Chapter 5

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^2 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 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^2 was not associated with physical performance. This should be accounted for when defining sarcopenia.

Introduction

Sarcopenia has been associated with self reported mobility limitations (1), cognitive decline (2), and mortality (3). The onset of age related loss of muscle mass occurs as early as 30 years of age, with a decrease of 1 to 2 percent after the age of 50 years, and results in a loss of over 50 percent by the age of 80 years (1;4). 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 appendicular lean mass (ALM) corrected for height (ALM/height^2) or total lean mass), muscle strength, walking speed or a combination of criteria (5;6). Previously, we have shown that the prevalence of sarcopenia is highly dependent on the diagnostic criteria (7).

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 (8-10). However, expressing muscle mass in a different way, such as the absolute muscle mass (ALM/height^2), has led to conflicting results with some studies showing an association with self-reported mobility limitations and physical performance (1;10), and others finding no significant relationship between absolute muscle mass and physical performance (11-13). There are also mixed reports from studies relating muscle strength with physical performance. For instance, muscle strength was associated with self-reported mobility limitation (9;14), and physical performance (9;12), but this is not a consistent finding (13). 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 mass, 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 and old 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 recruited in Leiden, the Netherlands, 105 in Jyvaskyla, Finland, 100 in Tartu, Estonia, 62 in Paris, France and 84 in Manchester, United Kingdom.

Exclusion criteria were aimed to ensure selection of healthy participants and minimize the confounding effect of comorbidity on sarcopenia. In short, exclusion criteria were: 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), haemocoagulative syndromes), use of medication (immunosuppressive drugs, insulin), immobilization for 1 week during the last 3 months, and orthopedic surgery during the last two years or still causing pain or functional limitation.

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; United Kingdom: 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 (8), and appendicular lean mass (ALM) percentage as the sum of lean mass of both arms and legs divided by body mass in percentage (12).

To obtain absolute muscle mass, ALM/height^2 was calculated as ALM divided by height squared (1), 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, New York, 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 degrees. Lever arm length was recorded as the distance between the knee axis of rotation and the centre 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 (MVC) force of the knee extensor muscles. For each attempt, maximal force or torque was recorded. Each trial was separated by one minute of rest. Knee extension torque was obtained either directly or by multiplying recorded peak force with the lever arm length (in m). 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 six-minute walking test. Participants were instructed to walk around cones placed 20 meters apart (or 25 meters 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.

Time needed to complete the Timed Up and Go test (TUG) was measured. Participants were instructed to rise from a chair without use of arms, walk around a cone placed three meters 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 maximal oxygen uptake (VO_2 max) according to the Astrand fitness test (15). This method has been shown to be a valid test in elderly participants (aged 60 to

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/m2)	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^2 (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. [a]Data available in n=344. [b]Excessive alcohol used defined as for males > 21 units/week and females > 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 available in a subgroup of n=108. MMSE: mini mental state examination. GDS: geriatric depression scale. TUG: Timed Up and Go test. ALM: appendicular lean mass.

70 years) (16). Participants pedalled at a cadence of 60 cycles per minutes (rpm) on a cycle ergometer at a selected workload (50, 75, 100 or 150 Watt) during six minutes. The workload was selected by asking subjects about their daily activity level and training status, and by taking 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 minute (bpm) after six minutes. Heart rate was measured continuously during the test using a polar heart rate monitor (Polar RS800CX, polar pro trainer 5). After a four minute warming up at a lower workload, the six minute 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 six minutes, if tolerated by the participant (17). The Astrand nomogram was used to calculate physical fitness (ml/kg/min) from submaximal heart rate, workload, body mass and gender (15).

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 measure of disease severity. Cognitive function was measured by use of the Mini Mental State Examination (MMSE) and depressive symptoms were measured by using the Geriatric Depression Scale (GDS).

Statistical analysis

Continuous variables with 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 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^2 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^2 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. P-values < 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 young participants.

Diagnostic criteria for sarcopenia and physical performance

Muscle mass

Table 2 shows the association between relative and absolute muscle mass 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

Table 2: Association between diagnostic criteria for sarcopenia and performance in 6 minute walk and Timed Up and Go test.

		Walking speed (SD in m/sec)						Timed Up and Go test (SD in sec)					
		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/height² (kg/m² 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. [a]Lean mass as percentage of total body mass; [b]ALM as percentage of total body mass. ALM: appendicular lean mass. All p-values are assessed with linear regression and adjustments in separate models. Bold indicates significance (p<0.05).

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/height² (kg/m² 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. [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. ALM: appendicular lean mass. All p-values are assessed with linear regression and adjustments in separate models. Bold indicates significance (p<0.05).

slightly. There were no associations between absolute muscle mass (ALM/height^2 and total lean mass) and walking speed or TUG. Only when additional adjustment for fat mass was applied, ALM/height^2 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 minute walking test.

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

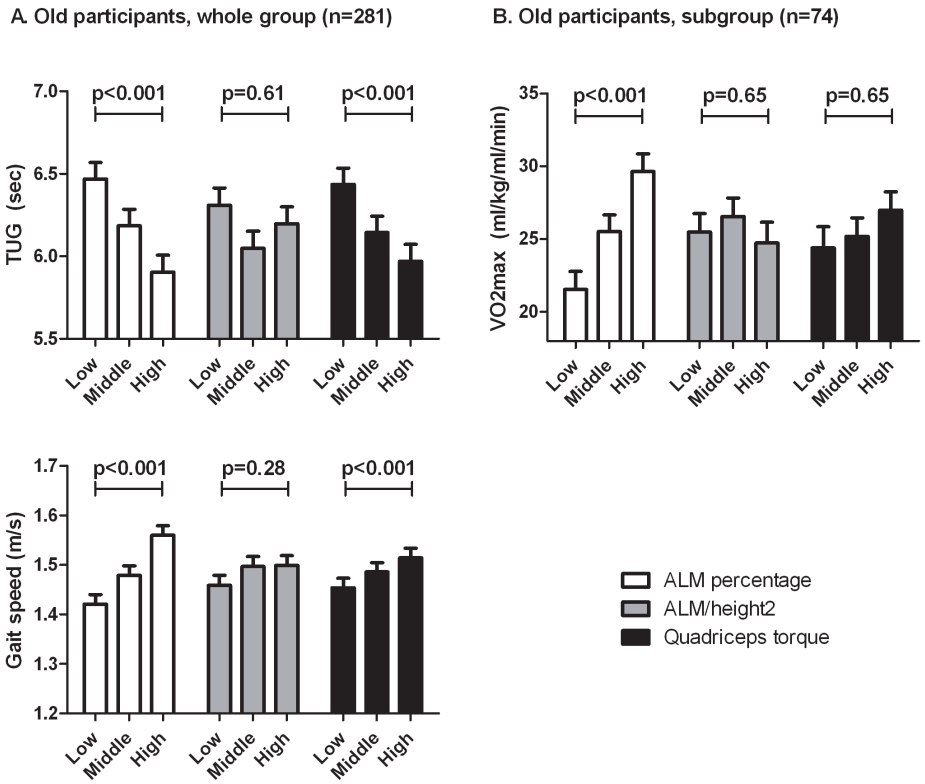

Figure: *Representation of the association between sex and country specific tertiles of different diagnostic criteria for sarcopenia and physical performance in old participants. Physical performance in A: Timed Up and Go test (TUG) and walking speed derived from 6 minutes walking test; in B: Physical fitness expressed as the estimate of maximal oxygen uptake as derived from Astrand fitness test. Muscle characteristics are ALM as percentage of body mass, ALM divided by height squared (ALM/height2) 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). ALM: appendicular lean mass.*

strength and physical fitness in young and old participants were found.

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 Table 2 and Table 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^2 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 lean mass percentage or ALM percentage was most associated with physical performance in old participants. Absolute muscle mass, expressed as ALM/height^2 and total lean mass, was only associated with TUG after adjustment for fat mass, and not associated with walking speed and physical fitness. This indicates that diagnostic criteria for sarcopenia based on unadjusted ALM/height^2 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 (8-10;12). Although the formula ALM/height^2 proposed by Baumgartner et al. (1) is the most commonly used diagnostic criterion for sarcopenia, we found no association between ALM/height^2 and physical performance without adjusting for fat mass. Studies reporting significant associations between ALM/height^2 and physical performance included adjustment models for fat percentage (1) or fat mass (10), which is in line with the present study, although we assessed ALM/height^2 on a continuous scale. Without

adjustments for fat mass, absence of an association between ALM/height^2 and physical performance or self-reported physical limitation is confirmed by other studies (11-13;18-20). In addition, no association was observed between total lean mass in kilograms and self-reported mobility limitation (14).

Differences between relative and absolute muscle mass 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 (9;21). With increasing chronological age, significant changes in body composition occur, 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 (19;22). The formula ALM/height^2 underestimates sarcopenia in obese elderly and overestimates sarcopenia in underweight elderly participants (19;21;23). Therefore, it is important to take muscle mass relative to body mass or fat mass into account when defining sarcopenia (18;21;24).

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 (9;12;14;25), but not in all studies (13). 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 (25). It has been suggested that muscle strength in the elderly is associated with physical performance rather than muscle mass (25-27). However, in these studies, muscle mass was not adjusted for fat mass or body mass, indicating possible misclassification of low muscle mass (23). The loss of muscle mass is closely related to the loss of muscle strength, although not at the same rate (26). 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 (28-30). Furthermore, muscle strength can be underestimated due to pain (4;23).

In young participants, no association was found for diagnostic criteria for saropenia 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 six minute 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 kg 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, although results cannot be generalized for the entire elderly 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 cut-off values. Therefore we cannot conclude on the use of cut-off 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^2 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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