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Diagnostic criteria for sarcopenia and physical performance

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Abstract Relative and absolute muscle mass and muscle strength are used as diagnostic criteria for sarcopenia. We aimed to assess which diagnostic criteria are most associated with physical performance in 180 young (18–30 years) and 281 healthy old participants (69–81 years) of the European study MYOAGE. Diagnostic criteria included relative muscle mass (total or appendicular lean mass (ALM) as percentage of body mass), absolute muscle mass (ALM/height squared and total lean mass), knee extension torque, and handgrip strength. Physical performance comprised walking speed, Timed Up and Go test (TUG), and in a subgroup physical fitness. Diagnostic criteria for sarcopenia and physical performance were standardized, and the associations were analyzed using linear regression models stratified by age category, with adjustments for age, gender, and country. In old participants, relative muscle mass was associated with faster walking speed, faster TUG, and higher physical fitness (all $p<0.001$). Absolute muscle mass was not associated with physical

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performance. Knee extension torque and handgrip strength were associated with faster walking speed (both $p \leq 0.003$). Knee extension torque was associated with TUG ($p=0.001$). Knee extension torque and handgrip strength were not associated with physical fitness. In young participants, there were no significant associations between diagnostic criteria for sarcopenia and physical performance, except for a positive association between relative muscle mass and physical fitness ($p<0.001$). Relative muscle mass, defined as lean mass or ALM percentage, was most associated with physical performance. Absolute muscle mass including ALM/height squared was not associated with physical performance. This should be accounted for when defining sarcopenia.

Keywords Sarcopenia · Aging · Mobility · Skeletal muscle · Gait speed

Introduction

Sarcopenia has been associated with self-reported mobility limitations (Baumgartner et al. 1998), cognitive decline (Burns et al. 2010), and mortality (Bunout et al. 2011). The onset of age-related loss of muscle mass occurs as early as 30 years of age, with a decrease of 1 to 2 % after the age of 50 years and results in a loss of over 50 % by the age of 80 years (Baumgartner et al. 1998; Lauretani et al. 2003). During the last two decades, several diagnostic criteria for sarcopenia have been proposed, which can be categorized into measures of relative muscle mass (defined as total or appendicular lean mass (ALM) as percentage of body mass), absolute muscle mass (defined as ALM corrected for height (ALM/height squared) or total lean mass), muscle strength, walking speed, or a combination of criteria (Cruz-Jentoft et al. 2010; Fielding et al. 2011). Previously, we have shown that the prevalence of sarcopenia is highly dependent on the diagnostic criteria (Bijlsma et al. 2012).

Evidence-based consensus on the most clinically relevant diagnostic criteria for sarcopenia requires exploration of its association with muscle-related clinical outcome, such as physical performance. Relative muscle mass (lean mass percentage or ALM percentage) has been consistently associated with physical performance (Janssen et al. 2002; Lebrun et al. 2006; Woo et al. 2009). However, expressing muscle mass in a different way, such as the absolute muscle mass (ALM/height squared), has led to conflicting results with some studies showing an association with self-reported mobility limitations and physical performance (Woo et al. 2009; Baumgartner et al. 1998), and the others find no significant relationship between absolute muscle mass and physical performance (Rolland et al. 2009; Estrada et al. 2007; Patil et al. 2012). There are also mixed reports from studies relating muscle strength with physical performance. For instance, muscle strength was associated with self-reported mobility limitation (Lebrun et al. 2006; Visser et al. 2005) and physical performance (Estrada et al. 2007; Lebrun et al. 2006), but this is not a consistent finding (Patil et al. 2012). There are no studies available that have explored these different indices of muscle mass and strength, with measurements of physical performance, in the same cohort.

We compared the association of different diagnostic criteria for sarcopenia (absolute and relative muscle masses, muscle strength) with physical performance, consisting of walking speed, Timed Up and Go test (TUG), and physical fitness as estimated with the Astrand fitness test in a group of young (aged 18–30 years) and old (aged 69–81 years) men and women participating in the MYOAGE study.

Methods

Study design

MYOAGE is a cross-sectional European multicenter study of young (aged 18 to 30 years) and relatively healthy old participants (aged 69 to 81 years). A detailed description of the study design has been reported elsewhere (McPhee et al., submitted). Participants were recruited by focused advertisement in newspapers, third generation university, association of emeriti, and universities, hereby selecting cognitively active individuals. In total, 461 participants were included: 110 were recruited in Leiden, the Netherlands; 105, in Jyvaskyla, Finland; 100, in Tartu, Estonia; 62, in Paris, France; and 84, in Manchester, UK.

Exclusion criteria were aimed to ensure the selection of healthy participants and to minimize the confounding effect of comorbidity on sarcopenia. In short, exclusion criteria were as follows: dependent living situation, inability to walk a distance of 250 m, presence of morbidity (neurologic disorders, metabolic diseases, rheumatic diseases, recent malignancy, heart failure, severe chronic obstructive pulmonary disease

(COPD), hemocoagulation syndromes), use of medication (immunosuppressive drugs, insulin), immobilization for 1 week during the last 3 months, and orthopedic surgery during the last 2 years or still causing pain or functional limitation. In addition, highly trained athletes were excluded.

Measurements were performed according to unified standard operating procedures during visits to the local study centers. The local medical ethical committees of the respective institutions approved the study. Written informed consent was obtained from all participants.

Diagnostic criteria for sarcopenia

Muscle mass

A whole body scan was performed using dual-energy X-ray absorptiometry (DXA) (Netherlands, Hologic QDR 4500, version 12.4, Hologic, Inc., Bedford, USA; Finland, Lunar Prodigy, version EnCore 9.30; Estonia, Lunar Prodigy Advanced, version EnCore 10.51.006; France, Lunar Prodigy, version EnCore 12.30; UK, Lunar Prodigy Advance, version EnCore 10.50.086). Participants wore a light cotton shirt to reduce measurement errors due to clothing absorption. A trained technician performed the dual-energy X-ray absorptiometry. From the DXA, total and compartmental lean mass and fat mass were measured. Lean mass was used as an estimation of muscle mass.

To obtain relative muscle mass, lean mass percentage was calculated as lean mass divided by body mass in percentage (Janssen et al. 2002), and ALM percentage, as the sum of lean mass of both arms and legs divided by body mass in percentage (Estrada et al. 2007).

To obtain absolute muscle mass, ALM/height squared was calculated as ALM divided by height squared (Baumgartner et al. 1998), and total lean mass was directly derived from DXA in kilograms.

Muscle strength

Isometric knee extension torque was measured with a knee extension dynamometer chair (Netherlands, Forcelink B.V., Culemborg, the Netherlands; Finland, custom made; Estonia, custom made; France, Biodex System 3 Pro Isokinetic Dynamometer, Biodex Medical Systems, Shirley, NY, USA; UK, custom made). The participants were positioned in an upright position, with straps to fix the hips to the chair and the ankle to a force or torque transducer at the knee angle of 90°. Lever arm length was recorded as the distance between the knee axis of rotation and the center of the force transducer located at the point of force application above the malleoli. After three warm-up trials at 50 and 90 % of self-perceived maximal strength, three trials were conducted to measure maximal voluntary contraction force of the knee extensor muscles. For each attempt, maximal force or torque was recorded. Each trial was separated by 1 min of rest. Knee extension torque was obtained either directly or by multiplying the recorded peak force with the lever arm length (in meter). The trial with the highest torque output was selected for analyses.

Handgrip strength was measured using the Jamar Handgrip Dynamometer (Sammons Preston, Inc., Bolingbrook, IL, USA). The width of the dynamometer was adjusted for each participant separately for optimal fit. Participants were instructed to stand upright with the dynamometer beside, but not against their body. Measurements were performed three times for each side. The best of all attempts was used for further analysis.

Physical performance

Walking speed was measured as the average speed during a 6-min walking test. Participants were instructed to walk around the cones placed 20 m apart (or 25 m in France). In Finland, Estonia, France, and UK, participants were instructed to walk as fast as possible; in the Netherlands, the instruction was to walk at their usual pace.

The time needed to complete the TUG was measured. Participants were instructed to rise from a chair without the use of arms, walk around the cone placed 3 m from the chair, and return to the original sitting position. Further instructions were to complete the test as quickly as possible, while taking care not to run and to remain safe. Participants were allowed three trials; the fastest attempt was used for analyses.

In the Netherlands, additional measurements included a physical fitness test, by estimating the maximal oxygen uptake (VO_2 max) according to the Astrand fitness test (Astrand and Rodahl 1986). This method has been shown to be a valid test in elderly participants (aged 60 to 70 years) (Siconolfi et al. 1982). Participants pedalled at a cadence of 60 cycles per min (rpm) on a cycle ergometer at a selected workload (50, 75, 100, or

150 W) during 6 min. The workload was selected by asking the subjects about their daily activity level and training status and by taking the age and gender into account. The workload was aimed to be at the highest tolerated intensity to ensure a heart rate of 110 beats per min (bpm) after 6 min. Heart rate was measured continuously during the test using a polar heart rate monitor (Polar RS800CX, Polar Pro Trainer 5). After a 4-min warming-up at a lower workload, the 6-min Astrand fitness test was performed at the selected workload. If mean steady state heart rate (submaximal heart rate) at the end of the test was over 110 bpm, the test was ended. If the submaximal heart rate was below 110 bpm, the workload was increased, and the test continued for another 6 min, if tolerated by the participant (Cink and Thomas 1981). The Astrand nomogram was used to calculate physical fitness (in milliliter per kilogram per minute) from submaximal heart rate, workload, body mass, and gender (Astrand and Rodahl 1986).

Participant characteristics and health status

Standing height was measured to the nearest millimeter. Information about lifestyle factors such as smoking, alcohol use, living status, and education were self-reported using a questionnaire. Excessive alcohol use was defined as more than 21 units per week for men or more than 14 units per week for women. Diseases were registered and categorized into cardiovascular disease (including cardiovascular events, arterial surgery, and hypertension), non-insulin-dependent diabetes mellitus, mild COPD, thyroid disease, and osteoarthritis. The sum score of diseases was calculated. The use of medication was registered, and a sum score of all oral and inhaled medication was calculated as a measure of disease severity. Cognitive function was measured using the mini-mental state examination, and depressive symptoms were measured using the Geriatric Depression Scale.

Statistical analysis

Continuous variables with the Gaussian distribution are presented as mean (standard deviation), and those with non-Gaussian distribution, as median (interquartile range (IQR)).

Results from the different countries were first analyzed separately and subsequently pooled if the effect sizes were comparable. In pooled analyses, all described diagnostic criteria for sarcopenia and physical performance parameters were standardized into country specific z-scores, to minimize the possible effects due to differences in equipment and to allow comparison of effect sizes of diagnostic criteria for sarcopenia in their association with physical performance.

Linear regression analyses were used to identify associations between diagnostic criteria for sarcopenia and physical performance and to calculate adjusted means and standard errors of the means. Adjusted means and standard errors of the means were calculated for sex and country-specific tertiles of the muscle characteristics. Three different adjustment models were used, stratified by age category. In model 1, analyses were adjusted for age (for residual confounding for age), sex, and country. In model 2, further adjustments were made for body mass or body fat and, additionally, for height in model 3. Lean mass percentage and ALM percentage were adjusted for body mass, since higher body mass is associated with physical performance and with lower relative muscle mass. As relative muscle mass is not associated with height, height was not included in the adjustment model. Lean mass and ALM/height squared were adjusted for fat mass, since these measures do not take fat mass into account. These measures were not adjusted for height, as ALM/height squared already includes height. Knee extension torque and handgrip strength were adjusted for body mass and height. Adjustment models for the association between diagnostic criteria for sarcopenia and physical fitness did not include body mass or fat mass, as the estimation of physical fitness is already adjusted for body mass.

Results of the regression analyses with standardized variables can be interpreted as follows: 1 standard deviation (SD) increase of diagnostic criteria for sarcopenia is related to the effect size (β)×SD change in physical performance.

SPSS 20 for Windows was used for all analyses. The p values of <0.05 were considered statistically significant.

Results

Participant characteristics and health status

Baseline characteristics of the study participants are shown in Table 1, stratified for age category. Overall, values for diagnostic criteria for sarcopenia and for physical performance were lower in old participants as compared to those in young participants.

Diagnostic criteria for sarcopenia and physical performance

Muscle mass

Table 2 shows the association between relative and absolute muscle masses and walking speed and duration of TUG. Old participants with a higher relative muscle mass (lean mass percentage and ALM percentage) had a faster walking speed and shorter duration of TUG. Additional adjustments for body mass affected the results only slightly. There were no associations between absolute muscle mass (ALM/height squared and total lean mass) and walking speed or TUG. When only additional adjustment for fat mass was applied, ALM/height squared and lean mass were associated with faster walking speed, but not with TUG. There were no associations between relative or absolute muscle mass and walking speed or TUG in young participants. Results did not change after excluding participants from the Netherlands who were instructed to walk at their usual pace during the 6-min walking test.

Table 3 shows the association between relative and absolute muscle masses and physical fitness. Relative

Table 1 Participant characteristics, stratified by age (n=461)

	Young (n=180)	Old (n=281)
Age (years)	23.4 (2.9)	74.4 (3.3)
Females, n (%)	94 (52.2)	144 (48.8)
Living with partner	40 (22.2)	148 (52.7)
Highly educated, n (%)[a]	132 (73.3)	96 (34.2)
Anthropometry		
Height (m)	1.73 (0.09)	1.67 (0.09)
Body mass (kg)	68.8 (12.3)	71.5 (12.8)
Body mass index (kg/m^2)	22.8 (3.0)	25.5 (3.4)
Lifestyle		
Excessive alcohol use, n (%)[b]	44 (24.4)	36 (12.8)
Current smoking, n (%)	23 (12.8)	13 (4.6)
Comorbidities		
Number of diseases, median (IQR)	0 (0–0)	1 (0–1)
Number of medications, median (IQR)	0 (0–1)	1 (0–3)
Mental state		
MMSE score (points), median (IQR)	30 (29–30)	29 (28–30)
GDS score (points), median (IQR)	0 (0–1)	1 (0–2)
Diagnostic criteria for sarcopenia		
Lean mass percentage (%)[c]	72.9 (9.1)	67.1 (8.3)
ALM percentage (%)[d]	33.1 (4.7)	28.7 (4.1)
ALM/height squared (kg/m^2)	7.5 (1.3)	7.2 (1.1)
Total lean mass (kg)	50.2 (11.3)	47.7 (9.9)
Knee extension torque (Nm)	197.5 (69.5)	124.3 (44.1)
Handgrip strength (kg)	42.4 (12.2)	32.9 (9.4)
Physical performance		
TUG (s)[e]	4.86 (0.91)	6.37 (1.16)
Walking speed (m/s)[f]	1.85 (0.30)	1.46 (0.22)
Physical fitness (ml/kg/min)[g]	37.9 (9.0)	25.7 (6.4)

Variables are presented as mean and standard deviation, unless indicated otherwise

MMSE mini-mental state examination, *GDS* Geriatric Depression Scale, *TUG* Timed Up and Go test, *ALM* appendicular lean mass

[a]Data available in n=344

[b]Excessive alcohol used defined as for males of >21 units/week and females of >14 units/week

[c]Total lean mass as percentage of total body mass

[d]ALM as percentage of total body mass

[e]Data available in n=457

[f]Data available in n=450

[g]Expressed as the estimate of maximal oxygen uptake as derived from the Astrand fitness test; data are available in a subgroup of n=108

muscle mass was positively associated with physical fitness in young and old participants. Absolute muscle mass was not associated with physical fitness.

Muscle strength

Table 2 shows the association of muscle strength with walking speed and TUG. Old participants with higher knee extension torque had a faster walking speed and shorter duration of TUG. After additional adjustments for body mass and height, the associations remained significant. Old participants with higher handgrip strength had a faster walking speed in all adjusted models. Higher handgrip strength was only associated with TUG after adjustment for body mass. There were no associations between knee extension torque or handgrip strength and walking speed or TUG in young participants.

As shown in Table 3, no associations between knee extension torque or handgrip strength and physical fitness in young and old participants were found.

Table 2 Association between diagnostic criteria for sarcopenia and physical performance in the 6-min walk test and Timed Up and Go test

	Walking speed (SD in m/s)						Timed Up and Go test (SD in s)					
	Young (n=176)			Old (n=274)			Young (n=178)			Old (n=278)		
	β	SE	p	β	SE	p	β	SE	p	β	SE	p
Relative muscle mass												
Lean mass percentage (% in SD)[a]												
Model 1 (age, sex, and country)	0.10	0.07	0.15	0.31	0.06	<0.001*	0.01	0.06	0.82	−0.29	0.07	<0.001*
Model 2 (as 1 and body mass)	0.16	0.09	0.06	0.36	0.09	<0.001*	0.02	0.07	0.70	−0.25	0.10	0.012*
ALM percentage (% in SD)[b]												
Model 1 (age, sex, and country)	0.11	0.08	0.19	0.42	0.07	<0.001*	−0.05	0.07	0.45	−0.33	0.08	<0.001*
Model 2 (as 1 and body mass)	0.14	0.09	0.12	0.45	0.08	<0.001*	−0.06	0.08	0.44	−0.28	0.10	0.004*
Absolute muscle mass												
ALM/height^2 (kg/m^2 in SD)												
Model 1 (age, sex, and country)	−0.00	0.07	0.97	0.09	0.08	0.28	−0.06	0.06	0.27	−0.05	0.09	0.61
Model 2 (as 1 and fat mass)	−0.02	0.07	0.77	0.21	0.08	0.007*	−0.07	0.06	0.24	−0.17	0.09	0.06
Total lean mass (kg in SD)												
Model 1 (age, sex, and country)	0.10	0.09	0.26	0.01	0.10	0.89	0.01	0.07	0.90	0.06	0.11	0.59
Model 2 (as 1 and fat mass)	0.14	0.09	0.13	0.23	0.10	0.023*	0.01	0.07	0.92	−0.15	0.11	0.18
Muscle strength												
Knee extension torque (Nm in SD)												
Model 1 (age, sex, and country)	0.12	0.08	0.13	0.33	0.09	0.001*	−0.08	0.06	0.18	−0.37	0.10	0.001*
Model 2 (as 1 and body mass)	0.15	0.09	0.09	0.50	0.10	<0.001*	−0.12	0.07	0.10	−0.55	0.11	<0.001*
Model 3 (as 2 and height)	0.18	0.09	0.05	0.46	0.10	<0.001*	−0.12	0.07	0.09	−0.54	0.11	<0.001*
Handgrip strength (kg in SD)												
Model 1 (age, sex, and country)	0.07	0.08	0.37	0.25	0.08	0.003*	−0.08	0.06	0.18	−0.14	0.09	0.13
Model 2 (as 1 and body mass)	0.08	0.08	0.36	0.39	0.09	<0.001*	−0.11	0.07	0.12	−0.26	0.10	0.008*
Model 3 (as 2 and height)	0.05	0.09	0.57	0.34	0.09	<0.001*	−0.11	0.07	0.12	−0.22	0.10	0.015*

All diagnostic criteria for sarcopenia, walking speed and Timed Up and Go test were standardized into country specific z-scores. All p values are assessed with linear regression and adjustments in separate models

ALM appendicular lean mass, *SE* standard error

[a] Lean mass as percentage of total body mass

[b] ALM as percentage of total body mass

*p<0.05

Comparison of diagnostic criteria for sarcopenia

To determine the strongest association of different diagnostic criteria for sarcopenia with physical performance, effect sizes (β) for these associations given in Tables 2 and 3 were compared. In Table 2, including all participants, effect sizes (β) were strongest for relative muscle mass and muscle strength in the association with walking speed and TUG in old participants. In Table 3, including a subgroup of participants, effect sizes (β) were strongest for relative muscle mass in the association with physical fitness in young and old participants.

Figure 1 visualizes the association between tertiles of diagnostic criteria for sarcopenia and physical performance in old participants. Relative muscle mass is represented by ALM percentage, absolute muscle mass by ALM/height squared, and muscle strength by knee extension torque. Relative muscle mass was the only diagnostic criterion for sarcopenia associated with all tested parameters of physical performance: walking speed, TUG, and physical fitness.

Discussion

In this cross-sectional study, relative muscle mass expressed as a lean mass percentage or ALM percentage was most associated with physical performance in old participants. Absolute muscle mass, expressed as ALM/height squared and total lean mass, was only associated with TUG after adjustment for fat mass

Table 3 Association between diagnostic criteria for sarcopenia and physical performance (physical fitness) expressed as the estimate of maximal oxygen uptake as derived from the Astrand fitness test

	Physical fitness (ml/kg/min)[a]					
	Young (n=34)			Old (n=74)		
	β	SE	p	β	SE	p
Relative muscle mass						
Lean mass (% in SD)[b]						
Model 1 (age, sex)	0.91	0.19	<0.001*	0.59	0.11	<0.001*
ALM (% in SD)[c]						
Model 1 (age, sex)	1.00	0.25	<0.001*	0.57	0.11	<0.001*
Absolute muscle mass						
ALM/height squared (kg/m^2 in SD)						
Model 1 (age, sex)	−0.10	0.21	0.64	−0.05	0.11	0.65
Total lean mass (kg in SD)						
Model 1 (age, sex)	−0.10	0.29	0.74	−0.25	0.14	0.09
Muscle strength						
Knee extension torque (Nm in SD)						
Model 1 (age, sex)	−0.10	0.32	0.76	0.07	0.16	0.65
Model 2 (as 1 and height)	−0.09	0.34	0.80	0.07	0.16	0.65
Handgrip strength (kg in SD)						
Model 1 (age, sex)	0.03	0.24	0.90	−0.09	0.13	0.48
Model 2 (as 1 and height)	0.04	0.25	0.88	−0.07	0.13	0.57

All diagnostic criteria for sarcopenia and physical fitness were standardized into z-scores. All p values are assessed with linear regression and adjustments in separate models

ALM appendicular lean mass, *SE* standard error

[a] Expressed as the estimate of maximal oxygen uptake as derived from the Astrand fitness test

[b] Lean mass as percentage of total body mass

[c] ALM as percentage of total body mass

*p<0.05

and not associated with walking speed and physical fitness. This indicates that diagnostic criteria for sarcopenia based on unadjusted ALM/height squared are not useful to predict physical performance. Greater muscle strength was associated with faster TUG and faster walking speed, but not with physical fitness. In young participants, diagnostic criteria for sarcopenia were not associated with TUG or walking speed, but there was a positive association between relative muscle mass and physical fitness.

Relative muscle mass expressed as ALM percentage or lean mass percentage was also a predictor for physical performance in other studies (Estrada et al. 2007; Janssen et al. 2002; Lebrun et al. 2006; Woo et al. 2009). Although the formula ALM/height squared proposed by Baumgartner et al. (1998) is the most commonly used diagnostic criterion for sarcopenia, we found no association between ALM/height squared and physical performance without adjusting for fat mass. Studies reporting significant associations between ALM/height squared and physical performance included adjustment models for fat percentage (Baumgartner et al. 1998) or fat mass (Woo et al. 2009), which is in line with the present study, although we assessed ALM/height squared on a continuous scale. Without adjustments for fat mass, absence of an association between ALM/height squared and physical performance or self-reported physical limitation is confirmed by other studies (Estrada et al. 2007; Rolland et al. 2009; Newman et al. 2003; Visser et al. 2002; Stenholm et al. 2008; Patil et al. 2012). In addition, no association was observed between total lean mass in kilograms and self-reported mobility limitation (Visser et al. 2005).

Differences between relative and absolute muscle masses can be explained by the role of fat mass. Most obese people have an increased muscle mass in addition to high fat mass but may still have a low muscle mass relative to their body mass. Underweight elderly participants may have a high proportion of muscle mass in relation to their total body mass (Delmonico et al. 2007; Lebrun et al. 2006). With increasing chronological age, significant changes in body composition occur,

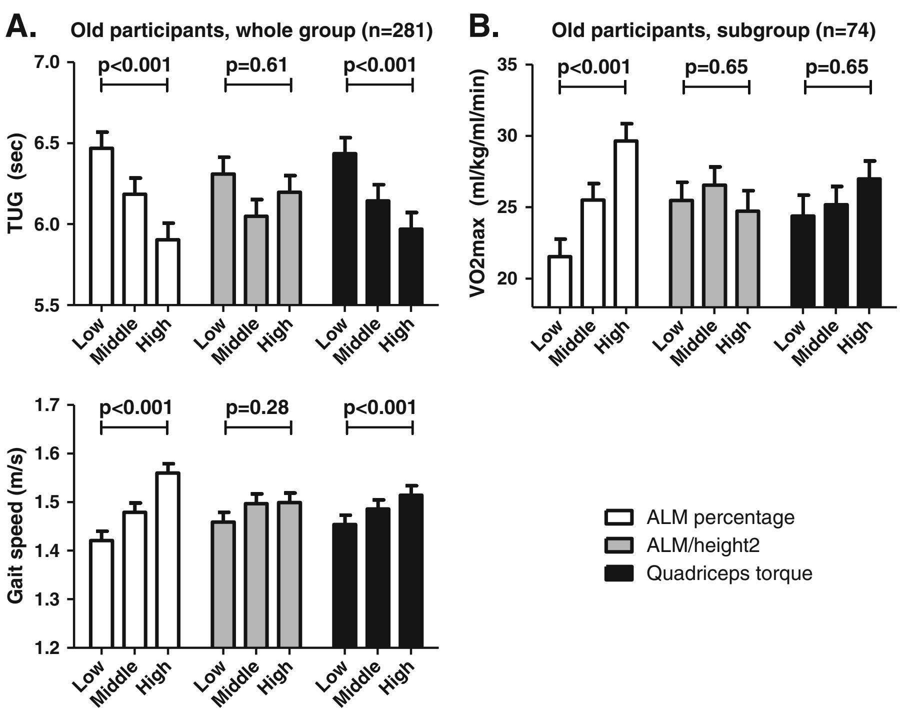

Fig. 1 Representation of the association between sex and country-specific tertiles of different diagnostic criteria for sarcopenia and physical performance in old participants. Physical performance in the *A* Timed Up and Go test (*TUG*) and walking speed derived from 6-min walking test and in *B* physical fitness expressed as the estimate of maximal oxygen uptake as derived from the Astrand fitness test. Muscle characteristics are appendicular lean mass (*ALM*) as percentage of body mass, ALM divided by height squared (ALM/height squared) and knee extension torque. *Bars* indicate adjusted means and standard errors. All *p* values are assessed with linear regression analyses including adjustments for gender and age (and country in *A*)

including a decrease in bone and muscle mass and an increase in the proportion of fat mass, even when the body mass remains the same (Baumgartner et al. 1995; Visser et al. 2002). The formula ALM/height squared underestimates sarcopenia in obese elderly and overestimates sarcopenia in underweight elderly participants (Visser et al. 2002; Rolland et al. 2008; Delmonico et al. 2007). In addition, older adults usually have become shorter, which could lead to an overestimation of muscle mass with the formula ALM/height squared. Therefore, it is important to take muscle mass relative to body mass or fat mass into account when defining sarcopenia (Delmonico et al. 2007; Newman et al. 2003; Auyeung et al. 2012).

In this study, muscle strength, in particular knee extension torque, was associated with the TUG test and walking speed in old participants, but not with physical fitness. Muscle strength has been associated with self-reported mobility limitation or physical performance (Estrada et al. 2007; Lebrun et al. 2006; Visser et al. 2005; Barbat-Artigas et al. 2012), but not in all studies (Patil et al. 2012). Recently, it has been advocated to use an index of muscle strength relative to body mass, which appeared to be strongly related to physical performance (Barbat-Artigas et al. 2012). It has been suggested that muscle strength in the elderly is associated with physical performance rather than muscle mass (Clark and Manini 2008; Hairi et al. 2010; Barbat-Artigas et al. 2012). However, in these studies, muscle mass was not adjusted for fat mass or body mass, indicating possible misclassification of low muscle mass (Rolland et al. 2008). The loss of muscle mass is closely related to the loss of muscle strength, although not at the same rate (Clark and Manini 2008). Using muscle strength to define sarcopenia has several limitations. To generate strength, other factors such as cardiovascular function, joint function, and neural control are involved (McCully and Posner 1995; Karttunen et al. 2011; Hyatt et al. 1990). Furthermore, muscle strength can be underestimated due to pain (Lauretani et al. 2003; Rolland et al. 2008).

In young participants, no association was found for diagnostic criteria for sarcopenia with TUG and walking speed. However, relative muscle mass was associated with physical fitness. This may be explained by the degree of challenge of these tests. For young participants, the TUG and the 6-min walking tests were submaximal and did not require the full recruitment of muscle mass and strength. The differences between young participants in these tests may arise from differences in motivation, stride length, and cardiorespiratory fitness. The Astrand fitness test is an individual challenging test. Under these circumstances even in young participants, there are differences in physical fitness which may be explained by their relative muscle mass. It should be noted that the Astrand nomogram already takes body mass into account to estimate oxygen uptake per kilogram body mass (but not muscle mass).

The strength of this study was the comparison of the associations of relative muscle mass, absolute muscle mass, and muscle strength with physical performance, both in young and old participants. The inclusion of a large group of cognitively active and healthy participants across Europe minimizes the influence of diseases and cognitive impairment but makes the fact that results cannot be generalized to the entire elderly population. Recruitment of young participants through advertisement may lead to a selection of motivated participants and may not be representative for the entire young population Even though old participants were healthy and not likely to suffer from sarcopenia, age differences between young and old participants on diagnostic criteria for sarcopenia were clearly present. Results were analyzed using continuous data rather than dichotomizing on cutoff values. Therefore, we cannot conclude on the use of cutoff values in sarcopenia. A weakness of this study is the cross-sectional design, which makes causal inference impossible.

In conclusion, when comparing different diagnostic criteria for sarcopenia, relative muscle mass was associated most consistently with physical performance, while ALM/height squared was only associated with physical performance after adjustments for fat mass were applied. This understanding is essential for the medical and scientific community to develop clinically applicable diagnostic criteria for sarcopenia.

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Conflict of interest None

Ethical approval The local medical ethical committees of the respective institutions approved the study. Written informed consent was obtained from all participants.

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