Echo intensity is negatively associated with functional capacity in older women

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Abstract Muscle quality is an important component of the functional profile of the elderly, and previous studies have shown that both muscle quantity and quality independently contribute to muscle strength of the elderly. This study aimed to verify the association between quadriceps femoris muscle quality, analyzed by specific tension and echo intensity (EI), and rate of torque development (RTD) of the knee extensor muscles with the functional performance in elderly active women. Forty-five healthy, active elderly women (70.28 ± 6.2) volunteered to participate in this study. Quadriceps femoris muscle thickness and EI were determined by ultrasonography. Knee extension isometric peak torque and RTD were obtained from maximal isometric voluntary contraction curves. The 30-s sit-to-stand-up (30SS) test and usual gait speed (UGS) test were applied to evaluate functional performance. Rectus femoris EI presented a significant negative correlation with 30SS ($r = -0.505$, $P < 0.01$), UGS ($r_s = -0.347$, $P < 0.05$), and

isometric peak torque ($r = -0.314$, $P < 0.05$). The quadriceps femoris EI correlated negatively with 30SS ($r = -0.493$, $P < 0.01$) and isometric peak torque ($r = -0.409$, $P < 0.01$). The EI of the quadriceps femoris and all quadriceps muscle portions significantly correlated with RTD. RTD significantly correlated with physical performance in both functional tests (30SS= $r = 0.340$, $P < 0.05$; UGS= $r_s = 0.371$, $P < 0.05$). We concluded that muscle EI may be an important predictor of functional performance and knee extensor power capacity in elderly, active women.

Keywords Muscle quality · Muscle power · Muscle strength · Ultrasonography

Introduction

The aging process is associated with significant alterations to the human body. One of the most important negative adaptations of aging is the loss of skeletal muscle mass, known as sarcopenia (Roubenoff and Hughes 2000; Doherty 2003; Muhlberg and Sieber 2004). Sarcopenia challenges functional capacity and balance and leads to an impaired quality of life and poor outcomes in hospitalized patients (Evans 1997; Candow 2011; Gariballa and Alessa 2013). In contrast with these consequences, it has been reported that sarcopenia explains only ~8 % of the decrease in skeletal muscle strength of older individuals (Delmonico et al. 2009). Part of the decline in muscle strength, associated with skeletal muscle wastage and sarcopenia,

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may be due to a reduced muscle quality (MQ), a measure proposed to be an important component of the functional profile of aged individuals (Wilhelm et al. 2014). While previous studies have shown that the muscle quantity and quality independently contribute to the muscle strength of middle-aged and elderly persons (Fukumoto et al. 2012; Watanabe et al. 2013), the precise contribution of these variables remains to be conclusively determined.

Muscle quality can be assessed using two different methodologies: specific tension (ST) and echo intensity (EI). ST is quantified by the quotient of strength produced per unit of active muscle mass and is suggested to be a superior indicator of muscle function than strength alone (Tracy et al. 1999). On the other hand, EI is assessed by ultrasonography using computer-assisted grayscale analysis and allows the measurement of the quantity of both muscle and noncontractile tissue (Walker et al. 2004; Pillen et al. 2009).

Previous cross-sectional studies aimed to evaluate the correlation between MQ measured by ST and EI and lower body muscle strength in elderly people. Mistic et al. (2007) postulated that ST was the best predictor of the maximal dynamic strength of the lower limb and gait speed in older adults. Similarly, Lynch et al. (1999) assessed knee extensor ST of men and women of various ages and reported a curvilinear age-associated decline in ST with accelerated reductions after the age of 50. ST may have an important influence in gait function of healthy, older adults, with a positive correlation observed with step and stance time (Shin et al. 2012). Finally, Volpato et al. (2012) verified that ST, as well as muscle strength and gait speed, was found to be decreased in older diabetic patients, when compared to age-matched controls. Additionally, EI also has been observed to be negatively correlated with strength and positively associated with age (Cadore et al. 2012; Fukumoto et al. 2012; Watanabe et al. 2013). Therefore, both ST and EI appear to be important features and predictors of strength capacity in the elderly. However, their association with functional tests performance remains unclear.

Muscle power, defined as the ability to develop a rapid rise in muscle force (Suetta et al. 2004), has been associated with functional performance in old age (Suzuki et al. 2001; Macaluso and De Vito 2004; Reid and Fielding 2012; Clark et al. 2013). The rate of torque development (RTD) is a safe and reliable method to measure the muscle power. Several factors related to

age affect RTD, such as co-activation and loss of skeletal muscle fibers (especially type II) (Pereira and Goncalves 2011; Nilwik et al. 2013). The relationship between the decline in ST and EI and how this may affect RTD have not been clearly demonstrated.

The aim of this study was to assess the relationship between quadriceps femoris MQ, using both ST and EI, and RTD of the knee extensor muscles and the functional performance of the lower body in elderly active women.

Methodological design

Participants

Forty-five elderly women participated in the present study. The participants were healthy and habitually physically active and were free from neurological, cardiovascular, and lower limb disease. All participants were informed of the possible risks and discomforts associated with the study, and written consent was obtained prior to participation. The study was conducted according to the Declaration of Helsinki, and all procedures were approved by the local institutional ethics committee.

Experimental procedures

The subjects visited the Exercise Research Laboratory (LAPEX) on three nonconsecutive days. On the first visit, the subjects were interviewed about their life habits and were classified as active, according to the International Physical Activity Questionnaire (IPAQ) (Craig et al. 2003). A familiarization session, involving all physical tests (i.e., the 30-s sit-to-stand-up test (30SS), isometric strength, and gait speed), was conducted to eliminate any learning effect associated with the experimental protocol. On visit 2, B-mode two-dimensional ultrasound (US) images were obtained for the measurement of muscle thickness (MT) and EI of the quadriceps femoris. Isometric strength tests were performed (handgrip and knee extensors), as well as the functional tests. On the last visit, participants had their anthropometric measurements acquired and body composition was measured by bioelectrical impedance (BIA).

Anthropometric measurements and bioelectrical impedance

Body weight, height, body mass index (BMI), and body composition were evaluated for the characterization of participants. Body weight (kilograms) was measured using a standard balance scale (Filizola, Brazil) and a linked stadiometer that was used to verify stature (meters). BMI was calculated as body weight (kilograms) divided by height square (square meters). Bioelectrical impedance was performed to access percent body fat (%BF), using a Maltron BF-906 Body Fat Analyzer (Maltron International, UK). Measurements were performed in the morning, between 7:30 and 9:00 a.m. The subjects arrived at the laboratory in a fasted state (8–10 h) and were instructed to avoid physical exercise for 8 h prior to arrival to avoid confounding factors such as diet, hydration status, and fatigue associated with recent exercise.

Muscle thickness and echo intensity evaluation

Ultrasound images were obtained using real-time B-mode ultrasonography (Nemio XG ultrasound, Toshiba, Japan). All ultrasound measurements were performed with a 38-mm, 9.0-MHz linear-array probe (depth 70 mm, gain 90 dB). Before measurements, the subjects rested in a supine position with their lower limbs relaxed and extended for 15 min to allow fluid shifts to stabilize (Berg et al. 1993). Transversal images of the right vastus lateralis (VL), rectus femoris (RF), vastus intermedius (VI), and vastus medialis (VM) muscles were acquired. A water-soluble gel was used to provide acoustic contact, and care was taken not to compress the dermal surface. The images from VL, RF, and VI muscles were obtained at 50 % of the distance between the lateral condyle of the femur and the greater trochanter, while the VM images were obtained at 30 % of the same distance.

Images of each muscle were analyzed using ImageJ 1.42q software (National Institute of Health, USA). Regions of interest, including as much muscle as possible but avoiding bone and surrounding fascia, were determined for EI calculation for all muscles of the quadriceps femoris. The mean EI of each muscle was determined using a standard histogram grayscale function and expressed as a value between 0 (black) and 255 (white) (rectus femoris echo intensity (RFEI), vastus lateralis echo intensity (VLEI), vastus intermedius echo

intensity (VIEI), vastus medialis echo intensity (VMEI)). The quadriceps femoris echo intensity (QEI) was calculated as the mean EI of the four individual quadriceps femoris muscles ($RFEI + VLEI + VIEI + VMEI / 4$). The test-retest reliability ICC of echo intensity is shown in previous study published by our group, in which echo intensity was studied in older women (Radaelli et al. 2013). The MT was determined as the distance between adipose tissue-muscle interface for VL, RF, and VM and as bone-muscle interface for VI. Whole quadriceps femoris muscle thickness (QMT) was obtained as the sum of the four individual quadriceps portions (Pinto et al. 2014).

Isometric peak torque, rate of torque development, and specific tension

Knee extension isometric peak torque (PT) and RTD were obtained from maximal isometric voluntary contraction (MIVC). MIVCs were performed on a Cybex Norm isokinetic dynamometer (Cybex Norm, USA), connected to a 2,000-Hz A/D converter (Miotec Equipamentos Biomédicos, Brazil) that allowed acquisition and exportation of data for RTD assessment. Subjects were seated with a hip flexion of 85° (0°=anatomic position) and the lateral femoral condyle of the right leg aligned with the axis of rotation of the dynamometer. A warm-up was performed (ten submaximal isokinetic knee extension/flexion repetitions at 120° s⁻¹) before the pretest was executed. One minute after the warm-up, subjects performed one submaximal isometric knee extension to re-familiarize with the testing commands and procedures from the familiarization session. Thereafter, three 5-s knee extensor MIVCs were performed at a knee joint angle of 60° (0°=knee fully extended), with a 90-s interval between trials. All subjects were instructed to “produce force as hard and fast as possible” after the start command and to avoid any possible countermovement before the initiation of the test. A MIVC with initial countermovement was discarded from the analysis. PT was determined by the dynamometer software (Humac version 9.6.2), and the highest PT of the three MIVCs was used for further analysis.

The RTD at 0–0.05, 0–0.1, 0–0.25, and 0–0.3 s was calculated in a custom-made Excel spreadsheet (Microsoft Corporation, USA) by the MIVC torque-time curve as $\Delta\text{torque}/\Delta\text{time}$, after the onset of muscular contraction, defined as the instant when the knee

extensor torque exceeded 7.5 N m^{-1} (Andersen and Aagaard 2006). All MIVCs were analyzed and the highest value obtained at each time point was selected for further analysis. The RTD generated at 0.05 and 0.1 s was assumed to be a measure of early RTD, while 0.25 and 0.3 s were assumed to be late RTD (Andersen and Aagaard 2006).

MQ evaluated by ST was calculated as PT divided by the sum of the MT of the four portions of the quadriceps femoris muscle, as previously proposed (Pinto et al. 2014). Thus, ST was assessed according to the following equation:

$$[\text{ST} = \text{knee extensors peak torque (N m}^{-1}) / \text{QMT (mm)}]$$

Handgrip strength test

Isometric handgrip strength was assessed in an isometric test using a manual dynamometer (Jamar, Brazil). The subjects were seated in a regular chair, without armrests, and were instructed to produce isometric force in the dominant arm over 6 s, with their shoulders adducted and elbow in a 90° flexion position (as the recommendations of the American Society of Hand Therapy). The mean result of three trials was used for further comparison.

Functional tests

To assess functional capacity, the 30SS test was performed with a standard chair (42 cm) (Jones et al. 1999). The subjects were seated on the chair with both hands crossed over their chest, with feet shoulder-width apart. Five submaximal repetitions were performed as a warm-up and, after a 30-s interval, the subjects completed the following functional test: After a verbal signal, subjects should rise to an upright position before returning to the initial position. The test was timed with a digital stopwatch, and subjects were instructed to perform as many repetitions as possible during a 30-s time period.

Usual gait speed (UGS) assessment was verified according to Cesari et al. (2005). Briefly, the subjects were instructed to stand with their feet behind a starting line and then to walk at their normal pace during a 6-m distance until the finish line. One-meter distance was given before the starting line to eliminate possible confounding factors such as acceleration and reaction time. The time was recorded with a digital stopwatch by an evaluator familiar with the test. Timing was started after the first footfall and stopped with the subject's first

footfall after the 6-m finish line. After two trials, the best time scored (meters per second) was considered for posterior analysis.

Statistical analysis

Statistical analysis was performed using SPSS version 13.0 (IBM, Somers, NY, USA). All values are reported as mean $\pm$ standard deviation (SD). The Shapiro-Wilk normality test was applied to verify the distribution of data. After assuming that the sample was normally distributed ($P > 0.05$), Pearson product-moment correlation coefficient (r) was used to determine correlations between parametric data. When the data did not present parametric distribution, Spearman's rank order correlation coefficient (r_s) was applied. Statistical significance was defined as $P < 0.05$.

Results

The physical characteristics of the participants, as well as ultrasound, strength, and functional measurements, are shown in Table 1. Table 2 shows the correlation coefficients between QEI, QMT, physical characteristics, and body composition. QEI showed a significant correlation with QMT, BMI, and %BF (correlation coefficient ranging from -0.572 to -0.446 , $P < 0.05$). QMT showed a positive correlation with both the BMI and %BF ($P < 0.05$). No variable presented any correlation with the age of the subjects.

Table 3 shows the correlation coefficients between the ultrasound measurements (QEI and QMT) and functional and strength tests. QEI correlated negatively with 30SS, MIVC, and handgrip strength (HS) (correlation coefficients ranging from -0.493 to -0.334 , $P < 0.01$); however, no correlation was found with UGS. QMT showed a significant and positive correlation with MIVC and HS and no correlation with the functional tests. HS showed a significant correlation with 30SS, UGS, and MIVC (correlation coefficients ranging from -0.308 to 0.516 , $P < 0.05$). The individual EI values for each portion of the quadriceps femoris are shown in Table 4. RFEI presented a significant correlation with all strength and functional tests applied (correlation coefficients ranging from -0.505 to -0.314 , $P < 0.05$). VLEI and VMEI presented a significant correlation with MIVC and 30SS (correlation coefficients ranging from

Table 1 Physical characteristics, ultrasound measurements, and physical performance of the subjects

	Mean±SD	Range
Physical characteristics		
Age (years)	70.28±6.2	60–83
Body weight (kg)	69.02±11.5	51.1–102.9
Height (m)	1.55±0.67	1.4–1.67
BMI (kg/m ²)	27.89±3.6	21.4–35.6
%BF	39.34±4.9	27.1–51.8
%MM	15.4±2.4	11.1–24.2
Ultrasound measurements		
VLEI (A.u.)	78.80±17.9	41.67–113.31
RFEI (A.u.)	89.1±18.04	49–128.8
VIEI (A.u.)	70.14±14.98	50.9–119.8
VMEI (A.u.)	77.6±16.01	43.8–112.38
QEI (A.u.)	79.2±13.5	52.6–100.9
QMT (mm)	70.4±10.8	49.5–91.4
Physical performance		
MIVC (N m)	108.09±28.7	61–163
30SS (repetitions)	12.9±2.3	8–19
UGS (m/s)	1.3±0.2	0.6–1.9
ST (N m/mm)	1.54±0.36	0.79–2.5
RTD at 0.05 s (N m/ms)	0.47±0.25	0.08–1.2
RTD at 0.1 s (N m/ms)	0.45±0.24	0.08–1
RTD at 0.25 s (N m/ms)	0.29±0.11	0.07–0.52
RTD at 0.3 s (N m/ms)	0.25±0.09	0.07–0.45
HS (kg)	24.7±5.3	10–36

BMI body mass index, *%BF* percent body fat, *%MM* percent muscle mass, *VLEI* vastus lateralis echo intensity, *RFEI* rectus femoris echo intensity, *VIEI* vastus intermedius echo intensity, *VMEI* vastus medialis echo intensity, *QEI* quadriceps echo intensity, *QMT* quadriceps muscle thickness, *MIVC* maximal isometric voluntary contraction, *30SS* 30-s sit-to-stand-up test, *UGS* usual gait speed, *ST* specific tension, *RTD* rate of torque development, *HS* handgrip strength

Table 2 Correlation coefficients between QEI, QMT, age, body mass index, and percent of body fat ($n=45$)

	QEI	QMT	Age	BMI	%BF
QEI (A.u.)	–	–0.572**	0.245	–0.446**	–0.472**
QMT (A.u.)		–	–0.183	0.341*	0.365*
Age (years)			–	–0.156	–0.155
BMI (kg/m ²)				–	0.896**

QEI quadriceps femoris echo intensity, *QMT* quadriceps femoris muscle thickness, *BMI* body mass index, *%BF* percent body fat

* $P<0.05$; ** $P<0.01$ (statistical difference)

–0.427 to –0.385, $P<0.05$), while VIEI only correlated with MIVC.

ST presented no significant correlation with any functional and strength tests. Table 5 shows the correlation coefficients between RTD, EI for each muscle of the quadriceps femoris, RFEI, QEI, QMT, and functional tests. VLEI was significantly correlated with the early and late RTDs. QEI was significantly correlated with the early (0–0.1 s) and late RTDs. Besides that, VIEI and VMEI correlated with the late RTD (0–0.25 and 0–0.3 s). MT showed a significant correlation with all RTD measures. The performance in the 30SS was correlated with the RTD at 0–0.1 s, as well as at the 0–0.25-s and 0–0.3-s time points (correlation coefficients ranging from 0.306 to 0.348, $P<0.05$). The USG correlated with the early 0–0.05-s and late 0–0.25-s and 0–0.3-s RTDs (correlation coefficients ranging from 0.299 to 0.393, $P<0.05$).

Discussion

The aim of the present study was to verify the association between morphologic proprieties of the knee extensors (EI, MT) with functional performance (30SS and UGS) and muscle strength (MIVC and RTD) of the knee extensors in active older women. This study shows that all EIs, except for VIEI, were significantly correlated with 30SS and RFEI was significantly correlated with both functional tests (30SS and UGS). Furthermore, functional tests, QMT, and all EIs were significantly correlated with RTD (Table 5). On the other hand, ST did not present a significant association with any functional test, suggesting that EI may be a better measure to estimate the functional capacity in active older women.

Pillen et al. (2009) evaluated the possible association between EI and the morphological features of the skeletal muscles in dogs. The authors concluded that EI may be an important tool for the assessment of structural aspects of the skeletal muscle tissue as it presented a significant correlation with the infiltration of fat and fibrous tissue (Reimers et al. 1993; Pillen et al. 2009). Accordingly, Arts et al. (2010) showed that the aging process can impact EI of different muscle groups, suggesting EI as a simple, painless, and costless method to access morphological modifications in older men and woman. Recently, Strasser et al. (2013) reinforced the importance of EI in the aging context. They showed that

Table 3 Correlation coefficients between QEI, QMT, functional, and strength tests ($n=45$)

	QEI	QMT	30SS	UGS	MIVC	HS
QEI (A.u.)	–	–0.572**	–0.493**	–0.270	–0.409**	–0.334*
QMT (A.u.)		–	0.136	0.153	0.509**	0.526**
30SS (reps)			–	0.498**	0.247	0.308*
UGS (s)				–	0.247	0.456**
MIVC (N.m)					–	0.516**

QEI quadriceps femoris echo intensity, *QMT* quadriceps femoris muscle thickness, *30SS* 30-s sit-to-stand-up test, *UGS* usual gait speed, *MIVC* maximal isometric voluntary contraction, *HS* handgrip strength

* $P<0.05$; ** $P<0.01$ (statistical difference)

EI of different portions of quadriceps femoris increased in the elderly, when compared with younger subjects.

In the present study, QEI significantly correlated with 30SS and MIVC, while a correlation between functional test performance and isometric strength (MIVC) was not observed. In addition, EI of all quadriceps portions was significantly correlated with MIVC, and only VIEI was not correlated with 30SS. The current results suggest that EI may be an important predictor of the functional capacity of active older women, more so than maximal muscle strength, and strategies to improve EI may result in an increased functional performance. In accordance with these results, Fukumoto et al. (2012), in a study of older women, found a significant negative association between RFEI and knee extension muscle strength, independently of the quantity of skeletal muscle mass. Similar results were found by Watanabe et al. (2013) who showed a significant negative association between RFEI and knee extensors' MIVC in older men. Likewise, Cadore et al. (2012) showed that RFEI correlated with maximal isometric and dynamic strength of

the knee extensors in older men. However, only Wilhelm et al. (2014) found a significant correlation between functional tests and EI in older men, suggesting that, in accordance with our results, EI may be a representative of functionality in both men and women.

The loss of muscle mass with aging is able to negatively affect the strength capacity in older men and women (Evans 1997). The MT is an ultrasound measure that estimates muscle quantity (Korhonen et al. 2009). We found a significant association between QMT and MIVC. These results are supported by evidence of a significant correlation between MT of all portions of the quadriceps femoris and MIVC (Strasser et al. 2013). In contrast to the present study, Fukumoto et al. (2012) and Watanabe et al. (2013) assessed the MT as the sum of the rectus femoris and vastus intermedius

Table 4 Correlation coefficients between individual echo intensity values for each portion of the quadriceps femoris and strength and functional tests ($n=45$)

	MIVC	30SS	UGS
RFEI (A.u.)	–0.314*	–0.505**	–0.347*
VLEI (A.u.)	–0.399**	–0.409**	–0.206
VIEI (A.u.)	–0.452**	–0.280	–0.152
VMEI (A.u.)	–0.385**	–0.427**	–0.195

RFEI rectus femoris echo intensity, *VLEI* vastus lateralis echo intensity, *VIEI* vastus intermedius echo intensity, *VMEI* vastus medialis echo intensity, *MIVC* maximal isometric voluntary contraction, *30SS* 30-s sit-to-stand-up test, *UGS* usual gait speed

* $P<0.05$; ** $P<0.01$ (statistical difference)

Table 5 Correlation coefficients between rate of torque development, echo intensity, and functional tests ($n=45$)

	RTD at 0–0.05 s	RTD at 0–0.1 s	RTD at 0–0.25 s	RTD at 0–0.3 s
RFEI (A.u.)	–0.268	–0.305*	–0.314*	–0.308*
VLEI (A.u.)	–0.426**	–0.441**	–0.417**	–0.644**
VIEI (A.u.)	–0.203	–0.303	–0.363*	–0.376*
VMEI (A.u.)	–0.236	–0.295	–0.355*	–0.384*
QEI (A.u.)	–0.290	–0.346*	–0.386*	–0.386**
QMT (A.u.)	0.385*	–0.465**	0.508**	0.545**
30SS (reps)	0.282	0.306*	0.340*	0.348*
UGS (m/s)	0.299*	0.284	0.371*	0.393**

RTD rate of torque development, *RFEI* rectus femoris echo intensity, *VLEI* vastus lateralis echo intensity, *VIEI* vastus intermedius echo intensity, *VMEI* vastus medialis echo intensity, *QEI* quadriceps femoris echo intensity, *QMT* quadriceps femoris muscle thickness, *30SS* 30-s sit-to-stand-up test, *UGS* usual gait speed

* $P<0.05$; ** $P<0.01$ (statistical difference)

MT, while we used the sum of all portions of the quadriceps femoris. However, our observations of significant correlations between MT and strength are in general agreement with previous published data (Fukumoto et al. 2012; Cadore et al. 2012; Watanabe et al. 2013; Wilhelm et al. 2014).

Recent studies observed that both muscle quantity and EI correlated with maximal isometric muscle strength in older women and men (Fukumoto et al. 2012; Watanabe et al. 2013; Wilhelm et al. 2014). Although we found a significant correlation between MT and strength tests, we could not observe any association between muscle quantity and functional capacity. Our results suggest that MT is associated only with maximal muscle strength, while EI may also be an important functional measure. Owing to the fact that EI may represent the composition of muscle with respect to infiltration of a noncontractile material, it could be a better estimator of muscle strength and functional capacity than muscle size itself.

Previous studies reported that ST, another method to access MQ, is decayed with the aging process in males and females and that older people may suffer from a progressive loss of muscle strength and quality (Lynch et al. 1999; Delmonico et al. 2009). No functional test was applied to ascertain if these changes in ST could culminate in some functional impairment, and our results showed no significant correlation between ST and any of the functional tests. This result was unexpected since ST is considered to be important for preventing functional disability (Tracy et al. 1999). Several studies found an increase in ST with strength training intervention followed by an increase in functional capacity (Reeves et al. 2004; Macaluso and De Vito 2004).

Although ST and EI are both considered as measures of MQ, our results suggest that EI may be a better indicator of muscle strength maximal capacity and functionality of knee extensors in active older women in a cross-sectional analysis. The MQ assessed by ST takes into account the whole quadriceps femoris and not individual muscle. However, our study indicates that the muscle composition (estimated by EI) of the quadriceps femoris may be more representative of muscle capacity. Pinto et al. (2014) reported a positive association between repetitions in 30SS and percent change ($\Delta\%$) of ST in elderly women after 6 weeks of strength training. Contrary to our study, the authors used one repetition maximum (1RM) test to assess maximal

strength capacity, which may explain the differences between these findings. Isometric test to assess maximal strength is extensively used in the literature and may present a different pattern of muscular activation in comparison to dynamic contractions (Gwin and Ferris 2012). Furthermore, our results showed that early and late RTDs correlated with both functional tests. The capacity to develop force rapidly has been associated with an increased risk of falls and postural sway in elderly people and is linked with morphological and neural features (Izquierdo et al. 1999; Klass et al. 2008; Bento et al. 2010; Lochynski et al. 2010; Edwen et al. 2013). RTD may be as much as 64 % lower in the older adults when compared with younger adults and even healthy aging can impair the neuromuscular capacity, limiting maximal rate of discharge by the motoneurons and leading to a less responsive muscle (Izquierdo et al. 1999; Klass et al. 2008; Edwen et al. 2013). Few studies evaluated RTD in a functional perspective; however, Edwén et al. (2013) studied the behavior of RTD along the life span, comparing men and women of 18 to 81 years old. The authors observed a decrease in the early RTD in elderly men and women that were not followed by decreases in maximal muscle strength. Moreover, Winters and Rudolph (2013) evaluated 26 older subjects with osteoarthritis and observed that the level of force at which the maximum RTD occurred was related to physical function. Several studies found an increased RTD concomitantly with a greater functional capacity as a consequence of strength training interventions in older subjects. However, these studies do not present correlation values for RTD and functional performance (Suetta et al. 2004; Caserotti et al. 2008; Helgerud et al. 2011). Thus, our results showed that, while MIVC did not present a significant association, RTD correlated with functional tests in the elderly population.

The variables QMT, RFEI, VLEI, and QEI also presented a significant correlation with the early and late RTDs. The capacity to develop force rapidly has been associated with muscle size and neuromuscular factors (Klass et al. 2008; Aagaard et al. 2010). However, the association between EI and RTD was not considered in previous studies. The results presented here suggest that EI, besides being important for functional capacity, may influence the power production of the knee extensors. It is interesting to note that VLEI presented the higher

correlation values with RTD, which indicates that the vastus lateralis may have more prominent participation in rapid force development than other quadriceps femoris portions.

Handgrip strength test has been considered as a practical method of determining the strength capacity in a clinical perspective (Bassey and Harries 1993). In addition to its simple acquisition, it has been shown to be an important descriptor of whole-body physical capacity and was associated with mortality in some pathological conditions (Yoda et al. 2012; Strasser et al. 2013). We found a significant positive association between HS and all physical tests applied (MIVC, 30SS, and UGS). This significant association was not expected, given that handgrip strength is not involved in the functional tests evaluated in this study. A satisfactory result in the HS test may indicate whole-body physical condition and may be applied even to estimate functional capacity of older subjects.

One consideration from the present study is the lack of association of QEI and age, a direct contrast to previous studies in this area (Arts et al. 2010). However, Arts et al. (2010) evaluated EI in different age groups, with the age of the participants varying between 15 and >80 years. The design chosen by the authors may have emphasized the effect of aging on EI. The present study evaluated only older women, which may be the reason for the lack of association. Besides that, our study utilized QEI as the mean EI of all quadriceps muscle portions, while Arts et al. (2010) evaluated only RFEI. This finding accentuates the importance of standardization of methods involving EI.

In summary, we found a negative association between EI and functional capacity, contrary to ST, which did not correlate with any functional test. The maximal isometric strength did not correlate with the functional tests; however, the early and late RTDs were positively associated with 30SS and UGS. Different measures of EI showed a negative association with RTD, suggesting a possible role in power production. Furthermore, handgrip strength may be an important tool for estimation of whole-body physical condition. We concluded that EI may be an important predictor of functional performance and knee extensor power capacity.

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