability than men, the reason for which could be that women present with less muscle mass than men at all ages.[31]

Sarcopenia is a multi-factorial syndrome that involves hormonal, physical activity and immunological changes as well as central and peripheral nervous system alterations.[32] With age, atrophy of muscle fibres causes a decline in muscle mass and strength.[33] Lower grip strength is present in the elderly where function of ciliary neutrophic factor, a protein that stimulates motor unit formation, is diminished.[34] Muscle detrition is a result of decreased protein synthesis and decreased satellite cell activation that is caused through a decrease in insulin-like growth factor-1 (IGF-1 and mechano growth factor).[35] Another key role triggering sarcopenia can be mitochondrial DNA mutation resulting from mitochondrial reactive oxygen species, which leads to cell death and breakdown.[36] Hormonal and immunological changes caused by increased catabolic activity (increased levels of interleukin (IL)-1, IL-6, myostatin and tumour necrosis factor-alpha) and the resistance or absence of anabolic factors (decreased levels of IGF-1, growth hormone and testosterone) also contribute to sarcopenia.[37]

Aerobic exercises can prevent functional decline of the lower extremities[38] and resistance training can increase the rate of mixed muscle protein synthesis in elderly participants.[39] Fiatarone et al.[40] conducted a randomised placebo-controlled trial wherein subjects were placed on progressive exercise training, multi-nutrient supplements and both interventions, and found a 3% to 11% increase in muscle cross-sectional area.[40] To maintain muscle strength and endurance Haskell et al. suggested that resistance training should be performed on two or more non-consecutive days each week using the major muscle groups.[41] The recommendations for maintaining healthy muscles with ageing report that optimal protein intake of 1 to 1.2 g/kg/day resulted in an increase in muscle function and muscle mass.[42] Similarly, Paddon-Jones and Rasmussen[43] found that high-quality protein meals of 25–30 g/meal increased protein synthesis and maintained skeletal muscle mass. Essential amino acid supplementation can also prevent muscle loss.[44] Paddon-Jones and Rasmussen also demonstrated a higher muscle protein synthesis with essential amino acid supplementation.[42] Vitamin D supplementation increases muscle strength and decreases the risk of falls.[45,46] A variety of pharmaceutical products such as testosterone, anabolic steroids or selective androgen receptor modulators, growth hormone, IGF-1, ghrelin, myostatin and activating II receptor inhibitors, espindolol, angiotensin converting enzyme inhibitor (perindopril) and fast skeletal troponin activators (Terasemtiv) are studied for the management of sarcopenia.[35]

In conclusion, CC is a useful surrogate indicator of ASM, with good sensitivity but moderate specificity, to diagnose physical performance or muscle strength in older black South African women. Future studies should include at least more than one physical performance test to diagnose sarcopenia, because sarcopenia is not only a loss of muscle mass, but also of muscle strength. Furthermore, similar studies should be conducted in male participants to establish gender-specific thresholds of surrogate markers to predict sarcopenia. A CC < 30 cm is a good indicator of muscle mass and correlated significantly with ASMI and may, therefore, be used as measurement to diagnose sarcopenia in public health settings for black South African women where resources are limited. Establishing that a cheaper alternative than DXA measurements can be used to diagnose sarcopenia is very valuable for low- and middle-income countries as a screening tool.

Disclosure statement
No potential conflict of interest was reported by the authors.

ORCID
PO Ukegbu http://orcid.org/0000-0002-6731-5344
HS Kruger http://orcid.org/0000-0002-5365-1777
C Nienaber-Rousseau http://orcid.org/0000-0001-9156-2989
C Botha-Ravyse http://orcid.org/0000-0001-6289-6840
MI Kruger http://orcid.org/0000-0002-8636-7174

References

1. Lynch GS. Tackling Australia's future health problems: developing strategies to combat sarcopenia--age-related muscle wasting and weakness. Intern Med J. 2004;34(5):294–6.

2. Roubenoff R, Hughes VA. Sarcopeniacurrent concepts. J Gerontol A Biol Sci Med Sci. 2000;55(12):M716–24.

3. Moulias R, Meaume S, Raynaud-Simon A. Sarcopenia, hypermetabolism, and aging. Zeitschrift für Gerontologie und Geriatrie. 1999;32 (6):425–32.

4. Cruz-Jentoft AJ, Baeyens J-P, Bauer JM, et al. Sarcopenia: European consensus on definition and diagnosis. Age Ageing. 2010;39 (4):412–23.

5. Abellan Van Kan G. Epidemiology and consequences of sarcopenia. J Nutr Health Aging. 2009;13(8):708–12.

6. Beaudart C, Buckinx F, Rabenda V, 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 Endocrin Metab. 2014;99(11):4336–45.

7. Hamaguchi Y, Kaido T, Okumura S, et al. Proposal for new diagnostic criteria for low skeletal muscle mass based on computed tomography imaging in Asian adults. Nutrition. 2016;32(11-12):1200–1205.

8. Kruger H, Micklesfield L, Wright HH, et al. Ethnic-specific cut-points for sarcopenia: evidence from black South African women. Euro J Clin Nutr. 2015;69(7):843–9.

9. Visser M, Goodpaster BH, Kritchevsky SB, et al. Muscle mass, muscle strength, and muscle fat infiltration as predictors of incident mobility limitations in well-functioning older persons. J Gerontol A Biol Sci Med Sci. 2005;60(3):324–33.

10. Fragala MS, Clark MH, Walsh SJ, et al. Gender differences in anthropometric predictors of physical performance in older adults. Gend Med. 2012;9(6):445–56.

11. Newman AB, Haggerty CL, Goodpaster B, et al. Strength and muscle quality in a well-functioning cohort of older adults: the health, aging and body composition study. J Am Geriatr Soc. 2003;51(3):323–30.

12. Lauretani F, Bandinelli S, Bartali B, et al. Axonal degeneration affects muscle density in older men and women. Neurobiol Aging. 2006;27 (8):1145–54.

13. Ferrucci L, Baroni M, Ranchelli A, et al. Interaction between bone and muscle in older persons with mobility limitations. Curr Pharm Design. 2014;20(19):3178–97.

14. Chien MY, Huang TY, Wu YT. Prevalence of sarcopenia estimated using a bioelectrical impedance analysis prediction equation in community-dwelling elderly people in Taiwan. J Am Geriatr Soc. 2008;56 (9):1710–5.

15. Baumgartner RN, Koehler KM, Gallagher D, et al. Epidemiology of sarcopenia among the elderly in New Mexico. Am J Epidem. 1998;147 (8):755–63.

16. Oliveira RJ, Bottaro M, Junior JT, et al. Identification of sarcopenic obesity in postmenopausal women: a cutoff proposal. Braz J Med Biol Res. 2011;44(11):1171–6.

17. Patrick JM, Bassey EJ, Fentem PH. Changes in body fat and muscle in manual workers at and after retirement. Euro J App Phy Occup Phy. 1982;49(2):187–96.

18. Kawakami R, Murakami H, Sanada K, et al. Calf circumference as a surrogate marker of muscle mass for diagnosing sarcopenia in Japanese men and women. Geriatr Gerontol Int. 2015;15(8):969–76.

19. Jauffret M, Jusot J, Bonnefoy M. Marqueurs anthropométriques et malnutrition de la personne âgée: Intérêt de la circonférence du mollet. Age Nutr. 1999;10(3):163–9.

20. Rolland Y, Lauwers-Cances V, Cournot M, et al. Sarcopenia, calf circumference, and physical function of elderly women: a cross-sectional study. J Am Geriatr Soc. 2003;51(8):1120–4.

21. Hajian-Tilaki K. Sample size estimation in diagnostic test studies of biomedical informatics. J Biomed Infomat. 2014;48:193–204.

22. Marfell-Jones MJ, Stewart A, De Ridder J. International standards for anthropometric assessment. 2012.

23. Kruger H, Micklesfield L, Wright HH, et al. Ethnic-specific cut-points for sarcopenia: evidence from black South African women. Eur J Clin Nutr. 2015;(69):843–849.

24. Taekema DG, Gussekloo J, Maier AB, 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):331–7.

25. Guralnik JM, Ferrucci L, Pieper CF, et al. Lower extremity function and subsequent disability: consistency across studies, predictive models, and value of gait speed alone compared with the short physical performance battery. J Geron. 2000;55(4):M221–M31.

26. Kim S, Kim M, Lee Y, et al. Calf circumference as a simple screening marker for diagnosing sarcopenia in older Korean adults: the Korean frailty and aging cohort study (KFACS). J Korean Med Sci. 2018;33(20):e151.

27. Nindl BC, Scoville CR, Sheehan KM, et al. Gender differences in regional body composition and somatotrophic influences of IGF-I and leptin. J Appl Physiol. 2002;92(4):1611–8.

28. Tresignie J, Scafoglieri A, Pieter Clarys J, et al. Reliability of standard circumferences in domain-related constitutional applications. Am J Hum Biol. 2013;25(5):637–42.

29. Leong DP, Teo KK, Rangarajan S, et al. Prognostic value of grip strength: findings from the prospective urban rural epidemiology (PURE) study. The Lancet. 2015;386(9990):266–73.

30. Tanimoto Y, Watanabe M, Sun W, et al. Sarcopenia and falls in community-dwelling elderly subjects in Japan: defining sarcopenia according to criteria of the european working group on sarcopenia in older people. Arch Gerontol Geriatr. 2014;59(2):295–9.

31. 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.

32. Purves-Smith FM, Sgarioto N, Hepple RT. Fiber typing in aging muscle. Exer Sport Sci Rev. 2014;42(2):45–52.

33. Narici MV, Maffulli N. Sarcopenia: characteristics, mechanisms and functional significance. Bri Med Bull. 2010;95(1):139–59.

34. McNeil CJ, Doherty TJ, Stashuk DW, et al. Motor unit number estimates in the tibialis anterior muscle of young, old, and very old men. Muscle Nerve. 2005;31(4):461–7.

35. Morley JE. Sarcopenia in the elderly. Fam Pract. 2012;29(suppl_1):i44–i8.

36. Dirks AJ, Leeuwenburgh C. The role of apoptosis in age-related skeletal muscle atrophy. Sports Med. 2005;35(6):473–83.

37. Doherty TJ. Invited review: aging and sarcopenia. J Appl Physiol. 2003;95(4):1717–27.

38. Pahor M, Guralnik JM, Ambrosius WT, et al. Effect of structured physical activity on prevention of major mobility disability in older adults: the life study randomized clinical trial. J Ame Med Asso. 2014;311 (23):2387–96.

39. Yarasheski K, Pak-Loduca J, Debbie LH. Resistance exercise training increases mixed muscle protein synthesis rate in frail women and men ≥76 yr old. Am J Physiol Endocrinol Metabol. 1999;277(1): E118–25.

40. Fiatarone MA, O'Neill EF, Ryan ND, et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. New Engl J Med. 1994;330(25):1769–75.

41. Haskell WL, Lee IM, Pate R, et al. Physical activity and public health: updated recommendation for adults from the American college of sports medicine and the American heart association. Circulation. 2007;116(9):1081–93.

42. Deutz NE, Bauer JM, Barazzoni R, et al. Protein intake and exercise for optimal muscle function with aging: recommendations from the ESPEN Expert Group. Clin Nutr. 2014;33(6):929–36.

43. Paddon-Jones D, Rasmussen BB. Dietary protein recommendations and the prevention of sarcopenia: protein, amino acid metabolism and therapy. Curr Opin Clin Nutr Metab Care. 2009;12(1):86–90.

44. Ferrando AA, Paddon-Jones D, Hays NP, et al. EAA supplementation to increase nitrogen intake improves muscle function during bed rest in the elderly. Clin Nutr. 2010;29(1):18–23.

45. Murad MH, Elamin KB, Abu Elnour NO, et al. The effect of vitamin D on falls: a systematic review and meta-analysis. J Clin Endocrinol Metabol. 2011;96(10):2997–3006.

46. Moreira-Pfrimer LD, Pedrosa MA, Teixeira L, et al. Treatment of vitamin D deficiency increases lower limb muscle strength in institutionalized older people independently of regular physical activity: a randomized double-blind controlled trial. Ann Nutr Metab. 2009;54 (4):291–300.