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Regional and total muscle mass, muscle strength and physical performance: The potential use of ultrasound imaging for sarcopenia

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ABSTRACT

Objective: To evaluate the relationship between the regional and total muscle mass, muscle strength and physical performance, and also to investigate the affected muscles, their strength and physical performance with aging.
Methods: A total of 145 healthy subjects were included for the cross-sectional descriptive study. Demographic data were obtained, and body composition was consecutively assessed by anthropometric methods, bioelectrical impedance analysis and ultrasound (muscle thickness, fascicule length and pennation angle). Functional status was assessed using hand grip strength and gait speed measurements.
Results: Abdominal and thigh muscles were thinner and triceps muscle was thicker in older subjects when compared with younger ones. Age and grip strength were significant predictors for physical performance. Gait speed, grip strength and regional muscle measurements decreased with age at higher rates (26–28%), skeletal muscle mass index was affected at a lower rate (15%).
Conclusions: Low muscle strength and regional muscle measurements should be used to confirm the diagnosis of sarcopenia.

1. Introduction

Muscle tissue can be evaluated/scanned by ultrasound (US) imaging in details. Its assessment has become even more important with increasing clinical attention to dynapenia (low muscle power) (Chang, Wu, Huang, Jan, & Han, 2018; Morley et al., 2011; Yamada et al., 2017) and sarcopenia i.e. low muscle strength and low muscle quality/quantity (Cruz-Jentoft et al., 2019). Sarcopenia is related to adverse outcome such as increased mortality, functional disability, risk of fall, cognitive impairment and depression (Beaudart, Zaaria, Pasleau, Reginster, & Bruyère, 2017; Chang, Chen et al., 2018; Chang, Hsu, Wu, Huang, & Han, 2016; Chang, Hsu, Wu, Huang, & Han, 2017). Yet, US can provide the assessment of muscle thickness and architecture (Kuyumcu et al., 2016) and it was shown to be a valid and reliable method (Ishida, Carroll, Pollock, Graves, & Leggett, 1992; Kwah, Pinto, Diong, & Herbert, 2013). It has been shown that quadriceps muscle thickness was positively correlated with muscle strength both in young people and elderly. In addition, pennation angle was positively correlated with muscle strength in young people, but not in elderly (Strasser, Draskovits, Praschak, Quittan, & Graf, 2013).

In routine clinical practice, regional and total muscle mass assessments are evaluated by different equipment. Herewith, US is readily available in majority of clinical settings and can be promptly used in the evaluation of patients at risk for sarcopenia (Ozcakar, Ata, Kaymak, Kara, & Kumbhare, 2018; Özçakar, Ata, Quittan, & Michail, 2018). To the best of our knowledge, there is no comprehensive/comparative study as regards sonographic quantification of several muscles, anthropometric measurements, total muscle mass, muscle strength and physical performance. Accordingly, the objective of this study was to evaluate the relationship between the regional and total muscle mass, muscle strength and physical performance, and also to investigate the affected muscles, their strength and physical performance with aging.

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Table 1
Ultrasonographic measurement sites.

Region	Site
Anterior arm	1/3 anterior distal level between the acromion and the antecubital fossa
Posterior arm	1/3 posterior distal level between the acromion and the antecubital fossa
Anterior forearm	2/5 anterior proximal level between the antecubital fossa and the ulnar styloid
Posterior forearm	2/5 posterior proximal level between the antecubital fossa and the ulnar styloid
Abdomen	2 cm lateral and 2 cm distal to the umbilicus level
Low back	L4-5 level
Anterior thigh	Anterior mid-point between the ASIS and the superior pole of patella
Posterior thigh	Posterior mid-point between the ischial tuberosity and the popliteal fossa
Anterior leg	1/4 anterior proximal level between the inferior pole of patella and the ankle
Calf	The bulkiest area

ASIS; anterior superior iliac spine.

2. Methods

2.1. Study design and participants

A total of 145 healthy adults were included from a tertiary care university hospital. Subjects who had cardiac pacemaker, metallic implant, severe edema, hypothyroidism, diabetes mellitus, renal/hepatic failure, neuromuscular diseases or amputees were not included in the study. All eligible participants were informed about the study procedure and those who consented to participate were evaluated further. The study protocol was approved by the local ethics committee.

Demographic data were obtained using face-to-face interviews. All US measurements (Table 1) were performed on the non-dominant side of the body, at selected sites, and in accordance with the previous literature (Arts, Pillen, Schelhaas, Overeem, & Zwarts, 2010; Bazzocchi et al., 2014; Wilson et al., 2016). Muscle strength was assessed by grip strength and physical performance was evaluated by gait speed. All assessments were performed by a single physiatrist (AMA), with four years of experience in musculoskeletal US. The validity and reliability of the evaluation methods have been shown previously (Cartwright et al., 2013; Fransen, Crosbie, & Edmonds, 1997; Ishida et al., 1992; Mathiowetz, Weber, Volland, & Kashman, 1984; Müller et al., 2013; Nijholt, Scafoglieri, Jager-Wittenaar, Hobbelen, & Schans, 2017).

2.2. Anthropometric assessments

All assessments were performed following an overnight fasting, with empty bladder and wearing light clothes without any metallic objects. Participants' weight, height, extremity circumferences, waist and hip circumferences were measured to the nearest 0.1 kg and 1 cm, using standardized procedures.

2.3. Bioelectrical impedance analysis

Bodystat quadscan 4000 device (Florida, USA) using a multi-frequency, tetrapolar technique was used as the participants were in supine position with their arms slightly abducted from the trunk and legs slightly separated. Electrodes were placed on the dorsal surfaces of the metacarpophalangeal and wrist joints, and metatarsophalangeal and ankle joints. Fat mass and fat-free mass were measured, and then skeletal muscle mass index (SMI) was calculated with (fat-free mass × 0.566) / height^2 formulation (Bahat et al., 2016).

2.4. Ultrasonographic measurements

A 5–12 MHz linear probe (Logiq P5, GE, Medical Systems, USA) was used. It was set to measure at a frequency of 10 MHz, with a gain of 54 dB and a depth of 8 cm. All US images were obtained without any compression (using plenty of gel), when the subject lied in supine and prone position. The thicknesses of muscles (distance between fasciae) were measured in the axial view at the same point (Fig. 1). Additionally, fascicle length and pennation angle were measured between the two parallel aponeuroses of the gastrocnemius muscle (bulkiest part of medial head) in the longitudinal view when subjects were in prone position with their ankles at 90° (Fig. 1).

2.5. Grip strength and gait speed evaluations

Grip strength was evaluated with Jamar dynamometer (Baseline Hydraulic Hand dynamometer Irvington, NY, USA), which was used at the second handle position while the subjects were in sitting position, their shoulders adducted and neutrally rotated, elbows flexed at 90°, and the forearms/wrists kept in neutral position. Gait speed was assessed by a chronometer. Subjects were asked to walk at their usual pace over a 6-meter course. They were instructed to stand with both feet touching the starting line and to start walking after the command. Timing began when the command was given, and completed at the end of the course. Three measurements (for gait speed, and grip strength in both hands) were obtained and the mean values were calculated for each participant.

As muscle mass and strength increase up to ˜40 years of age, maintain in midlife and then decrease after the age of 50 years (Cruz-Jentoft et al., 2019); we divided the participants into two groups, as those < 50 years of age (Group I; n = 98), and those ≥ 50 years of age (Group II; n = 47).

2.6. Statistical analysis

Statistical analyses were performed using the SPSS software version 23. Numeric variables are presented as mean ± standard deviation. The goodness of fit test of numeric variables to normal distribution was determined using Shapiro-Wilk's ($n < 50$) or Kolmogorov-Smirnov ($n > 50$) tests. The difference between independent groups was tested by Student's *t*-test if normality assumption was satisfied; otherwise, Mann Whitney U test was used. Correlations were assessed using Pearson or Spearman correlation coefficients, where appropriate.

Multiple linear regression model using the backward elimination method was used to reach the most parsimonious, yet, statistically significant model. The criteria value to consider the variables for the multivariate analyses was $p < 0.10$. β (standardized coefficients) for all independent variables (other than the grip strength) included in the regression equations (range of values: −1 to 1), r^2 (coefficient of determination) and r (correlation coefficient) values) (for the total model; Model 1) were analyzed. Alternatively, the grip strength was added together with the other significant variables included in the Model 1 (Model 2). Statistical significance was set at $p < 0.05$.

3. Results

Demographic and clinical data are given in Table 2. A total of 145 healthy subjects (45 M, 100 F) aged 18–83 years were enrolled. Most of the subjects (N = 134, 92.4%) were right-handed. The younger subjects

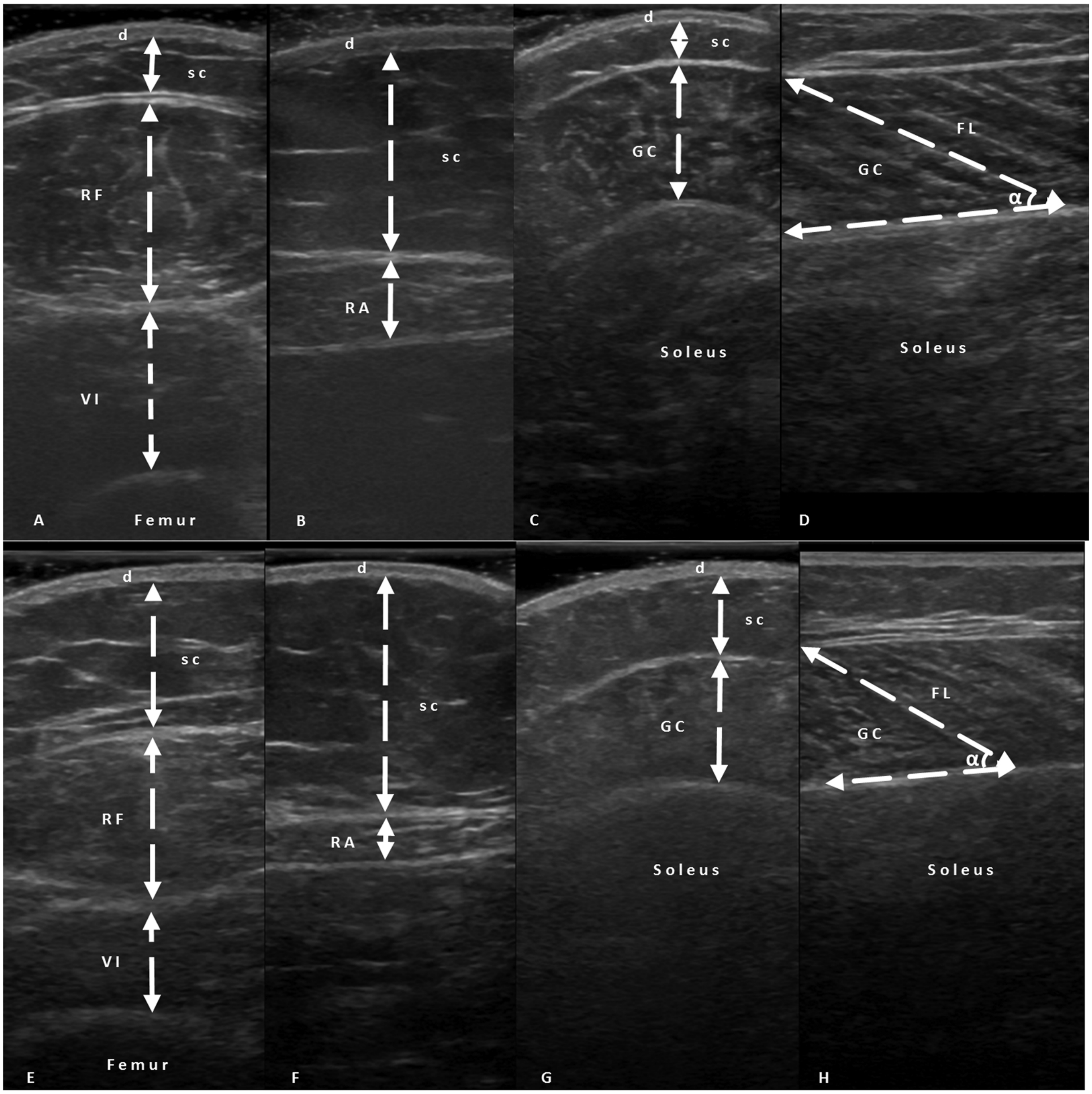

Fig. 1. Axial ultrasound images of the rectus femoris (RF), vastus intermedius (VI), rectus abdominis (RA) and medial head of the gastrocnemius (GC) muscles in a healthy young adult (A,B,C) and an older subject (E,F,G), respectively. Corresponding longitudinal images of the GC muscle show pennation angle (α) and fascicle length (FL).
d; *dermis, sc*; *subcutaneous fat tissue.*

(aged < 50 years) were taller than the older ones ($p < 0.001$). Waist, hip and arm circumference values were higher in older subjects. Gait speed and grip strength values were higher in younger subjects (both $p < 0.001$). SMI was similar between the two groups ($p > 0.05$). In the older group; 31 patients (66.0%) had lower values (below 2SD) than the gender-matched healthy young adult values for any of the following parameters (Table 3) (Bahat et al., 2016; Chen et al., 2014; Cruz-Jentoft et al., 2019; Minetto et al., 2016): SMI, grip strength, gait speed and rectus femoris (RF) muscle thickness (Fig. 2A). Two patients (4.3%) had low SMI (both of them had also low grip strength and low gait speed). If we consider regional muscle measurements (rather than SMI) for sarcopenia diagnosis/confirmation; additional six patients (12.8%) would have sarcopenia, two patients (4.3%) would have regional sarcopenia, and seven subjects would have dynapenia (Fig. 2A).

Ultrasound (US) measurements are given in Table 4. Abdominal (rectus abdominis (RA) and thigh (RF, vastus intermedius and biceps femoris) muscle thicknesses were found to be thinner and triceps muscle was thicker in the older subjects than the younger ones (all $p < 0.05$). The other muscle thicknesses, pennation angle and fascicle length of the gastrocnemius muscle were found to be similar between the groups (all $p > 0.05$).

According to the correlation analyses, gait speed was correlated with age ($r = -0.675$), grip strength ($r = 0.415$), gender ($r = 0.281$), height ($r = 0.417$), waist circumference ($r = -0.402$), and RA ($r = 0.407$), multifidus ($r = 0.239$), RF ($r = 0.237$) and biceps femoris ($r = 0.285$) muscle thicknesses (all $p < 0.01$)). When stepwise multiple linear regression analysis was performed (Table 5); age, height and RF muscle thickness (Model 1) were found to be significant predictors for gait speed ($r = 0.724$, $r^2 = 0.524$). When grip strength was added to Model 1 (Model 2); only age and grip strength were significant predictors for gait speed ($r = 0.774$, $r^2 = 0.599$) (Table 5). Age was the strongest predictor (with a higher standardized regression coefficient)

Table 2
Comparison of the clinical characteristics of the groups.

Characteristic	Group I (Age < 50, n = 98)	Group II (Age ≥50, n = 47)	p
Age (year)	30.7 ± 8.5	66.5 ± 8.9	**< 0.001**
Gender (F/M)	66/32	34/13	0.341
Height (cm)	165.0 ± 10.4	161.4 ± 7.8	**< 0.001**
Weight (kg)	70.3 ± 13.4	72.9 ± 11.4	0.055
Circumference (cm)			
Waist	86.8 ± 11.9	98.4 ± 11.9	**< 0.001**
Hip	102.1 ± 8.1	105.8 ± 8.1	**0.022**
Arm	27.8 ± 3.3	30.7 ± 3.6	**< 0.001**
Forearm	23.7 ± 3.1	23.8 ± 3.9	0.808
Thigh	57.4 ± 5.9	59.1 ± 6.4	0.129
Calf	37.3 ± 3.9	36.7 ± 3.7	0.573
SMI (kg/m^2)	10.2 ± 1.5	9.8 ± 1.1	0.139
Gait speed (m/s)	1.57 ± 0.23	1.17 ± 0.30	**< 0.001**
Grip strength (kg)	31.6 ± 12.0	23.6 ± 9.9	**< 0.001**

BIA; bioelectrical impedance analysis, SMI; skeletal muscle mass index, F; female, M; male.
Data are given as ratio or mean ± standard deviation.

Table 3
Cut-off values* that are used for the evaluated parameters.

Parameters	Male	Female	Reference
SMI	9.2 kg/m^2	7.4 kg/m^2	Bahat et al. (2016)
Gait speed	1 m/sec	1 m/sec	Chen et al. (2014)
Grip strength	32 kg	19 kg	Dodds et al. (2014)
RF muscle thickness	20 mm	16 mm	Minetto et al. (2016)

SMI; skeletal muscle mass index, RF; rectus femoris.
* These values have been taken from the indicated references as 2 SD lower that the gender-matched healthy young individuals.

Table 4
Ultrasonographic measurements of muscle thicknesses (mm).

Muscle	Group I (Age < 50, n = 98)	Group II (Age ≥50, n = 47)	p
Biceps brachii	21.4 ± 4.8	20.6 ± 4.1	0.315
Brachialis	5.8 ± 3.0	6.7 ± 2.4	0.104
Triceps brachii	24.8 ± 9.3	31.4 ± 10.9	**< 0.001**
FDS	15.0 ± 3.0	14.3 ± 2.5	0.207
FDP	19.5 ± 3.9	18.8 ± 2.9	0.272
ECR	12.8 ± 3.4	12.3 ± 3.0	0.419
Rectus abdominis	10.8 ± 2.3	8.1 ± 2.2	**< 0.001**
Multifidus	33.1 ± 5.1	32.5 ± 5.7	0.118
Rectus femoris	22.4 ± 4.1	18.1 ± 4.6	**0.003**
Vastus intermedius	20.4 ± 5.4	16.1 ± 5.0	**0.030**
Biceps femoris	31.7 ± 6.8	27.8 ± 5.8	**< 0.001**
Tibialis anterior	26.2 ± 3.9	25.8 ± 3.4	0.495
Gastrocnemius	19.0 ± 3.2	17.0 ± 3.3	0.278
PA (°)	26.9 ± 5.4	26.2 ± 5.4	0.483
FL	39.7 ± 5.6	35.6 ± 6.8	0.304

FDS; flexor digitorum superficialis, FDP; flexor digitorum profundus, ECR; extensor carpi radialis, PA; pennation angle, FL; fascicle length.
Thickness values are given as mean ± standard deviation.

Table 5
Statistically significant predictors of gait speed.

Model	Independent variable	β	p	R	R^2	SEE
1[a]	**Age**	−0.575	< 0.001	0.724	0.524	0.20
	Height	0.196	0.007			
	Rectus femoris	0.150	0.023			
2[b]	**Age**	−0.590	< 0.001	0.774	0.599	0.18
	Grip strength	0.289	< 0.001			

β; standardized coefficients, R^2; coefficient of determination, R; correlation coefficient.
SEE; standard estimation error.
[a] The significant variables ($p < 0.10$ according to correlation analyses) included in Model 1; age, height, weight, gender, waist and hip circumferences, rectus femoris, rectus abdominis and multifidus muscle thicknesses and skeletal muscle mass index.
[b] After adding grip strength together with the other significant variables included in the Model 1.

for gait speed in both models.

When we grouped all the subjects according to decades; we observed that the most significant declines were in the gait speed (34%), grip strength (30%) and regional muscle thicknesses (RF; 26% and RA; 28%) between the ages of 30–83 years (Fig. 2B). On the other hand, SMI declined at the lowest rate (15%).

4. Discussion

We found that abdominal and thigh muscles were thinner and triceps muscle was thicker in older subjects when compared with younger ones. We also observed that only age and grip strength (not anthropometric and regional/total muscle mass measurements) were significant predictors for physical performance. Our preliminary findings demonstrated that while gait speed, grip strength and regional muscle

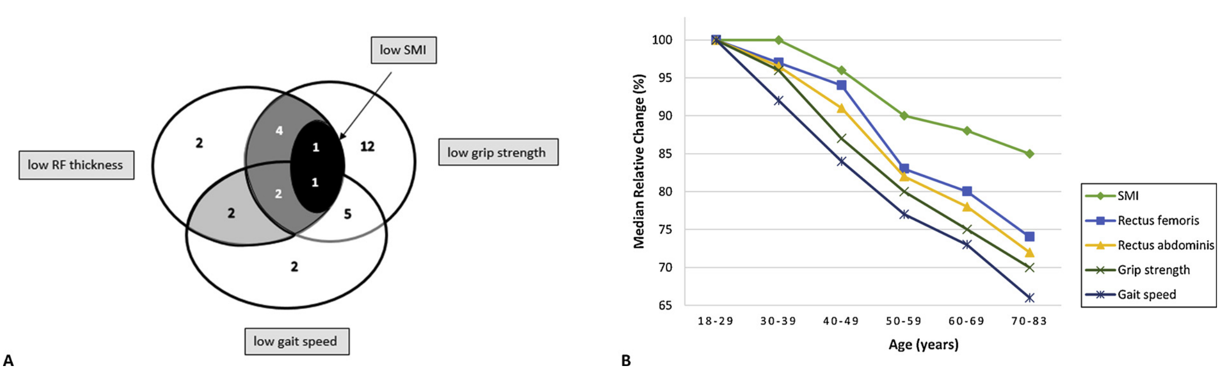

Fig. 2. A: The prevalence of sarcopenia in the older group (aged ≥ 50 years). 31 individuals (66.0%) had lower values (below 2SD) than those of the gender-matched healthy young adults for at least one of the following parameters; skeletal muscle mass index (SMI), grip strength, rectus femoris (RF) muscle thickness and gait speed.
Black intersection zone shows severe sarcopenia (low SMI + grip strength and/or gait speed); 1 + 1 = 2 subjects.
Dark grey intersection zone shows sarcopenia (low grip strength + low RF muscle thickness); 4 + 2 = 6 subjects.
Light grey intersection zone shows regional sarcopenia (low gait speed + low RF muscle thickness); 2 subjects.
B: Graphical demonstration for the median relative declines (%) in gait speed, skeletal muscle mass index (SMI), grip strength and regional muscle measurements between the ages of 30–83 years. Baseline median values at ages 18–29 were taken as 100%.

measurements (RF and RA) decreased with age at higher rates (26–28%), SMI was affected at a lower rate (15%). Therefore, when we use regional muscle measurements rather than total muscle mass; the prevalence of sarcopenia increases from 4.3% to 21.3%.

In our study, the abdominal and thigh muscles were thinner in the older subjects than the younger ones. It has been previously reported that anterior thigh and abdominal muscles are the first affected muscles with aging (Abe, Kawakami, Kondo, & Fukunaga, 2011; Abe, Loenneke, Thiebaud, & Fukunaga, 2014; Abe, Sakamaki et al., 2011). This is related with reduced physical activity i.e. neuromuscular change with aging (Abe, Ogawa, Thiebaud, Loenneke, & Mitsukawa, 2014). Reduced number of motor fibers (and also their motor neurons) are seen in lower extremities. Type 2 fast twitch muscle fibers are affected more than type 1 slow twitch fibers. The muscle fiber reduction starts earlier, especially in the RA and anterior thigh muscles (Aagaard, Suetta, Caserotti, Magnusson, & Kjær, 2010). On the contrary, the upper extremity muscles are less affected by aging (Hughes et al., 2001). Likewise, most of the upper extremity muscle thicknesses were not changed in our study. We imply that the increase in triceps muscle thickness could be compensatory, possibly due to repetitive use of the upper limb for push up from a sitting to standing position.

In our study, gait speed was associated with RF muscle thickness, but not with SMI. The regional muscle thickness seems to be more important for walking performance than total muscle mass measurements. However, if we add grip strength, gait speed was strongly/only associated with age and grip strength ($r^2 = 0.60$). This can be explained by the fact that regional muscle thicknesses and/or total muscle mass are less important/contributory for walking than muscle strength, and that decline in neuromuscular control (and muscle quality) with aging has a critical role for gait speed (Bohannon, 1997). With aging; gait speed and grip strength showed the highest decline, followed by muscle thicknesses and the SMI showing the lowest decline (15%). Longitudinal studies in the previous literature showed similar findings. For instance, in a 10-year follow-up study (examining the knee/elbow muscle strength and total muscle mass changes), the decrease in the lower extremity was more than the upper extremity and the total muscle mass (Hughes et al., 2001). Again, in a 12-year follow-up study evaluating the knee and elbow muscle strength and cross-sectional area (CSA); a decrease in strength about 29% in the lower extremity and 19–26% in the upper extremity were seen, while the reduction of CSA in all muscles were 12–16% (Frontera et al., 2000). Similarly, at a 5-year follow-up study, knee extensor strength decreased 13–16%, and the muscle CSA decreased 3–5% (Delmonico et al., 2009). All these studies show that lower limb strength is affected earlier than upper limb strength as well as regional and total muscle mass. This may be due to a decrease in neuromuscular activation. Likewise, a longitudinal study showed that although muscle power reduction was accompanied with loss of neuromuscular activation, there was no reduction in muscle CSA in healthy people (Reid et al., 2014). This may be related to compensatory mechanisms. Nonetheless, in light of our aforementioned findings, we can also arrive at a conclusion suggesting that RF muscle thickness be measured (for predicting gait speed or performance) where grip strength evaluation is not available/appropriate. Of additional note, to confirm the diagnosis of sarcopenia, measuring RF muscle thickness (instead of total muscle mass) might be sufficient.

For sarcopenia, it is suggested that muscle strength assessment should be performed initially, and if there is a decline, muscle mass should also be assessed (Cruz-Jentoft et al., 2019). Herewith, physical performance assessment is recommended only in the diagnosis of severe sarcopenia (Cruz-Jentoft et al., 2019). Of note, and as shown before, physical performance decline precedes the loss of total muscle mass (Frontera et al., 2000; Hughes et al., 2001). Similarly, in our study, gait speed - the parameter of physical performance – decreased at a higher rate with aging. As such, it may be more accurate to evaluate gait speed first. Actually, muscle power (performance) is the most rapidly affected parameter of the aging muscle and it is more related with mobility than strength but its evaluation requires special equipment (Bean et al., 2003; Hicks et al., 2011).

Concerning muscle mass measurements for the diagnosis of sarcopenia; it is been recently suggested that total muscle mass measurements are taken into account (Cruz-Jentoft et al., 2019). However, based on both our study findings and those of the literature, anterior thigh and abdominal muscles are affected initially. Yet, while the rate of decline in total muscle mass was only 15%; the rate of decline in RF and RA muscle thicknesses were 26% and 28%, respectively. To this end, assessment of these muscles (rather than total muscle mass) will definitely provide earlier detection about the muscle loss. More importantly, our results also ascertained that at the time of significant decrease in the total muscle mass, muscle strength and physical performance will have already be reduced. This, for sure, means that the subjects will have already become frail due to severe sarcopenia. For this reason, it seems more reasonable to measure local muscles (RF and RA) in subjects with low gait speed and/or low grip strength; and those with low values should be diagnosed as "sarcopenia" (or "regional sarcopenia" if the patient has normal grip strength but has low gait speed). Further, if we consider regional muscle measurements, additional 17% seems to be diagnosed as sarcopenia. Therefore, sarcopenia becomes not overlooked.

The major limitations of our study are its cross-sectional design and small sample size. Considering that especially the lower extremity muscles are affected with aging, the lack of power and strength assessment of the lower extremity muscles would be another drawback.

5. Conclusion

As total muscle mass shows only a mild decline and a weak/inconsistent predictor of physical performance with aging; together with low muscle strength, regional muscle measurements should be used to confirm the diagnosis of sarcopenia. Taking into account the increased burden of sarcopenia in aging populations, US can be a useful/appropriate method not only for assessing/confirming sarcopenia but also for qualitative and architectural assessments of the skeletal muscle. Further longitudinal studies with larger samples, also evaluating knee extensor power and strength are awaited.

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Declarations of interest

None.

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