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The definition of sarcopenia

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Chapter 8

Muscle strength rather than muscle mass is associated with standing balance in elderly outpatients

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Abstract

Objectives: Assessment of the association of muscle characteristics with standing balance is of special interest as muscles are a target for potential intervention, i.e. by strength training.

Design: Cross-sectional study

Setting: Geriatric outpatient clinic

Participants: The study included 197 community-dwelling elderly outpatients (78 males, 119 females, mean age 82 years).

Measurements: Muscle characteristics included handgrip and knee extension strength, appendicular lean mass divided by height squared (ALM/height^2), and lean mass as percentage of body mass. Two aspects of standing balance were assessed: the ability to maintain balance, and the quality of balance measured by Center of Pressure (CoP) movement during ten seconds of side-by-side, semi-tandem and tandem stance, with both eyes open and eyes closed. Logistic and linear regression models were adjusted for age, and additionally for height, body mass, cognitive function and multimorbidity.

Results: Handgrip and knee extension strength, adjusted for age, were positively related to the ability to maintain balance with eyes open in side-by-side (p=0.011; p=0.043), semi-tandem (p=0.005; p=0.021) and tandem stance (p=0.012; p=0.014), and with eyes closed in side-by-side (p=0.004; p=0.004) and semi-tandem stance (not significant; p=0.046). Additional adjustments affected the results only slightly. ALM/height^2 and lean mass percentage were not associated with the ability to maintain standing balance, except for an association between ALM/height^2 and tandem stance with eyes open (p=0.033) that disappeared after additional adjustments. Muscle characteristics were not associated with CoP movement.

Conclusion: Muscle strength rather than muscle mass was positively associated with the ability to maintain standing balance in elderly outpatients. Assessment of CoP movement was not of additional value.

Introduction

Among 37 million elderly aged over 65 years, 7 million reported impaired standing balance in the past 12 months in the National Health Interview Survey in 2008 (1). Standing balance is dependent on integrated functioning of the sensory systems (vestibular, visual, and proprioceptive system), neural control, and muscle characteristics. These systems degenerate with increasing chronological age, by cumulative tissue damage, specific diseases and medication use (2-6). Muscle characteristics are of special interest, as recent evidence suggests that strength training can improve muscle strength and muscle mass, even in elderly (7-9). To develop targeted interventions for impaired standing balance in elderly outpatients, it is important to understand the contribution of muscle strength and muscle mass to standing balance.

In healthy elderly it was shown that muscle strength is associated with the ability to maintain standing balance (10;11). Quadriceps muscle mass has also been associated with the ability to maintain standing balance in healthy elderly (12). Besides the ability to maintain standing balance, the quality of balance can be assessed additionally by measuring the Center of Pressure (CoP) movement. In healthy elderly, muscle mass (12;13) but not muscle strength has been associated with CoP movement (14-16).

It remains unknown if associations between muscle characteristics and standing balance are present in elderly outpatients, while this group is obviously of clinical interest. These outpatients are more likely to suffer from multimorbidity and deterioration in more than one system involved in standing balance (11;17;18). Only few studies describe the association between muscle characteristics and standing balance in elderly with mobility difficulties, often applying exclusion criteria for co-morbidity or severe mobility limitations (19;20). We assessed the association between muscle characteristics and two aspects of standing balance, the ability to maintain balance as well as the CoP movement, in community-dwelling elderly referred to a geriatric outpatient clinic.

Methods

Setting

This cross-sectional study included 207 community-dwelling elderly who were referred to a geriatric outpatient clinic in a middle-sized teaching hospital (Bronovo Hospital, The Hague, Netherlands) for a comprehensive geriatric assessment (CGA) between March 2011 and January 2012. CGA was performed during a two hour visit including questionnaires and physical and cognitive measurements. All tests were performed by trained nurses or medical staff. Medical charts were retrospectively evaluated. The study was reviewed and approved by the institutional review board of the Leiden University Medical Center (Leiden, the Netherlands). Because this research is based on regular patient care, the need for individual informed consent was waived. In the present analyses, 10 elderly outpatients (4.8%) were excluded due to missing data on standing balance, leaving 197 outpatients for analyses.

Elderly outpatient characteristics

Questionnaires included information on marital status, current smoking, alcohol use and living arrangements. Anthropometric data included assessment of body mass, height and body mass index. Information on diseases and use of medication was extracted from medical records. Multimorbidity was rated as the presence of two or more diseases, including chronic obstructive pulmonary disease, heart failure, diabetes mellitus, hypertension, malignancy, myocardial infarction, Parkinson's disease, (osteo)arthritis, transient ischemic attack and stroke. The Hospital Anxiety and Depression scale (HADS) was used to detect depressive symptoms (21). A score higher than 8 out of 21 points indicated depressive symptoms. Global cognitive function was assessed using the Mini Mental State Examination (MMSE) (22). Physical functioning was self-reported in a questionnaire with questions on experienced falls during the last 12 months, walking difficulties, impaired standing balance and use of walking aids. Physical functioning was assessed with a 10 meter walking test at usual pace in steady state, and with the short physical performance battery (SPPB) (23). The SPPB comprises the ability to maintain balance in three different standing positions with eyes open, a timed four meter walk, and a timed sit-to-stand test.

Standing balance

The ability to maintain standing balance

The ability to maintain standing balance was tested in different standing conditions. Elderly outpatients, wearing non slip socks, were instructed to maintain balance for 10 seconds in each standing condition. Three different standing positions characterized by a progressive narrowing of the base of support were performed both with eyes open and eyes closed. During side-by-side stance, elderly outpatients were instructed to stand with the medial malleoli as close together as possible; during semi-tandem stance, elderly outpatients were standing with the medial side of the heel of one foot touching the big toe of the other foot; during tandem stance, elderly outpatients were standing with both feet in line while the heel of one foot

Table 1: Elderly outpatient characteristics.

	All (n=197)	Male (n=78)	Female (n=119)
Age, years	81.9 (7.1)	80.7 (6.8)	82.7 (7.2)
Widowed, n (%) [a]	80 (41.5)	17 (21.8)	63 (54.8)
Living arrangements, n (%) [a]			
Institutionalized	0 (0)	0 (0.0)	0 (0.0)
Sheltered	40 (20.6)	13 (16.9)	27 (23.1)
Independent	154 (79.4)	64 (83.1)	90 (76.9)
Current smoking, n (%) [b]	22 (16.2)	9 (16.1)	13 (16.3)
Excessive alcohol use, n (%) #	8 (4.1)	5 (6.4)	3 (2.5)
Body mass, kg	71.8 (15.5)	78.7 (12.1)	67.3 (15.8)
Height, cm	167 (10)	176 (7)	161 (6)
BMI, kg/m2	25.8 (4.5)	25.5 (3.6)	25.9 (5.0)
Multimorbidity, n (%) c, †	95 (50.3)	43 (55.1)	52 (46.8)
Number of medication, median (IQR) c	5 (3-7)	6 (3-7)	5 (2-7)
Depressive symptoms, n (%) d, ‡	28 (23.1)	17 (30.9)	11 (16.7)
MMSE, points; median (IQR)	27 (24-29)	27 (25-29)	27 (24-29)
Gait speed, m/s	0.87 (0.29)	0.93 (0.31)	0.83 (0.27)
SPPB, points; median (IQR)	7 (5-10)	8 (6-10)	7 (5-9)
Self-reported functioning, n (%)			
Fall incident previous 12 months	127 (64.5)	45 (57.7)	82 (68.9)
Walking difficulties [a]	143 (73.0)	52 (66.7)	91 (77.1)
Use of walking aid [a]	108 (55.1)	33 (42.9)	75 (63.0)
Impaired standing balance [a]			
Never	34 (17.4)	10 (12.8)	24 (20.5)
Sometimes	73 (37.4)	33 (42.3)	40 (34.2)
Regularly	57 (29.2)	24 (30.8)	33 (28.2)
Always	31 (15.9)	11 (14.1)	20 (17.1)
Handgrip strength, kg	26.1 (8.2)	33.7 (6.2)	21.1 (4.9)
Knee extension strength, N [b]	202 (96)	261 (108)	162 (60)
ALM/height^2, kg/m^2 [b]	7.14 (1.20)	7.82 (0.84)	6.63 (1.19)
Lean mass percentage, % [b]	63.8 (8.9)	69.6 (6.6)	59.6 (7.9)

All parameters are presented as mean with standard deviation unless indicated otherwise. Data available in [a] n=194/195, [b] n=132, [c] n=189 and [d] n=121. # Defined as > 14 units per week for females or > 21 per week for males. †Present in outpatients with two or more diseases, including chronic obstructive pulmonary diseases, decompensatio cordis, diabetes mellitus, hypertension, malignancy, myocardial infarction, Parkinson's disease, (osteo)arthritis, transient ischemic attack and stroke. ‡Present with a depression subscore of >8 on the Hospital Anxiety and Depression Scale. IQR: inter quartile range. MMSE: Mini Mental State Examination. SPPB: Short Physical Performance Battery. ALM: appendicular lean mass.

touched the toes of the other. Standing positions were first assessed with eyes open as part of the SPPB (23). Subsequently, all standing positions were repeated with eyes closed. The elderly outpatients were allowed three trials if standing balance was lost prematurely. When the elderly outpatients could not complete a standing position, consecutive positions were not performed. Six elderly outpatients did not attempt the standing positions with eyes closed due to lack of time or lack of motivation, leaving 191 outpatients for analyses of standing balance conditions with eyes closed.

Center of Pressure movement

All standing conditions were performed on a triangular six degrees of freedom force plate (Forcelink B.V., Culemborg, The Netherlands) to measure CoP movement. Only successful trials, i.e. completion of 10 seconds of maintaining balance without stepping out in case of loss of balance, were considered for further analyses (i.e. n=183 were able to maintain balance in side-by-side stance). Because of missing data due to technical problems (n=18) and unknown reasons (n=29), CoP movement was available in 136 elderly outpatients (in side-by-side stance eyes open). Time series of CoP movement in medio-lateral and anterior-posterior direction were used to calculate single CoP parameters (24). Direction specific CoP composite scores were calculated from standardized single CoP parameters (mean amplitude, amplitude variability, mean velocity, velocity variability and range), in anterior-posterior (AP) and medial-lateral (ML) direction (25). As age related differences in CoP movement are most pronounced in ML direction (25) analyses are shown in ML direction. Analyses in AP direction are given in supplementary tables.

Muscle characteristics

Muscle strength

Handgrip strength was measured using an isometric hand dynamometer (JAMAR hand dynamometer, Sammons Preston, Inc., Bolingbrook, IL, USA). Outpatients were instructed to maintain an upright standing position with their arms along the side, while holding the dynamometer in one hand. The width of the dynamometer's handle was adjusted to hand size such that the middle phalanx rested on the inner handle. Three trials were performed alternately for each hand. Outpatients were actively encouraged to squeeze with maximal strength. The best performance of all trials was used for analyses.

Isometric knee extension strength was measured in a seated position with hips and knees in 90 degrees by a force transducer mounted in a chair (Forcelink B.V., Culemborg, The Netherlands). Outpatients were asked to push with maximal effort against a cuff positioned just above the talocrural joint. Holding on to the armrest of the chair or leaning backward was allowed, but not rising from the seating. This was checked by the investigator and corrected if necessary. Three trials were performed for each leg. The best performance of all trials was used for analyses. Structural measurement of knee extension strength was added to the CGA in May 2011.

Muscle mass

Body composition was measured using a direct segmental multi-frequency bioelectrical impedance analysis (BIA, InBody 720, Biospace Co., Ltd, Seoul, Korea). This technique has been shown to be a valid tool for the assessment of whole body composition and segmental lean measurements (26). The elderly outpatients wore normal indoor clothing and were instructed to stand barefoot on the machine platform holding a sensor in each hand. Two formulas were used to represent muscle mass. ALM/height^2 was calculated as the sum of lean mass in all four limbs (appendicular lean mass (ALM)) divided by the height squared (4). Lean mass percentage was calculated as total lean mass as percentage of total body mass (27).

In case of inability to stand on the machine platform without assistance for two minutes (n=5), wearing compressive stockings (n=22), having a pacemaker (n=15), or unknown reasons (n=14), BIA was not assessed. After exclusion of data due to technical problems (n=9) valid BIA data were available in 132 elderly outpatients.

Statistical analyses

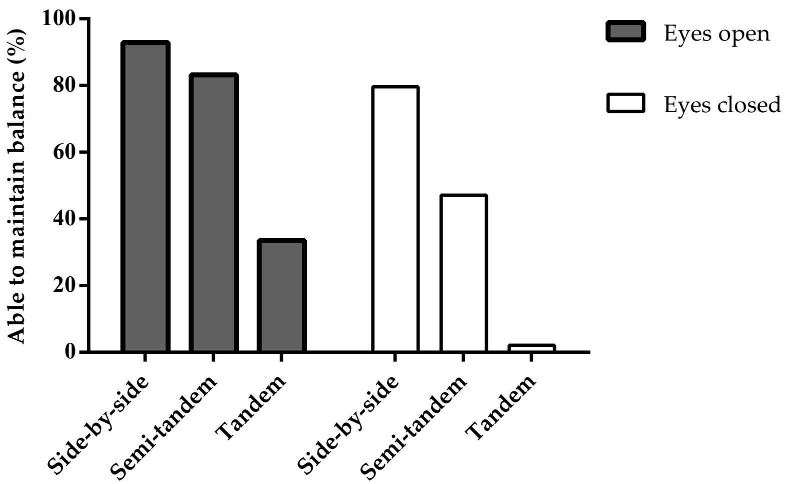

Figure 1: *Percentage of elderly outpatients able to maintain balance in the different standing positions with eyes open and eyes closed.*

Continuous variables with Gaussian distribution are presented as mean and standard deviation, otherwise as median and interquartile range or number and percentage. All muscle characteristics were standardized into sex-specific z-scores. The association between standardized muscle characteristics and the ability to maintain standing balance was analyzed using logistic regression with adjustment for age. Additional adjustment models included body mass, height, MMSE score and multimorbidity. The association between muscle characteristics and CoP movement was studied using linear regression with the same adjustment models. Statistical analyses were performed using SPSS for Windows (SPSS Inc, Chicago, USA), version 20. P values <0.05 were considered statistically significant.

Results

Elderly outpatient characteristics

The characteristics of elderly outpatients are presented in Table 1. Mean age was 81.9 years. 64.5 Percent of the elderly outpatients had at least one fall incident in the 12 months prior to the visit to the outpatient clinic.

Standing balance

Ability to maintain standing balance

The percentage of elderly outpatients able to maintain balance in different standing conditions is shown in Figure 1. In more difficult standing conditions, less elderly outpatients were able to maintain standing balance. In the standing positions with eyes open 183 elderly outpatients (92.9%) were able to maintain side-by-side stance, 164 (83.2%) semi-tandem stance and 66 (33.5%) tandem stance. In standing positions with eyes closed 152 elderly outpatients (79.6%) were able to maintain side-by-side stance, 90 (47.1%) semi-tandem stance and 4 (2.1%) tandem stance.

Center of Pressure movement

Table 2 shows the CoP movement represented by different CoP parameters used for calculating composite scores in anterior-posterior (AP) and medio-lateral (ML) direction. CoP parameters were higher in more difficult standing conditions.

Muscle characteristics and standing balance

Muscle strength

The association between muscle strength and the ability to maintain balance in different standing conditions is displayed in Table 3. Elderly outpatients with a

Table 2: CoP movement, represented by CoP parameters, within elderly outpatients able to maintain different standing positions with eyes open and eyes closed in anterior-posterior and medio-lateral direction.

	Side-by-side		Semi-tandem		Tandem	
	AP	ML	AP	ML	AP	ML
Eyes open (available)	(n=136)		(n=120)		(n=56)	
Mean amplitude (cm)	0.56 (0.02)	0.60 (0.02)	0.61 (0.04)	0.72 (0.03)	0.74 (0.04)	0.72 (0.03)
Range (cm)	3.38 (0.11)	3.51 (0.13)	3.88 (0.19)	4.25 (0.18)	4.94 (0.28)	3.92 (0.17)
Mean velocity (cm/s)	5.51 (0.10)	4.09 (0.10)	5.89 (0.13)	4.78 (0.13)	6.85 (0.22)	5.41 (0.21)
Amplitude var (cm)	0.71 (0.02)	0.75 (0.03)	0.77 (0.04)	0.91 (0.04)	0.95 (0.05)	0.88 (0.04)
Velocity var (cm/s)	7.87 (0.14)	5.70 (0.14)	8.41 (0.22)	6.76 (0.23)	9.88 (0.38)	7.55 (0.28)
Eyes closed (available)	(n=119)		(n=75)			
Mean amplitude (cm)	0.74 (0.03)	0.85 (0.03)	0.78 (0.04)	1.03 (0.04)	n.a.*	
Range (cm)	4.38 (0.15)	4.86 (0.17)	4.91 (0.25)	5.64 (0.23)		
Mean velocity (cm/s)	6.59 (0.15)	5.67 (0.14)	7.24 (0.24)	6.76 (0.26)		
Ampltiude var (cm)	0.93 (0.03)	1.06 (0.04)	0.99 (0.05)	1.27 (0.05)		
Velocity var (cm/s)	9.09 (0.20)	7.88 (0.20)	10.02 (0.34)	9.33 (0.37)		

Data are given in mean and standard error. *Not applicable, number of patients able to maintain the task is less than 5. AP = anterior-posterior direction, ML = medio-lateral direction, var=variability.

higher handgrip strength or knee extension strength were significantly more likely to be able to maintain standing balance for ten seconds in all standing conditions, except for handgrip strength and semi-tandem stance with eyes closed. Further adjustments for body mass, height, MMSE score, and multimorbidity, attenuated the associations, but overall significance remained.
Handgrip strength and knee extension strength were not associated with CoP movement in ML (Table 4) and in AP (Table 5) direction.

Muscle mass
Table 3 displays the association between muscle mass and the ability to maintain standing balance in different standing conditions. There was no association between ALM/height^2 or lean mass percentage and the ability to maintain standing balance, except for a positive association between ALM/height^2 and tandem stance with eyes open that disappeared in the fully adjusted model.
Both indices of muscle mass, ALM/height^2 as well as lean mass percentage, were not associated with the CoP movement in ML (Table 4a) and in AP (Table 4b) direction.

Table 3: Association between muscle characteristics and ability to maintain balance in different standing positions with eyes open and eyes closed.

		Side-by-side			Semi-tandem			Tandem		
		OR	95% CI	P	OR	95% CI	P	OR	95% CI	P
Eyes open	Handgrip strength									
	Model 1	2.81	1.27-6.21	0.011	1.98	1.23-3.18	0.005	1.58	1.11-2.26	0.012
	Model 2	2.17	0.89-5.33	0.09	1.78	1.07-2.95	0.026	1.59	1.09-2.31	0.016
	Model 3	2.16	0.85-5.45	0.11	1.69	1.01-2.81	0.046	1.47	1.00-2.16	0.050
	Knee extension strength									
	Model 1	3.87	1.04-14.36	0.043	2.11	1.12-3.99	0.021	1.67	1.11-2.51	0.014
	Model 2	5.33	1.14-24.96	0.034	2.38	1.21-4.68	0.012	1.78	1.16-2.74	0.008
	Model 3	5.34	1.04-27.33	0.045	2.11	1.06-4.23	0.035	1.76	1.11-2.78	0.016
	ALM/height^2									
	Model 1				0.81	0.48-1.35	0.41	1.57	1.04-2.39	0.033
	Model 2[a]				0.64	0.34-1.21	0.17	1.57	1.03-2.41	0.038
	Model 3[a]		n.a.		0.65	0.34-1.24	0.19	1.44	0.85-2.46	0.18
	Lean mass percentage									
	Model 1				1.24	0.69-2.20	0.47	0.96	0.66-1.40	0.82
	Model 2[b]				1.26	0.70-2.26	0.45	0.95	0.65-1.39	0.78
	Model 3[b]				1.69	0.87-3.30	0.12	0.90	0.60-1.36	0.62
Eyes closed	Handgrip strength									
	Model 1	1.94	1.24-3.03	0.004	1.11	0.80-1.54	0.54			
	Model 2	2.03	1.26-3.30	0.004	1.17	0.83-1.66	0.37			
	Model 3	2.00	1.22-3.27	0.006	1.19	0.83-1.71	0.34			
	Knee extension strength									
	Model 1	2.62	1.37-5.03	0.004	1.5	1.01-2.23	0.046			
	Model 2	3.33	1.61-6.89	0.001	1.72	1.13-2.63	0.012			
	Model 3	2.95	1.40-6.18	0.004	1.74	1.11-2.73	0.017			
	ALM/height^2								n.a.	
	Model 1	0.99	0.60-1.62	0.95	0.87	0.59-1.29	0.50			
	Model 2[a]	1.02	0.55-1.89	0.95	0.98	0.59-1.62	0.94			
	Model 3[a]	1.00	0.54-1.85	1.00	0.96	0.56-1.64	0.88			
	Lean mass percentage									
	Model 1	1.30	0.77-2.20	0.33	1.16	0.80-1.68	0.44			
	Model 2[b]	1.30	0.77-2.19	0.33	1.16	0.80-1.69	0.43			
	Model 3[b]	1.41	0.80-2.48	0.23	1.23	0.83-1.83	0.31			

All muscle characteristics were standardized in gender-specific Z-scores. Ability to maintain standing balance: 0=unable, 1=able. Model 1: adjusted for age, model 2: as model 1 and body mass and height, model 3: as model 2 and MMSE score and multimorbidity. [a] not adjusted for height. [b] not adjusted for body mass. n.a.: not applicable, number of elderly outpatients able or unable to maintain the standing condition is less than 5. MMSE: mini mental state examination. ALM: appendicular lean mass.

Discussion

Muscle strength is positively associated with the ability to maintain standing balance in community-dwelling elderly referred to a geriatric outpatient clinic. Muscle mass did not associate with the ability to maintain standing balance in most balance conditions, although a positive association was found between ALM/height^2 and tandem stance with eyes open. Muscle strength and muscle mass were not associated with quality of balance as measured with CoP movement. This is the first study that examines different muscle characteristics in association with the ability to maintain standing balance as well as CoP movement during standing balance in a population of elderly outpatients without any exclusion criteria.

When comparing the present study to previous studies, two aspects need to be considered. First, no exclusion criteria were applied in the present study, which contrasts other studies including healthy elderly. Elderly outpatients are more likely to have multimorbidity and deterioration in more than one system involved in standing balance (11;17;18). Second, "balance" is inconsistently defined in literature for standing (static) and dynamic balance, i.e. not as isolated standing conditions, but as the score from SPPB (23), a sum score of the three foot positions (10;20), or as different dynamic balance tests as assessed with the Timed Up and Go test, walking speed, or chair-stand test (19). It has been shown that standing balance tests are different from dynamic balance tests (28;29). Therefore we discuss our results with respect to studies that measured standing balance (also called quiet stance, or static balance).

To the best of our knowledge, there are no studies describing the association of muscle strength with both the ability to maintain standing balance and the CoP movement during standing balance in elderly. In line with this study, a positive association between muscle strength and the ability to maintain balance has been described in healthy elderly (10;11) as well as elderly with mobility difficulties (19;20) aged 65 years and older. In 985 elderly women with mobility difficulties, those with a higher knee extension strength had a higher ability to maintain balance in side-by-side, semi-tandem, and tandem stance with eyes open (20). The association between muscle strength and standing balance was not present in previous studies evaluating quality of standing balance by CoP movement in healthy elderly (14-16;28;30). This is also in line with our study, as no association was found between muscle strength and CoP movement. However, a positive association between muscle strength and CoP movement has also been reported in healthy elderly (13) and women with osteoporosis (31).

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Table 4a: Association between muscle characteristics and CoP movement in medio-lateral direction in different standing positions with eyes open and eyes closed.

	Side-by-side			Semi-tandem			Tandem		
	Beta	SE	P	Beta	SE	P	Beta	SE	P
Eyes open (available)	*(n=136)*			*(n=120)*			*(n=56)*		
Handgrip strength									
Model 1	−0.08	0.08	0.33	0.02	0.09	0.86	−0.09	0.13	0.52
Model 2	−0.10	0.09	0.23	−0.03	0.09	0.78	−0.15	0.14	0.27
Model 3	-0.09	0.09	0.34	−0.03	0.10	0.78	−0.14	0.15	0.33
Knee extension strength									
Model 1	−0.02	0.08	0.77	0.03	0.07	0.64	0.04	0.14	0.78
Model 2	−0.01	0.09	0.92	0.07	0.07	0.31	0.01	0.14	0.95
Model 3	0.01	0.09	0.88	0.07	0.08	0.35	0.02	0.15	0.88
ALM/height^2									
Model 1	0.06	0.09	0.54	-0.04	0.12	0.75	-0.12	0.12	0.30
Model 2[a]	0.06	0.12	0.64	-0.17	0.17	0.31	-0.25	0.16	0.14
Model 3[a]	0.10	0.12	0.42	-0.17	0.18	0.34	-0.19	0.17	0.28
Lean mass percentage									
Model 1	0.09	0.09	0.33	0.01	0.10	0.96	-0.06	0.10	0.55
Model 2[b]	0.07	0.09	0.45	-0.03	0.10	0.78	-0.09	0.11	0.41
Model 3[b]	0.10	0.10	0.31	-0.04	0.11	0.74	-0.07	0.11	0.51
Eyes closed (available)	*(n=119)*			*(n=75)*					
Handgrip strength									
Model 1	0.09	0.08	0.30	0.10	0.10	0.32			
Model 2	0.06	0.08	0.46	0.08	0.11	0.47			
Model 3	0.05	0.09	0.55	0.05	0.12	0.67			
Knee extension strength									
Model 1	0.14	0.10	0.15	0.23	0.12	0.06			
Model 2	0.17	0.10	0.08	0.27	0.13	0.033			
Model 3	0.14	0.10	0.16	0.17	0.14	0.23		n.a.	
ALM/height^2									
Model 1	0.06	0.11	0.60	0.04	0.17	0.82			
Model 2[a]	-0.10	0.15	0.53	-0.04	0.25	0.88			
Model 3[a]	-0.07	0.15	0.65	0.06	0.27	0.81			
Lean mass percentage									
Model 1	-0.02	0.09	0.80	0.11	0.13	0.43			
Model 2[b]	-0.06	0.09	0.53	0.04	0.13	0.78			
Model 3[b]	-0.10	0.09	0.28	0.03	0.15	0.85			

(Table legend for Table 4a and 4b) All muscle characteristics were standardized in gender-specific Z-scores. Model 1: adjusted for age, model 2: as model 1 and body mass and height, model 3: as model 2 and Mini Mental State Examination and multimorbidity. [a]: not adjusted for height. [b]:not adjusted for body

Table 4b: Association between muscle characteristics and CoP movement in anterior-posterior direction in different standing positions with eyes open and eyes closed.

	Side-by-side			Semi-tandem			Tandem		
	Beta	SE	P	Beta	SE	P	Beta	SE	P
Eyes open (available)	*(n=136)*			*(n=120)*			*(n=56)*		
Handgrip strength									
Model 1	0.04	0.08	0.62	0.05	0.08	0.58	0.03	0.12	0.81
Model 2	0.07	0.08	0.37	0.002	0.09	0.98	−0.01	0.13	0.96
Model 3	0.07	0.08	0.37	−0.01	0.09	0.93	−0.05	0.14	0.70
Knee extension strength									
Model 1	0.05	0.08	0.48	−0.01	0.07	0.91	−0.06	0.14	0.69
Model 2	0.11	0.08	0.18	0.02	0.07	0.76	−0.08	0.15	0.63
Model 3	0.13	0.08	0.11	0.02	0.07	0.75	-0.06	0.16	0.73
ALM/height^2									
Model 1	-0.18	0.09	0.04	0.03	0.11	0.80	-0.19	0.12	0.11
Model 2[a]	-0.18	0.11	0.11	-0.12	0.16	0.45	-0.23	0.17	0.18
Model 3[a]	-0.15	0.11	0.19	-0.11	0.16	0.50	-0.22	0.18	0.22
Lean mass percentage									
Model 1	0.10	0.08	0.24	0.00	0.09	0.96	-0.03	0.11	0.82
Model 2[b]	0.09	0.09	0.28	-0.02	0.10	0.80	-0.04	0.11	0.75
Model 3[b]	0.14	0.09	0.14	-0.02	0.10	0.85	-0.04	0.12	0.75
Eyes closed (available)	*(n=119)*			*(n=75)*					
Handgrip strength									
Model 1	0.06	0.08	0.45	−0.11	0.10	0.28			
Model 2	0.05	0.08	0.54	−0.14	0.10	0.17			
Model 3	0.05	0.08	0.57	-0.18	0.11	0.11			
Knee extension strength									
Model 1	0.11	0.09	0.21	0.04	0.12	0.74			
Model 2	0.17	0.09	0.06	0.07	0.13	0.57			
Model 3	0.15	0.09	0.12	0.01	0.14	0.93			
ALM/height^2								n.a.*	
Model 1	-0.05	0.11	0.68	0.22	0.15	0.16			
Model 2[a]	-0.14	0.14	0.32	-0.42	0.23	0.08			
Model 3[a]	-0.08	0.15	0.61	-0.31	0.25	0.23			
Lean mass percentage									
Model 1	0.02	0.09	0.87	0.02	0.13	0.89			
Model 2[b]	-0.01	0.09	0.93	-0.04	0.13	0.76			
Model 3[b]	0.00	0.09	1.00	-0.02	0.14	0.91			

(continued from Table legend 4a) mass. n.a.: not applicable, number of elderly outpatients able to maintain the balance condition is less than 5. ALM: appendicular lean mass.

No association between measures of muscle mass and the ability to maintain standing balance was found in the present study. A limited number of studies describe the association between muscle mass and ability to maintain standing balance (12;27). A positive association has been described between quadriceps muscle mass and one-leg standing time in healthy elderly (12). Furthermore, Janssen et al. reported a positive association between lean mass percentage and the ability to maintain balance in tandem stance in males aged over 60 years (27). Previous research on the association between muscle mass and CoP movement is limited, reporting a positive association for quadriceps muscle mass (12), and no association for lean mass divided by height squared (14).

The fact that in the current study muscle strength was found to be associated with the ability to maintain standing balance rather than muscle mass, is explained by the differences between the characteristics "muscle strength" and "muscle mass". Muscle strength appears to decline more with age than muscle mass (32-35). Other factors in addition to muscle mass are important to generate muscle strength such as neural control, cognition, cardiovascular and joint function (35). Furthermore, due to pain muscle strength may be underestimated (36;37). Muscle tissue is not only a force generator, but has an important function as an internal organ, i.e. involved in glucose metabolism (38;39). Maintenance of standing balance obviously reflects the role of muscle as a strength generator (35;40). In this respect, this article provides further evidence to include assessment of muscle strength in clinical practice (41-43).

A possible explanation for the absence of an association between muscle characteristics and CoP movement could be selection of the fittest. CoP movement could only be assessed in outpatients who completed the standing balance conditions. Another explanation is large heterogeneity among elderly outpatients: the presence of multimorbidity and the deterioration of multiple systems involved in standing balance, i.e. sensory systems and neural control may interfere with the association between muscle characteristics and CoP movement (11;17;18). For instance, in patients with an intact sensory system and neural control, a higher muscle mass or strength may be associated with low CoP movement. In patients with deterioration of the sensory or neural system, high muscle strength could also be the result of repetitive use of muscles as compensatory strategy. For these patients, higher muscle mass or strength would therefore be associated with higher CoP movement. A decline of distinct systems and compensatory strategies can result in comparable CoP movement (44). In fact, lower CoP movement may not be related to better quality of standing balance, despite previously described differences in CoP movement between young and old adults (25).

The question arises whether an increase in muscle strength does improve standing balance in elderly outpatients. Physical exercise and training programmes have been shown to be beneficial in elderly, as they lead to an increase of muscle mass, muscle strength and even neuromuscular activity (45;46), although not all trials show a positive effect (47). Suppletion of hormones (48), vitamin D, or nutrients (46;49) may increase or prevent further decrease of muscle mass and strength. However, evidence is still very weak, as large scale placebo controlled intervention studies for long term effects of interventions are missing. Regarding strength training, a systematic review of randomized controlled trials including elderly showed a positive effect of resistance training to improve balance in 18 of 33 randomized controlled trials. These studies included a range of methods (static and dynamic) to measure 'balance' (50). Two of these randomized controlled trials included elderly with mobility difficulties (51;52): one trial found an improved balance after training in a small number of elderly in the intervention group (51), and one trial found no effect on balance (52).

Strength of this study was the combined analyses of both muscle strength and muscle mass with the ability to maintain standing balance and CoP movement. The population of elderly outpatients is unique as there were no exclusion criteria. By assessing the ability to maintain standing balance in elderly outpatients, results of this study will be highly relevant in clinical practice. The heterogeneity of the study population implies that larger numbers of outpatients need to be assessed to relate outcome measures to function of specific systems involved in standing balance, i.e. sensory systems and neural control. Another limitation is the cross-sectional design, which prevents assessments causal inference.

Conclusion

Muscle strength rather than muscle mass is associated with the ability to maintain standing balance in community-dwelling elderly referred to a geriatric outpatient clinic. This indicates the additional value of assessment of muscle strength in clinical practice. Improvement of muscle strength is a target for potential intervention for impaired standing balance in this population of elderly outpatients with multimorbidity.

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