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Comparison of methods to identify individuals with obesity at increased risk of functional impairment among a population of home-dwelling older adults

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Abstract

Obesity is associated with increased muscle mass and muscle strength. Methods taking into account the total body mass to reveal obese older individuals at increased risk of functional impairment are needed. Therefore, we aimed to detect methods to identify obese older adults at increased risk of functional impairment. Home-dwelling older adults (*n* 417, ≥ 70 years of age) were included in this cross-sectional study. Sex-specific cut-off points for two obesity phenotypes (waist circumference (WC) and body fat mass (FM %)) were used to divide women and men into obese and non-obese groups, and within-sex comparisons were performed. Obese women and men, classified by both phenotypes, had similar absolute handgrip strength (HGS) but lower relative HGS (HGS/total body mass) ($P < 0{\cdot}001$) than non-obese women and men, respectively. Women with increased WC and FM %, and men with increased WC had higher appendicular skeletal muscle mass ($P < 0{\cdot}001$), lower muscle quality (HGS/upper appendicular muscle mass) ($P < 0{\cdot}001$), and spent longer time on the stair climb test and the repeated sit-to-stand test ($P < 0{\cdot}05$) than non-obese women and men, respectively. Absolute muscle strength was not able to discriminate between obese and non-obese older adults. However, relative muscle strength in particular, but also muscle quality and physical performance tests, where the total body mass was taken into account or served as an extra load, identified obese older adults at increased risk of functional impairment. Prospective studies are needed to determine clinically relevant cut-off points for relative HGS in particular.

Key words: Older adults: Obesity: Relative handgrip strength: Muscle quality: Muscle functions: Functional impairment

Ageing and inactivity are associated with loss of muscle mass, muscle strength and muscle quality[1–4]. Obesity and low muscle strength are strong predictors of functional decline among older adults[5], and serious health consequences such as limitations in daily living activities[6], disability, risk of falling, fracture and mortality[7,8]. Ageing is characterised by changes in body composition where loss of muscle mass is often accompanied by increased fat mass (FM). Age-related changes in body composition also include fat redistribution, with reduction in peripheral subcutaneous fat and increased visceral fat, and fat deposition in non-adipose tissue such as skeletal muscles[3,9]. Along with the rising number of older adults aged above 65 years, the prevalence of obesity among older adults is expected to increase[10,11]. Obesity, excessive accumulation of body fat, is associated with higher muscle mass[12–14], suggesting that the strength production capacity is higher in obese than non-obese individuals[15–17]. Additionally, since obesity is related to reduced muscle function and mobility limitation[18–20], muscle strength and physical performance tests, where the total body mass is taken into account or serve as an extra load, may be useful tests to identify obese individuals at increased risk of functional impairment

Handgrip strength (HGS) is widely used as an indicator of overall muscle strength, especially among older people[21].

Abbreviations: BIA, bioimpedance analyser; FM, fat mass; HGS, handgrip strength; SPPB, Short Physical Performance Battery; WC, waist circumference.

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Low HGS in older adults has consistently been linked to poor health outcomes such as long-term disability onset, low quality of life[22,23], functional decline and mortality[24]. However, in individuals with obesity, where FM serves as an extra load while moving, a limitation with measuring the absolute HGS is the reduced ability to reflect the actual physical performance capacity. Relative HGS (HGS/total body mass) has been suggested as a more sensitive method than absolute HGS to discriminate between obese and non-obese older adults at risk of impaired physical performance[25]. Further, muscle quality, defined as the ratio of muscle strength or power per unit muscle mass[26], is another suggested parameter to identify muscle function in older adults, and the use of muscle quality is expected to grow in importance[27,28].

To prevent negative health outcomes and to enable older adults to remain living independently in their homes, effective and low-cost strategies to early identify functional impairment related to obesity are needed. In the present study, we aimed to detect methods to identify obese older adults at increased risk of functional impairment. Using two common phenotype definitions of obesity, we wanted to compare muscle strength (absolute HGS, relative HGS and stair climb test), muscle quality (absolute HGS/upper body appendicular skeletal muscle mass) and physical performance (balance test, repeated sit-to-stand test and gait speed) between obese and non-obese home-dwelling older adults.

Methods

Participants

The present study was conducted in 2014–2015 at Oslo and Akershus University College of Applied Sciences, Norway. Invitation letters were sent to home-dwelling women and men (≥ 70 years) living in the area of Skedsmo, Norway, listed in the National Population Register. In total, 2860 older adults (≥ 70 years of age) were invited to participate, of which 477 (17 %) responded to the invitation and thus 438 (16 %) participated. One participant withdrew the informed consent. Bioimpedance analyser (BIA) measurements were only available in 417 individuals; thus, 417 were included in this study. There were no exclusion criteria. Cognitive health and nutritional status were measured using the Mini-Mental State Examination test form and the Mini Nutritional Assessment form®, respectively. Both the Mini-Mental State Examination and Mini Nutritional Assessment have a maximum score of thirty points, and high scores indicate a high cognitive function and good nutritional status, respectively. In a previous study, data on cognitive health (Mini-Mental State Examination score), nutritional status (Mini Nutritional Assessment score), co-morbidities and dietary intake (2 × 24 h dietary recall method) in the same study population (*n* 417) have been shown[29]. The data included in the current study were obtained from a cross-sectional study which served as a screening visit for a randomised controlled study (Clinicaltrials.gov, ID no. NCT02218333)[30]. The present study was conducted according to the guidelines in the Declaration of Helsinki, and all procedures involving human subjects were approved by the Regional Committees for Medical and Health Research Ethics, Health Region South East, Norway (2014/150/REK). Written informed consent was obtained from all participants. Extracts from the National Population Registry were used according to and with approval by the Norwegian Tax Administration.

Study design

In this cross-sectional study, sex-specific cut-off points for two obesity phenotypes (waist circumference (WC) and percentage of body fat (FM %)) were used to create groups that allowed within-sex comparisons of muscle strength, muscle mass, muscle quality and physical performance between obese and non-obese. For women, the cut-off points were > 35 % FM and ≥ 88 cm (obese) or ≤ 35 % and < 88 cm (non-obese). For men, the cut-off points were > 25 % FM and ≥102 cm (obese) or ≤ 25 % and < 102 cm (non-obese)[31].

Body composition and waist circumference

Body composition was measured by a single frequency BIA (BC-418 MA; Tanita Corp.), operating at 50 kHz, providing measurements of fat-free mass, body FM and FM % for the whole body. The participants were standing barefoot on the instrument platform. Four pairs of electrodes were positioned at each hand and foot, in which the low-voltage current entered the limbs. Appendicular skeletal muscle mass was derived from the sum of the fat-free mass of the four limbs based on equations incorporated in the software by the manufacturer. In-house validation of BIA against dual-energy X-ray absorptiometry was performed in forty-seven individuals of the current study population, showing comparable estimates of appendicular skeletal muscle mass measured with BIA on group level. Between-day CV % (SD/mean) of the BIA measurement of fat-free mass was calculated in a subgroup (*n* 46). Each subject was measured twice, on separate days. The between day CV % was 1·8 %. To identify subjects with low appendicular skeletal muscle mass, sex-specific cut-off points (< 15 kg in women and < 20 kg in men) were used[28,32]. WC (cm) was measured with the use of a measuring band in standing position with arms hanging loosely, and on exhalation at the midpoint between the top of the iliac crest and the lower margin of the last palpable rib. The measurement was performed with the abdomen relaxed at the end of expiration[33].

Muscle strength, muscle quality and physical performance

HGS of both hands was measured using a digital handheld dynamometer (KE-MAP80K1, Kern MAP). Participants were placed in a sitting position, elbow in 90° flexion and wrist in a neutral position. The participants were asked to squeeze the dynamometer as hard as possible simultaneously by breathing out. The maximal HGS of three measurements was registered from each hand. Absolute HGS was defined as the maximum HGS, regardless of dominant or non-dominant hand. Low absolute HGS was defined as < 16 kg in women and < 27 kg in men[28,34]. Relative HGS was defined as the absolute HGS (kg)/total body mass (kg). Upper body muscle quality was calculated by absolute HGS/upper body appendicular skeletal muscle mass[26,35–38].

As described elsewhere, in a subgroup of forty-seven participants the between-day CV of absolute HGS was 5·0 %[29]. Low muscle quality was defined as muscle quality < 5·475 in women and < 5·760 in men[36]. The stair climb test (16 steps, 18 cm height) has been found to be a relevant measure of leg power (force and speed) impairments[39]. The test was performed where each participant was given two attempts with at least 2 min rest in between, and the best performance was registered. The time was recorded to the nearest 100th of a second. No cut-off points for slow stair climb exist. The Short Physical Performance Battery (SPPB) tests (balance test, repeated sit-to-stand test and gait speed) were performed according to the SPPB protocol[40]. According to SPPB, scores of 0–4 of the three tests were summed to give a maximum total score of 12 points, and a total score ≤ 8 points indicates poor physical performance. To describe subjects with reduced muscle strength in the lower body and reduced gait speed, cut-off points for the repeated sit-to-stand test (> 15·0 s) and gait speed (≤ 0·8 m/s) were used[28].

Statistic

All continuous normally distributed data were presented as mean and standard deviation; not normally distributed data were presented as median (25–75 percentiles) and categorical data as number and percentage. For continuous variables, independent sample *t* test or Mann–Whitney *U* test was used in normally distributed and not normally distributed data, respectively, and for categorical variables, the χ^2 test was used. Cohen's kappa (κ) was used to determine the agreement between the two phenotypes (WC and FM%) of obesity used to define women and men as either obese or non-obese. The level of significance was defined as $P < 0.05$. All analysis was performed using SPSS for Windows (version 26·0; SPSS, Inc.).

Results

Characteristic of the study population

In this study, 417 community-dwelling older women (*n* 217, 52 %) aged 74 (71–77) years and men (*n* 200, 48 %) aged 78 (74–82) years were included. The Mini-Mental State Examination and Mini Nutritional Assessment scores were skewed towards high values, and the median scores were 28 (26–30) and 28 (27–29) in women and 29 (26–30) and 28 (27–29) in men, respectively. As shown in Table 1, using WC and FM % to define obesity, 59 and 62 % of the women, respectively, were obese. In men, 38 and 49 % were defined as obese, respectively. Agreement between WC and FM % classification was κ = 0·62 (95 % CI 0·51, 0·73) $P < 0.001$ in women and κ = 0·54 (95 % CI 0·43, 0·65) $P < 0.001$ in men. Mean absolute HGS was 21·8 (SD 4·7) kg in women and 38·1 (SD 7·0) kg in men. Few women and men had low absolute HGS (7 and 6 %, respectively), low SPPB score (6 and 8 %, respectively) and low appendicular skeletal muscle mass (7 and 8 %, respectively). Despite

Table 1. Anthropometric measurements, muscle strength, quality and physical performance in women and men
(Mean values and standard deviations; numbers and percentages; median values and interquartile range)

	Women (*n* 217)				Men (*n* 200)			
	Mean/Median	SD/Q1–Q3	*n*	%	Mean	SD	*n*	%
Waist circumference (cm)	91·4	12·5			99·2	10·3		
Women ≥ 88 cm, men ≥ 102 cm			128	59			75	38
Fat mass (%)	36·2	7·0			25·2	6·1		
Women > 35 %, men > 25 %			135	62			97	49
Absolute hand grip strength (kg)*	21·8	4·7			38·1	7·0		
Women < 16 kg, men < 27 kg			16	7			11	6
Relative handgrip strength (kg/kg)*	0·32	0·07			0·47	0·09		
Muscle quality (kg/kg)*	5·2	1·0			6·2	1·0		
Women < 5·475, men < 5·760			138	64			68	34
Appendicular skeletal mucsle mass (kg)	17·8	2·6			24·3	3·3		
Women < 15 kg, men < 20 kg			16	7			15	8
Stair climb test (s)†	7·9	2·3			6·7	1·8		
Repeated sit-to-stand test (s)‡	11·7	3·3			11·1	2·4		
> 15·0 s‡			26	12			12	6
Gait speed (m/s)	1·2	0·1			1·3	0·2		
≤ 0·8 m/s			13	6			5	3
Balance test < 10 s§			35	16			20	10
SPPB (score)	11	1–12			11	1–12		
≤ 8 points			13	6			8	4
BMI (kg/m^2)	26·3	4·5			26·0	3·5		
> 30 kg/m^2			40	18			24	12
Fat-free mass (kg)	43·5	5·6			60·0	7·2		
Fat mass (kg)	25·7	8·7			20·8	7·2		
Body weight (kg)	69·2	12·9			80·8	12·0		
Height (cm)	162	6·0			176	6·5		

* Two women and four men missing.
† Three women missing.
‡ Two women missing.
§ One women missing.

Table 2. Absolute and relative handgrip strength, muscle quality and mass, and physical performance in obese and non-obese older women
(Mean values and standard deviations)

	FM % > 35		FM % ≤ 35		WC ≥ 88 cm		WC < 88 cm			
	n 135		*n* 82		*n* 128		*n* 89			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P**	*P***
Absolute HGS (kg)	21·7	4·6†	21·8	4·9†	22·1	4·6†	21·4	4·7†	0·89	0·27
Relative HGS (kg/kg)	0·29	0·06†	0·37	0·08†	0·29	0·06†	0·36	0·08†	< 0·001	< 0·001
Muscle quality (kg/kg)	5·0	0·1†	5·5	1·1†	4·9	0·9†	5·5	1·0†	< 0·001	< 0·001
Appendicular skeletal muscle mass (kg)	18·4	2·5	16·7	2·4	18·8	2·6†	16·3	1·7†	< 0·001	< 0·001
Stair climb test (s)	8·2	2·1‡	7·4	2·5†	8·3	2·4‡	7·4	2·1†	0·01	0·01
Repeated sit-to-stand test (s)	12·2	3·5‡	11·0	2·7	12·2	3·3‡	11·1	3·2	0·01	0·02
Gait speed (m/s)	1·2	0·2	1·3	0·2	1·2	0·2	1·3	0·2	0·08	0·10

FM, total body fat mass; WC, waist circumference; HGS, handgrip strength.
* Between women with FM > 35 % *v.* ≤ 35%.
** Between women with WC ≥ 88 cm *v.* < 88 cm.
† One missing.
‡ Two missing.

this, low muscle quality was observed in 64 and 34 % of the women and men, respectively. Data on relative HGS, muscle quality, physical performance and body composition in women and men are further outlined in Table 1.

Body composition, muscle strength, muscle quality and physical performance

As shown in Table 2, older women with obesity defined by increased WC or FM % had significantly higher appendicular skeletal muscle mass but similar absolute HGS than non-obese women. However, the obese women had significantly lower relative HGS and muscle quality, and they spent significantly longer time performing the stair climb test and the repeated sit-to-stand test than the non-obese women (Table 2). As shown in Table 3, obese men defined by WC or FM % had similar absolute HGS but lower relative HGS compared with non-obese men. Further, obese men defined by WC had higher appendicular skeletal muscle mass, lower muscle quality, spent longer time on the stair climb test and the repeated sit-to-stand test than the non-obese men. The only difference between obese and non-obese men defined by FM % was lower relative HGS among obese men.

Discussion

In the present study, where home-dwelling older adults had high cognitive function and good nutritional status, we show that the absolute muscle strength was not able to discriminate between obese and non-obese older adults. However, relative muscle strength in particular, but also muscle quality and physical performance tests where the total body mass was taken into account or served as an extra load, identified the obese older adults at increased risk of functional impairment.

Obesity is associated with higher FM and muscle mass[12–14,41], and HGS produced by obese individuals is higher than in non-obese[16,17]. HGS is widely used for the measurement of muscle strength, and cut-off points for low HGS have been lowered by the European Working Group on Sarcopenia in Older People[28] compared with previous recommendations[42]. Thus, the probability to misclassify obese individuals has increased. To identify obese older individuals with low muscle strength, the total body mass must also be taken into account. Further, this may incorrectly lead to the suggestion that the actual muscle strength in obese individuals is sufficient. The present study shows that obese and non-obese older adults had similar absolute HGS, but the obese individuals had poorer physical

Table 3. Absolute and relative handgrip strength, muscle quality and mass, and physical performance in obese and non-obese older men
(Mean values and standard deviations)

	FM % > 25		FM % ≤ 25		WC ≥ 102 cm		WC < 102 cm			
	n 97		*n* 103		*n* 75		*n* 125			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P**	*P***
Absolute HGS (kg)	38·0	6·8†	38·1	7·2†	38·6	6·7†	37·7	7·2†	0·91	0·38
Relative HGS (kg/kg)	0·44	0·08†	0·50	0·09†	0·43	0·07†	0·50	0·08†	< 0·001	< 0·001
Muscle quality (kg/kg)	6·1	0·9†	6·3	1·0†	5·8	0·8†	6·5	1·0†	0·23	< 0·001
Appendicular skeletal muscle mass (kg)	24·6	3·4	24·1	3·2	26·2	2·8	23·2	3·1	0·21	< 0·001
Stair climb test (s)	7·0	1·9	6·5	1·8	7·2	1·9	6·5	1·7	0·06	0·004
Repeated sit-to-stand test (s)	11·1	2·2	11·1	2·7	11·6	2·4	10·8	2·5	0·96	0·04
Gait speed (m/s)	1·3	0·2	1·3	0·2	1·3	0·2	1·3	0·2	0·30	0·63

FM, total body fat mass; WC, waist circumference; HGS, handgrip strength.
* Between men with FM > 25 % *v.* ≤ 25%.
** Between women with WC ≥ 102 cm *v.* < 102 cm.
† Two missing.

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performance where total body mass served as an extra load (repeated sit-to-stand and stair climb tests) than the non-obese. Even though absolute HGS is a highly efficient screening tool[43], it may misclassify individuals as it only accounts for ~40 % of the variance in lower body strength[44]. Thus, caution should be taken into account when estimating overall strength from absolute HGS in obese individuals and from one single measurement tool[45–47]. Since strength production capacity relative to body mass was lower among the obese than non-obese, it may indicate that relative HGS is a more sensitive method than absolute HGS to identify obese older adults at the risk of functional impairment. Furthermore, relative HGS has been associated with cardiometabolic disease risk factors[14,48,49]. Currently, no population-specific cut-off points for low relative HGS exist. Future prospective studies are needed to establish sex-specific cut-off points that predict clinically relevant impaired muscle function.

Despite finding a higher appendicular skeletal muscle mass in obese compared with non-obese individuals, differences were not observed in absolute HGS between the two groups. It is well known that obesity leads to fat infiltration into muscle tissue, causing decline in muscle strength to a greater extent than loss of muscle mass[2]. Previous studies in older adults have shown that increased FM contributes to a deterioration of muscle strength and lower absolute HGS[50,51]. Muscle quality, expressing muscle strength relative to muscle mass, declines with age and obesity[14,52], and marked inter-individual differences in rates of loss have been reported[26,35,53]. In accordance with previous studies, lower muscle quality was observed in obese women and men, which may explain the lack of differences in absolute HGS between obese and non-obese individuals[14,54]. By definition, muscle quality provides a good indication of muscle function. However, muscle quality referring both to micro- and macroscopic changes in muscle architecture and composition[27,55] and may thus be technically difficult to measure accurately[27,56–58]. Further, previous studies have shown that both muscle mass, obesity and age affect the relationship between muscle quality and physical function[53]. Consequently, despite similar values of muscle quality, obese individuals may have poorer muscle function than non-obese. Muscle quality measurement is suggested to grow in importance, but cut-off points for low values need to be established and validation of muscle quality as an assessment tool is needed. However, since the active muscle mass may only be a small part of the total muscle mass, it is important to emphasise that both relative HGS and muscle quality estimated by absolute HGS/upper body muscle mass have limitations. Further, muscle quality (HGS/upper body muscle mass) would not necessarily be a good measure of overall muscle quality because the muscle mass may be differently distributed on the body. Thus, implementation of muscle quality as a screening measurement for functional impairment in older adults, especially among obese, should be done with caution.

Absolute HGS has traditionally been used as a measure of muscle strength in the assessment of muscle function in older adults. However, as previously shown, lower body strength may better reflect the functional capacity compared with absolute HGS, which is necessary for activities of daily living such as mobility, gait speed and stairs climbing[41,59,60]. In addition, although absolute HGS has been shown to strongly correlate with leg strength in older adults, absolute HGS does not provide valid results when evaluating the efficacy of exercise intervention programmes to increase muscle mass or strength in an older population[47]. The repeated sit-to-stand and stair climb tests are widely used as lower extremity strength measurement[21,61] and have been shown relevant measures of leg power impairments[39]. Further, these methods take total body mass into account and are affected by muscle strength, dynamic balance and cardiorespiratory endurance, and thus represent overall physical performance rather than overall muscle strength[62,63]. The short gait speed test (4 m) may not be as sensitive as repeated sit-to-stand and stair climb tests in older obese adults, but studies where longer walking distances have been used (20 and 500 m)[64,65] show differences between the obese and non-obese. In a clinical context, repeated sit-to-stand test and stair climbing test are simple tests that could be easily implemented.

More women than men were classified as obese, and a substantial agreement between WC and FM % was observed among women. A moderate agreement between the methods was observed in men, and only obesity defined by WC identified individuals at increased risk for functional impairment. In a previous study, where the two obesity phenotypes WC and FM % were compared, WC was more sensitive to identify older adults at the risk of functional impairment than FM %[66]. However, in our study, more men were defined as obese by FM % than WC. Thus, the lower agreement between the obese phenotypes in men than in women could be explained by the cut-off point to define obesity by FM % in men is too low. Furthermore, WC is a surrogate measure of visceral adiposity and may reflect greater inflammatory potential[67] and insulin resistance[68], which may contribute to progressive loss of muscle mass, muscle strength and muscle quality[68–70]. In a clinical context, WC measurement may be preferred because it is easier to implement than FM %. Moreover, increased WC is associated with lower quality of life, a decline in physical function and a slightly higher risk of disability over time[64]. Thus, WC has been suggested to be measured routinely in clinical practice[71].

There are, however, some limitations in this study. Food intake and physical activity may affect BIA measurements. Due to practicalities, non-fasting measurement of body composition BIA was performed in this study. To reduce the effect of physical activity, all physical tests were performed after the BIA measurement was performed. However, the participants had no restrictions on physical activity the last 24 h prior to the study visit. Thus, the non-fasting measurement and the activity level may thus have influenced the estimation of fat-free mass and FM in our study. Whether this has contributed to the reduced agreement between WC and FM % is plausible, but uncertain. Furthermore, the majority of older adults had high SPPB score, and the study population included was relatively healthy having high cognitive function, adequate nutritional status and dietary intake, and only a few had severe inflammatory disease (9 %) or respiratory diseases (5 %) as further described elsewhere[29]. Despite this, we cannot exclude the possibility that diseases, pain or motivation may have affected the ability to perform the physical tests in some individuals. Unfortunately, we were not able to reveal age-related intra-muscular changes which

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affect the muscle quality. The participants included in the present study had high muscle mass and physical performance, and thus, the results may not be generalised to obese older frail or sarcopenic older adults. A strength of the present study was the large number of participants, and the fact that several tests were included to assess body composition and muscle function.

In conclusion, methods to identify obese older adults with increased risk of functional impairment are needed. We show that neither muscle mass nor absolute muscle strength was able to discriminate between obese and non-obese older adults at increased risk of functional impairment. However, relative muscle strength, muscle quality and physical performance tests where body mass serves as an extra load identified obese older adults with an increased risk of functional impairment. Relative HGS is a simple and an effective method that is easy to implement for routine clinical practice. Thus, prospective studies are needed to investigate clinically relevant cut-off points for relative HGS in relation to functional impairment in older adults.

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References

1. Visser M, Goodpaster BH, Kritchevsky SB, *et al.* (2005) Muscle strength, and muscle fat infiltration as predictors of incident mobility limitations in well-functioning older persons. *J Gerontol Ser A: Biol Sci Med Sci* **60**, 324–333.
2. Goodpaster BH, Park SW, Harris TB, *et al.* (2006) The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. *J Gerontol Ser A: Biol Sci Med Sci* **61**, 1059–1064.
3. Delmonico MJ, Harris TB, Visser M, *et al.* (2009) Longitudinal study of muscle strength, quality, and adipose tissue infiltration. *Am J Clin Nutr* **90**, 1579–1585.
4. Hughes VA, Frontera WR, Wood M, *et al.* (2001) Longitudinal muscle strength changes in older adults: influence of muscle mass, physical activity, and health. *J Gerontol Ser A: Biol Sci Med Sci* **56**, B209–B217.
5. Schaap LA, Koster A & Visser M (2013) Adiposity, muscle mass, and muscle strength in relation to functional decline in older persons. *Epidemiol Rev* **35**, 51–65.
6. Vermeulen J, Neyens JC, van Rossum E, *et al.* (2011) Predicting ADL disability in community-dwelling elderly people using physical frailty indicators: a systematic review. *BMC Geriatr* **11**, 33.
7. Newman AB, Kupelian V, Visser M, *et al.* (2006) Strength, but not muscle mass, is associated with mortality in the health, aging and body composition study cohort. *J Gerontol Ser A: Biol Sci Med Sci* **61**, 72–77.
8. Van Kan GA (2009) Epidemiology and consequences of sarcopenia. *J Nutr Health Aging* **13**, 708–712.
9. Hughes VA, Roubenoff R, Wood M, *et al.* (2004) Anthropometric assessment of 10-year changes in body composition in the elderly. *Am J Clin Nutr* **80**, 475–482.
10. Lim W-S, Canevelli M & Cesari M (2018) Editorial: dementia, frailty and aging. *Front Med* **5**, 168.
11. Roubenoff R (2004) Sarcopenic obesity: the confluence of two epidemics. *Obes Res* **12**, 887–888.
12. Janssen I, Heymsfield SB, Wang Z, *et al.* (2000) Skeletal muscle mass and distribution in 468 men and women aged 18–88 years. *J Appl Physiol* **89**, 81–88.
13. Lafortuna CL, Maffiuletti NA, Agosti F, *et al.* (2005) Gender variations of body composition, muscle strength and power output in morbid obesity. *Int J Obes* **29**, 833–841.
14. Koster A, Ding J, Stenholm S, *et al.* (2011) Does the amount of fat mass predict age-related loss of lean mass, muscle strength, and muscle quality in older adults? *J Gerontol Ser A: Biol Sci Med Sci* **66A**, 888–895.
15. Lawman HG, Troiano RP, Perna FM, *et al.* (2016) Associations of relative handgrip strength and cardiovascular disease biomarkers in U.S. Adults, 2011–2012. *Am J Prev Med* **50**, 677–683.
16. Cava E, Yeat NC & Mittendorfer B (2017) Preserving healthy muscle during weight loss. *Adv Nutr* **8**, 511–519.
17. Tallis J, James RS & Seebacher F (2018) The effects of obesity on skeletal muscle contractile function. *J Exp Biol* **221**, jeb163840.
18. Batsis JA (2019) Obesity in the older adult: special issue. *J Nutr Gerontol Geriatr* **38**, 1–5.
19. Koster A, Patel KV, Visser M, *et al.* (2008) Joint effects of adiposity and physical activity on incident mobility limitation in older adults: adiposity, physical activity, and mobility limitation. *J Am Geriatr Soc* **56**, 636–643.
20. Newman AB, Haggerty CL, Goodpaster B, *et al.* (2003) Strength and muscle quality in a well-functioning cohort of older adults: the health, aging and body composition study. *J Am Geriatr Soc* **51**, 323–330.
21. Beaudart C, McCloskey E, Bruyère O, *et al.* (2016) Sarcopenia in daily practice: assessment and management. *BMC Geriatr* **16**, 170.
22. Rantanen T, Volpato S, Luigi Ferrucci M, *et al.* (2003) Handgrip strength and cause-specific and total mortality in older disabled women: exploring the mechanism. *J Am Geriatr Soc* **51**, 636–641.
23. Cooper R, Kuh D & Hardy R (2010) Mortality review group, on behalf of the FALCon and HALCyon study teams. Objectively measured physical capability levels and mortality: systematic review and meta-analysis. *BMJ* **341**, c4467.
24. Rijk JM, Roos PR, Deckx L, *et al.* (2016) Prognostic value of handgrip strength in people aged 60 years and older: a systematic review and meta-analysis: prognostic value of handgrip strength. *Geriatr Gerontol Int* **16**, 5–20.
25. Ramírez-Vélez R, Pérez-Sousa MÁ, García-Hermoso A, *et al.* (2020) Relative handgrip strength diminishes the negative effects of excess adiposity on dependence in older adults: a moderation analysis. *J Clin Med* **9**, 1152.

British Journal of Nutrition

26. Barbat-Artigas S, Rolland Y, Zamboni M, *et al.* (2012) How to assess functional status: a new muscle quality index. *J Nutr Health Aging* **16**, 67–77.
27. McGregor RA, Cameron-Smith D & Poppitt SD (2014) 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* **3**, 9.
28. Cruz-Jentoft AJ, Bahat G, Bauer J, *et al.* (2019) Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing* **48**, 16–31.
29. Ottestad I, Ulven SM, Øyri LKL, *et al.* (2018) Reduced plasma concentration of branched-chain amino acids in sarcopenic older subjects: a cross-sectional study. *Br J Nutr* **120**, 445–453.
30. Ottestad I, Løvstad AT, Gjevestad GO, *et al.* (2017) Intake of a protein-enriched milk and effects on muscle mass and strength. A 12-week randomized placebo controlled trial among community-dwelling older adults. *J Nutr Health Aging* **21**, 1160–1169.
31. World Health Organization (2000) *Obesity: Preventing and Managing the Global Epidemic: Report of a WHO Consultation. WHO Technical Report Series no. 253.* Geneva: World Health Organization.
32. Studenski SA, Peters KW, Alley DE, *et al.* (2014) The FNIH Sarcopenia Project: rationale, study description, conference recommendations, and final estimates. *J Gerontol: Ser A* **69**, 547–558.
33. World Health Organization (2005) *WHO Steps Surveillance Manual: The WHO Stepwise Approach to Chronic Disease Risk Factor Surveillance*. Geneva: WHO.
34. Dodds RM, Syddall HE, Cooper R, *et al.* (2014) Grip strength across the life course: normative data from twelve British studies. *PLOS ONE* **9**, e113637.
35. Hairi NN, Cumming RG, Naganathan V, *et al.* (2010) Loss of muscle strength, mass (sarcopenia and quality (specific force) and its relationship with functional limitation and physical disability: the concord health and ageing in men project: age-related muscle changes and physical function. *J Am Geriatr Soc* **58**, 2055–2062.
36. Cooper R, Hardy R, Bann D, *et al.* (2014) Body mass index from age 15 years onwards and muscle mass, strength, and quality in early old age: findings from the MRC National Survey of Health and Development. *J Gerontol: Ser A* **69**, 1253–1259.
37. Lees MJ, Wilson OJ, Hind K, *et al.* (2019) Muscle quality as a complementary prognostic tool in conjunction with sarcopenia assessment in younger and older individuals. *Eur J Appl Physiol* **119**, 1171–1181.
38. Sui SX, Holloway-Kew KL, Hyde NK, *et al.* (2020) Handgrip strength and muscle quality in Australian women: cross-sectional data from the Geelong Osteoporosis Study. *J Cachexia Sarcopenia Muscle* **11**, 690–697.
39. Bean JF, Kiely DK, LaRose S, *et al.* (2007) Is stair climb power a clinically relevant measure of leg power impairments in at-risk older adults? *Arch Physical Med Rehabil* **88**, 604–609.
40. Guralnik JM, Ferrucci L, Pieper CF, *et al.* (2000) 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 Gerontol Ser A: Biol Sci Med Sci* **55**, M221–M231.
41. Bouchard DR, Héroux M & Janssen I (2011) Association between muscle mass, leg strength, and fat mass with physical function in older adults: influence of age and sex. *J Aging Health* **23**, 313–328.
42. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, *et al.* (2010) Sarcopenia: European consensus on definition and diagnosis: report of the European Working Group on Sarcopenia in Older People. *Age Ageing* **39**, 412–423.
43. Martin HJ, Yule V, Syddall HE, *et al.* (2006) Is hand-held dynamometry useful for the measurement of quadriceps strength in older people? A comparison with the gold standard bodex dynamometry. *Gerontology* **52**, 154–159.
44. Manini TM & Clark BC (2012) Dynapenia and aging: an update. *J Gerontol A Biol Sci Med Sci* **67**, 28–40.
45. Bohannon RW (2008) Hand-grip dynamometry predicts future outcomes in aging adults. *J Geriatr Phys Ther* **31**, 3–10.
46. Mitchell WK, Williams J, Atherton P, *et al.* (2012) Sarcopenia, dynapenia, and the impact of advancing age on human skeletal muscle size and strength; a quantitative review. *Front Physiol* **3**, 260.
47. Tieland M, Verdijk LB, de Groot LC, *et al.* (2015) Handgrip strength does not represent an appropriate measure to evaluate changes in muscle strength during an exercise intervention program in frail older people. *Int J Sport Nutr Exerc Metab* **25**, 27–36.
48. Silva CR, Saraiva B, Nascimento DDC, *et al.* (2018) Relative handgrip strength as a simple tool to evaluate impaired heart rate recovery and a low chronotropic index in obese older women. *Int J Exerc Sci* **11**, 844–855.
49. Lombardo M, Padua E, Campoli F, *et al.* (2021) Relative handgrip strength is inversely associated with the presence of type 2 diabetes in overweight elderly women with varying nutritional status. *Acta Diabetol* **58**, 25–32.
50. de Carvalho DHT, Scholes S, Santos JLF, *et al.* (2019) Does abdominal obesity accelerate muscle strength decline in older adults? Evidence from the English longitudinal study of ageing. *J Gerontol: Ser A* **74**, 1105–1111.
51. Kim S, Leng XI & Kritchevsky SB (2017) Body composition and physical function in older adults with various comorbidities. *Innovat Aging* **1**, igx008.
52. Goodpaster BH, Carlson CL, Visser M, *et al.* (2001) Attenuation of skeletal muscle and strength in the elderly: the Health ABC Study. *J Appl Physiol* **90**, 2157–2165.
53. Barbat-Artigas S, Pion CH, Leduc-Gaudet J-P, *et al.* (2014) Exploring the role of muscle mass, obesity, and age in the relationship between muscle quality and physical function. *J Am Med Dir Assoc* **15**, 303–e13.
54. Valenzuela PL, Maffiuletti NA, Tringali G, *et al.* (2020) Obesity-associated poor muscle quality: prevalence and association with age, sex, and body mass index. *BMC Musculoskeletal Disord* **21**, 200.
55. Fragala MS, Kenny AM & Kuchel GA (2015) Muscle quality in aging: a multi-dimensional approach to muscle functioning with applications for treatment. *Sport Med* **45**, 641–658.
56. Buckinx F, Landi F, Cesari M, *et al.* (2018) Pitfalls in the measurement of muscle mass: a need for a reference standard. *J Cachexia Sarcopenia Muscle* **9**, 269–278.
57. Masanés F, I Luque XR, Salvà A, *et al.* (2017) Cut-off points for muscle mass – not grip strength or gait speed – determine variations in Sarcopenia prevalence. *J Nutr Health Aging* **21**, 825–829.
58. Walowski CO, Braun W, Maisch MJ, *et al.* (2020) Reference values for skeletal muscle mass – current concepts and methodological considerations. *Nutrients* **12**, 755.
59. Coelho-Junior HJ & Rodrigues B, de Oliveira Gonçalves I, *et al.* (2018) The physical capabilities underlying timed «Up and Go» test are time-dependent in community-dwelling older women. *Exp Gerontol* **104**, 138–146.
60. Yeung SSY, Reijnierse EM, Trappenburg MC, *et al.* (2018) Handgrip strength cannot be assumed a proxy for overall muscle strength. *J Am Med Dir Assoc* **19**, 703–709.
61. Cesari M, Kritchevsky SB, Newman AB, *et al.* (2009) Added value of physical performance measures in predicting adverse health-related events: results from the health, aging and body

British Journal of Nutrition

composition study: physical performance and prediction of events. *J Am Geriatr Soc* **57**, 251–259.
62. Lord SR, Murray SM, Chapman K, *et al.* (2002) Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people. *J Gerontol A Biol Sci Med Sci* **57**, M539–M543.
63. Bohannon RW, Bubela DJ, Magasi SR, *et al.* (2010) Sit-to-stand test: performance and determinants across the age-span. *Isokinet Exerc Sci* **18**, 235–240.
64. Batsis JA, Zbehlik AJ, Barre LK, *et al.* (2014) The impact of waist circumference on function and physical activity in older adults: longitudinal observational data from the osteoarthritis initiative. *Nutr J* **13**, 81.
65. Stenholm S, Rantanen T, Heliövaara M, *et al.* (2008) The mediating role of C-reactive protein and handgrip strength between obesity and walking limitation. *J Am Geriatr Soc* **56**, 462–469.
66. Khor EQ, Lim JP, Tay L, *et al.* (2020) Obesity definitions in sarcopenic obesity: differences in prevalence, agreement and association with muscle function. *J Frailty Aging* **9**, 37–43.
67. Power ML & Schulkin J (2008) Sex differences in fat storage, fat metabolism, and the health risks from obesity: possible evolutionary origins. *Br J Nutr* **99**, 931–940.
68. Racette SB, Evans EM, Weiss EP, *et al.* (2006) Abdominal adiposity is a stronger predictor of insulin resistance than fitness among 50–95 year olds. *Diabetes Care* **29**, 673–678.
69. Schaap LA, Pluijm SMF, Deeg DJH, *et al.* (2006) Inflammatory markers and loss of muscle mass (Sarcopenia) and strength. *Am J Med* **119**, 526–e9.
70. Visser M, Pahor M, Taaffe DR, *et al.* (2002) Relationship of interleukin-6 and tumor necrosis factor- with muscle mass and muscle strength in elderly men and women: the health ABC study. *J Gerontol Ser A: Biol Sci Med Sci* **57**, M326–M332.
71. Ross R, Neeland IJ, Yamashita S, *et al.* (2020) Waist circumference as a vital sign in clinical practice: a consensus statement from the IAS and ICCR Working Group on Visceral Obesity. *Nat Rev Endocrinol* **16**, 177–189.

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