Relationship between quadriceps femoris echo intensity, muscle power, and functional capacity of older men

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Received: 6 October 2013 / Accepted: 28 January 2014 / Published online: 11 February 2014
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Abstract Increased proportion of non-contractile elements can be observed during aging by enhanced skeletal muscle echo intensity (EI). Studies have demonstrated that an increase in rectus femoris EI may affect physical performance. However, it is still unknown whether the whole quadriceps femoris EI (QEI) influences strength, power, and functional capacity of an older population. Therefore, the aim of the present study was to determine the correlation between QEI, the four individual quadriceps portions EI, and muscular performance of older men. Fifty sedentary healthy men (66.1 ± 4.5 years, 1.75 ± 0.06 m, 80.2 ± 11.0 kg) volunteered for the present study. The QEI and EI of the four quadriceps portions were calculated by ultrasound imaging. Knee extension one repetition maximum (1RM), isometric peak torque (PT), and rate of torque development (RTD) were obtained as measures of muscular strength. Muscular power was determined by knee extension with 60 % of 1RM and countermovement jump (CMJ). The 30-s sit-to-stand test was evaluated as a functional capacity parameter. QEI and all individual EI were correlated to functional capacity and power

during CMJ ($p \leq 0.05$), but rectus femoris EI was not related to knee extension average power ($p > 0.05$). There were significant correlations between all EI variables, 1RM, PT, and RTD at 0.2 s ($p \leq 0.05$), but only vastus medialis EI and QEI were correlated to RTD at 0.05 s ($p \leq 0.05$). The results of the present study suggest that QEI is related to muscular power and functional capacity of older subjects, but the EI of some individual quadriceps portions may underestimate the correlations with muscular performance.

Keywords Aging · Ultrasound · Muscular performance · Muscle strength · Muscle quality · Muscle thickness

Introduction

The aging process is associated with reduced skeletal muscle capacity to produce strength and power (Izquierdo et al. 1999b, 2001; Klein et al. 2001; Lynch et al. 1999; Bosco and Komi 1980; Morse et al. 2004), in a condition referred to as dynapenia (Clark and Manini 2008, 2012). This phenomenon has severe consequences on the quality of life and independence of older populations by affecting the capacity to perform functional activities such as standing up from a chair (Jones et al. 1999; Suzuki et al. 2001), walking (Suzuki et al. 2001), and stair-climbing (Suzuki et al. 2001); as well as increasing the risk of falls (Bento et al. 2010; Pijnappels et al. 2008).

Dynapenia is a multifactorial process, influenced by neural and muscular properties (Clark and Manini 2008,

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2012). One of the most investigated factors related to the reduction in skeletal muscle strength (Strasser et al. 2013; Izquierdo et al. 1999b; Klein et al. 2001) and power (Izquierdo et al. 1999b, 2001) in advanced age is sarcopenia. Beyond the decrease in muscle mass however, aging may also lead to increased infiltration of non-contractile intramuscular elements. It is believed that this change in muscular composition is greatly caused by muscular lipid deposition (Arts et al. 2010; Goodpaster et al. 2001) that may be caused by the higher expression of adipocyte differentiation-related protein content in muscles of older individuals (Conte et al. 2013). Although the mechanisms underpinning the accumulation intramuscular fat warrants further investigation, the increase in non-contractile elements may mask skeletal muscle wasting (Sipila and Suominen 1993), thereby constituting an important mechanism related to dynapenia.

Changes in the proportion of non-contractile intramuscular elements can be easily assessed using the non-invasive and safe method of ultrasound imaging, where an increase in image echo intensity (EI) is thought to be primarily caused by increases in fat and connective tissue (Arts et al. 2010; Pillen et al. 2009; Sipila and Suominen 1993). Early research determined the EI of the whole quadriceps femoris by a four-point scale visual analysis and reported a negative correlation between muscular EI and knee extension isometric strength (Sipila and Suominen 1991). However, visual analysis is dependent on the experience of the investigators performing the task and less sensitive in clinical evaluation than the currently available quantitative EI analysis (Pillen et al. 2006). Recently, the EI has been determined by computed aid gray-scale analysis (Arts et al. 2010; Pillen et al. 2006; Cadore et al. 2012; Fukumoto et al. 2012; Strasser et al. 2013), and negative correlations have been found between transversal images of rectus femoris EI in older subjects in relation to maximal isometric (Cadore et al. 2012; Fukumoto et al. 2012) and isokinetic knee extension strength (Cadore et al. 2012). However, no correlation between longitudinal images from the other three portions of the quadriceps and isometric muscle strength was observed in this population (Strasser et al. 2013), and no study to date has determined whether muscular EI is related to the functional capacity of aging individuals.

The aforementioned data suggest that infiltration of non-contractile elements may influence muscle strength

of older people, but only when transversal images of the rectus femoris are investigated. Thus, no information is available regarding the correlation of transversal images of whole quadriceps EI (QEI) and muscular strength in this population, with even less known about the relationship between EI, muscular power, and functional capacities of older populations. Although maximum lower limb strength is important for healthy aging, the maintenance or increase of muscle power is also very important for functional status and capacity (Bottaro et al. 2007; Foldvari et al. 2000). For example, it has been shown that lower limb muscle power can predict functional limitations in older women (Foldvari et al. 2000; Suzuki et al. 2001), and the countermovement jump (CMJ) height (i.e., a variable dependent on power output) differs between older fallers and non-fallers (Pijnappels et al. 2008). Therefore, the aim of the present study was to correlate the QEI and individual EI of the four components of the quadriceps with muscular strength, power, and functional capacity in older men. The initial hypothesis was that QEI would have a stronger correlation with muscular function than EI of some individual muscles.

Methods

Participants

Fifty healthy older men (66.1 ± 4.5 years, 1.75 ± 0.06 m, 80.2 ± 11.0 kg) not engaged within any systematic physical exercise program for at least the last 6 months were recruited for the present study (Table 1). All participants volunteered for the study following an announcement in a local newspaper. Patients with treated mild hypertension were included in the investigation, but smokers, obese, and subjects with history of metabolic and/or endocrine diseases were excluded. Before participation, all participants signed an informed consent and were carefully informed about the procedures involved as well as the risks and benefits of the study. The number of participants in the present investigation was similar to the total number of male volunteers in an early research that used the same methodology (Strasser et al. 2013). The study was approved by the ethics committee of the local university and was conducted according to the Declaration of Helsinki.

Table 1 Characteristics of subjects ($n=50$). Mean $\pm$ SD

Isometric PT (N.m)	211.0 $\pm$ 50.0
RTD 0–0.05 s (N.m.s ⁻¹)	1010.0 $\pm$ 4000.0
RTD 0–0.2 s (N.m.s ⁻¹)	700.0 $\pm$ 240.0
1RM (kg)	25.3 $\pm$ 7.0
KE peak power (W)	246.6 $\pm$ 95.1
KE average power (W)	121.0 $\pm$ 51.4
CMJ peak power (W)	2252.1 $\pm$ 528.1
CMJ average power (W)	1324.8 $\pm$ 354.4
30-s sit-to-stand (repetitions)	16.6 $\pm$ 2.6
VL EI (A.U)	74.9 $\pm$ 14.8
RF EI (A.U)	78.3 $\pm$ 12.5
VI EI (A.U)	59.5 $\pm$ 14.2
VM EI (A.U)	66.3 $\pm$ 11.3
QEI (A.U)	69.7 $\pm$ 11.4
QMT (mm)	76.8 $\pm$ 13.1

PT peak torque, *RTD* rate of torque development, *1RM* one repetition maximum, *KE* knee extension, *CMJ* countermovement jump, *EI* echo intensity, *VL* vastus lateralis, *RF* rectus femoris, *VI* vastus intermedius, *VM* vastus medialis, *QEI* whole quadriceps echo intensity, *QMT* whole quadriceps muscle thickness

Experimental design

All participants visited the laboratory on three separate days, with at least 72 h between each testing day. Participants were instructed to abstain from vigorous physical activities during the 72 h prior to and between the testing days, and effort was made to perform each test at the same period of the day. On the first day, the participants were familiarized with the physical tests. On the second day, the ultrasound measurements were made followed by the one repetition maximum (1RM) and CMJ tests. During the final visit, participants performed the knee extension maximal isometric voluntary contraction (MIVC), knee extension power measurements, and 30-s sit-to-stand (30SS) test.

Ultrasound measurements

Ultrasound images of the right vastus lateralis (VL), rectus femoris (RF), vastus intermedius (VI), and vastus medialis (VM) muscles were obtained with a Nemio XG ultrasound (Toshiba, Japan). No changes occurred in the ultrasound setup (70 mm depth; 90 dB gain; neutral time gain compensation without additional adjustment) during the study period. On arrival at the laboratory,

participants were placed in a supine position with the lower limbs relaxed and extended for 15 min in order to allow fluid shifts to occur (Berg et al. 1993). Transversal images were acquired using a 9.0-MHz linear-array probe, coated with a water-soluble transmission gel to provide acoustic contact without depressing the dermal surface. Images from VL, RF, and VI muscles were obtained at 50 % of the distance between the lateral condyle of the femur and the great trochanter, while the VM images were obtained at 30 % of this distance (Korhonen et al. 2009).

Four consecutive images of each muscle were digitized and thereafter 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 using polygon selections for EI calculation (Fig. 1). The mean EI of each muscle was determined by gray-scale analyses function and expressed in arbitrary units as a value between 0 (black) and 255 (white). The QEI was calculated as the mean EI of the four individual quadriceps muscles. Muscle thickness 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.

Knee extension one repetition maximum

The unilateral 1RM test of the right leg was performed on a knee extension machine (Taurus, Brazil), using the same settings of the familiarization session. An initial warm-up of 10 repetitions was performed at 40–50 % of the maximal load determined in the familiarization session, followed by the 1RM test started with the highest load obtained from the same familiarization visit. A 5-min interval was given between each trial, and the actual knee extension 1RM was determined as the highest load the participant could lift with the correct technique and complete range of motion. No more than four trials were necessary to successfully reach the maximal load of each participant.

Vertical jump power

The CMJ was employed on a 600-Hz sample rate force plate (Jump Power, CEFISE, Brazil) interfaced with a microcomputer with the Jump Power software. Before

Fig. 1 Example of rectus femoris (**a**, *top*) and vastus intermedius (**b**, *top*) region of interest with respective gray-scale histograms (*bottom*)

each test, the force plate was calibrated as instructed by the manufacturer and participants performed 3–4 trials for practice and warm-up. The CMJ was performed with both hands over the waist, and participants were instructed to jump as high as possible while avoiding horizontal displacement and without bending the knees during the flight time. The jump technique was analyzed by the researcher, and four valid CMJ were recorded. Peak and average power of the propulsion phase were calculated by the Jump Power software based on ground reaction force and velocity of center of mass. The highest peak and average CMJ power values were used for further analysis.

Isometric peak torque and rate of torque development

Knee extension isometric peak torque (PT) and rate of torque development (RTD) were obtained from MIVC curves. The MIVCs were performed on a Cybex Norm isokinetic dynamometer (Cybex Norm, EUA), calibrated according to the manufacturer's instructions and connected to a 2,000-Hz A/D converter (Miotec–Equipamentos Biomédicos, Brazil) to allow acquisition and exportation of data for RTD calculation. Participants were seated with the hip flexed at 85° (0°=anatomic

position), and the lateral femoral condyle of the right leg was aligned with the axis of rotation of the dynamometer. An initial warm-up of 10 submaximal isokinetic knee extension/flexion repetitions at 120° s⁻¹ was performed. Two minutes after the warm-up, subjects performed one submaximal isometric knee extension to remind themselves of the testing commands and procedures. Then, three 5-s knee extension MIVC at a knee angle of 60° (0°=knee fully extended) were performed with 90-s intervals between trials. All subjects were instructed to “produce force as hard and fast as possible” after the start command. No knee flexion countermovement was allowed and visual inspections of torque-time curves were performed to guarantee no initial countermovement. Any MIVC with initial countermovement was discarded, and an extra trial was performed. The PT was determined by the dynamometer software and the highest PT of the three MIVCs was used for further analysis.

The RTD at 0.05 and 0.2 s was calculated in a custom-made Excel spreadsheet (Microsoft Corporation, EUA) by the MIVC torque-time curve as $\Delta\text{torque}/\Delta\text{time}$ following the onset of muscular contraction. The onset of muscular contraction was defined as the instant when the knee extensor torque exceeded

7.5 N.m (Andersen and Aagaard 2006). All MIVCs of each subject were analyzed, and the highest value obtained in each time point was selected for further analyses. The RTD generated at 0.05 and 0.2 s were assumed to be measures of early and late RTD respectively (Andersen and Aagaard 2006).

Knee extension power

Concentric knee extension peak and average power outputs of the right limb were obtained at 60 % of 1RM load. A 50-Hz linear encoder (Peak Power, CEFISE, Brazil) was attached to the knee extension machine weight stack, with peak and average power calculated by the Peak Power 2.0 software (CEFISE, Brazil). The test was undertaken with the same machine settings of the 1RM test. After the warm-up, 5 knee extensions at 60 % of 1RM were performed with 5 s between each repetition. All participants were instructed to complete the repetitions as fast as possible, and the repetition with the greatest peak and average power was used for further comparison.

30-s sit-to-stand test

The 30SS test was performed with a standard chair (42 cm) to determine the functional capacity of the participants (Jones et al. 1999; Rikli and Jones 1999). Participants remained seated on the chair with both hands crossed over their chest and feet shoulder-width apart. The test started with a verbal signal, following which participants rose to an upright stance before returning to their initial position. The test was timed with a digital stopwatch by the researcher, and participants were instructed to perform as many repetitions as possible during the 30 s.

Statistical analysis

Descriptive data are shown as mean±standard deviation, with the distribution of data verified by a D'Agostino normality test. Average knee extension power, RTD at 0.05 s, and VI EI presented nonparametric distribution, while the remaining data showed parametric distribution. Pearson product-moment correlation coefficient (r) was used to determine correlations between parametric data, and the Spearman's rank order correlation coefficient (r_s) was run for nonparametric data. Correlations were considered as weak (correlation

coefficients from 0.1 to 0.35 or −0.1 to −0.35), moderate (correlation coefficients from 0.36 to 0.67 or −0.36 to −0.67), and strong (correlation coefficients from 0.68 to 1 or −0.68 to −1) (Taylor 1990). Statistical analyses were performed on Graphpad Prism 5.0 (Graphpad Software, USA), and significance level was set a priori as $\alpha \leq 0.05$.

Results

Significant negative correlations were observed between individual quadriceps portions EI, QEI, and all muscle power variables ($p \leq 0.05$, correlation coefficient ranging from −0.285 to −0.746) (Table 2). Strong correlations were observed between QEI, CMJ peak power, and CMJ mean power, while moderate correlations were found between QEI and knee extension power. EI of individual muscles showed weak to moderate correlation with muscular power variables. Moderate to strong positive correlations were found between QMT and all muscle power variables ($p \leq 0.05$) (Table 2).

Moderate correlations were observed between all EI values, 1RM, and isometric PT ($p \leq 0.05$, correlation coefficients ranging from −0.460 to −0.657), but only VL EI, VM EI, and QEI were significantly correlated to RTD at 0.05 s ($p \leq 0.05$) (Table 3). VI EI presented a weak negative correlation with RTD at 0.02 s, while moderate correlations were observed between RTD at 0.02 s and other EI variables ($p \leq 0.05$). Significant moderate correlations occurred between QMT, 1RM, isometric PT, and RTD at 0.05 and 0.2 s ($p \leq 0.05$).

Table 2 Correlation coefficient between EI and MT with KE and CMJ power output ($n=50$)

	KE peak power	KE average power	CMJ peak power	CMJ average power
VL EI	−0.362*	−0.527*	−0.725*	−0.694*
RF EI	−0.290*	−0.285*	−0.511*	−0.570*
VI EI	−0.339*	−0.426*	−0.594*	−0.587*
VM EI	−0.442*	−0.523*	−0.643*	−0.648*
QEI	−0.411*	−0.498*	−0.746*	−0.741*
QMT	0.393*	0.592*	0.753*	0.709*

EI echo intensity, *MT* muscle thickness, *KE* knee extension, *CMJ* countermovement jump, *VL* vastus lateralis, *RF* rectus femoris, *VI* vastus intermedius, *VM* vastus medialis, *QEI* whole quadriceps echo intensity, *QMT* whole quadriceps muscle thickness

* $p \leq 0.05$ significant correlation

Table 3 Correlation coefficient between EI and MT with maximal strength and RTD ($n=50$)

	1RM	Isometric PT	RTD 0–0.5 s	RTD 0–0.2 s
VL EI	−0.562*	−0.551*	−0.304*	−0.387*
RF EI	−0.498*	−0.460*	−0.227	−0.450*
VI EI	−0.501*	−0.484*	−0.191	−0.280*
VM EI	−0.656*	−0.640*	−0.393*	−0.574*
QEI	−0.657*	−0.628*	−0.320*	−0.501*
QMT	0.656*	0.620*	0.361*	0.418*

EI echo intensity, *MT* muscle thickness, *RTD* rate of torque development, *1RM* one repetition maximum, *PT* peak torque, *VL* vastus lateralis, *RF* rectus femoris, *VI* vastus intermedius, *VM* vastus medialis, *QEI* whole quadriceps echo intensity, *QMT* whole quadriceps muscle thickness

* $p \leq 0.05$ significant correlation

The maximal number of repetitions completed in the 30SS test presented weak to moderate significant correlation with EI of the four quadriceps components (VL, VM, RF, VI) ($p \leq 0.05$, correlation coefficients ranging from -0.296 to -0.595) (Fig. 2). QEI and QMT were moderately correlated with performance in the 30SS test ($p \leq 0.05$) (Fig. 3).

Discussion

It is well known that aging affects the neuromuscular system, reducing the muscular capacity to produce force and power and subsequently impairing the mobility,

independence, and quality of life of elderly people (Foldvari et al. 2000; Izquierdo et al. 2001; Jones et al. 1999). For this reason, identifying factors responsible for dynapenia is currently relevant for counteracting this process. The inverse relationship between QEI and muscular power/functional capacity observed in the present study suggests that accumulation of non-contractile elements in the quadriceps muscle may be a key mechanism related to dynapenia. In previous studies analyzing transversal ultrasound images, only RF EI was investigated (Cadore et al. 2012; Fukumoto et al. 2012). However, the quadriceps femoris has four muscle portions with different functions, thus it was hypothesized that QEI could better explain muscular capacities than individual portions analyzed separately. Accordingly, the novel aspect of the present investigation was the QEI calculation and the correlation with muscular power and functional capacity. Indeed, the use of the QEI resulted in significant correlations with all muscular variables investigated, and the strongest correlation coefficient was found between QEI and CMJ peak power. On the other hand, individual EI of RF and VI were not correlated to RTD at 0.05 s.

As an individual gets older, there are pronounced alterations in skeletal muscle fibers number and volume (Andersen 2003; Larsson et al. 1978). These changes consequently result in a reduction of muscle mass in a phenomenon known as sarcopenia. The sarcopenia, however, does not completely explain the muscle strength losses in the upper and lower limb of older individuals (Klein et al. 2001; Izquierdo et al. 2001;

Fig. 2 Correlation between vastus lateralis (VL), rectus femoris (RF), vastus intermedius (VI), vastus medialis (VM) echo intensity, and 30-s sit-to-stand test

Fig. 3 Correlation between whole quadriceps echo intensity, muscle thickness, and 30-s sit-to-stand test

Lynch et al. 1999; Clark and Manini 2012). Depending on the muscle group, other mechanisms such as diminished activation capacity of agonist muscles (Morse et al. 2004) and increased co-activation of antagonist muscles (Klein et al. 2001; Pereira and Goncalves 2011) may also be responsible for dynapenia. In addition, it has been suggested that muscular infiltration of non-contractile elements may influence maximal muscular performance (Sipila and Suominen 1993; Cadore et al. 2012; Fukumoto et al. 2012). In the present study, muscular EI of the four quadriceps components were negatively correlated to maximal strength, in agreement with results of early studies by Fukumoto et al. (2012) and Cadore et al. (2012) which showed similar correlation between RF EI with isometric and/or isokinetic PT (with r ranging from -0.40 to -0.67). Moreover, the QEI presented a higher relationship to isometric and isotonic strength than most of individual quadriceps portions in this investigation, and a similar but inverse correlation was found between maximal strength and both QMT and QEI, suggesting a contribution of muscle wasting and infiltration of non-contractile elements on strength losses.

In contrast to the present study, Strasser et al. (2013) found no relationship between EI from the VL, VI, VM, and maximal isometric strength of elderly volunteers. One possible explanation for this discrepancy may lie in the different measurement techniques applied to assess EI. In current studies that found muscular EI to be related to performance variables, the EI was determined from transversal images. In contrast, Strasser et al. (2013) analyzed longitudinal images in order to allow simultaneous pennation angle determination. It is known that EI is highly influenced by the ultrasound probe positioning and, therefore, the distinct probe orientation may explain the divergent results in literature. Based on current data, it is possible to speculate that muscular deposition of non-contractile elements in the four quadriceps portions has a considerable influence on maximal knee extension strength of older men.

Older individuals are generally more susceptible to falls than younger people because of several factors, including a reduced capacity of rapidly generated force (Izquierdo et al. 1999a). The RTD represents the ability of producing torque rapidly, and older subjects with higher RTD are less likely to lose balance and experience falls (Bento et al. 2010; Izquierdo et al. 1999a; Pijnappels et al. 2008). Izquierdo et al. (1999a) reported that aging reduces RTD of lower limbs and demonstrated that lower RTD increased the risk of losing balance in older volunteers. In the same way, Pijnappels et al. (2008) found lower ankle plantar flexion and knee extension RTD in older men and women fallers when compared to non-fallers, while Bento et al. (2010) demonstrated a diminished knee flexion RTD in older women with previous fall history. Therefore, it is important to identify factors that influence RTD in aging subjects. To the authors' knowledge, this is the first study to correlate muscle EI and RTD and the present data demonstrated a negative correlation between all individual quadriceps portions EI and RTD at 0.2 s, whereas only VL EI, VM EI, and QEI were related to RTD at 0.05 s. This finding is in accordance with the initial hypothesis that individual quadriceps portion EI may underestimate the correlation coefficients. In addition, the correlation coefficients were greater between EI and RTD at 0.2 s than 0.05 s. In young subjects, Andersen and Aagaard (2006) have demonstrated that early knee extension RTD is influenced to a greater extent by intrinsic muscular properties, while late RTD is more dependent on maximal strength. Based on the results of the present study, it may be speculated that fat and connective tissue infiltration in muscles has a primary influence on the late phase of RTD and the correlation between EI and maximal knee extension strength of middle-aged and older men and women observed in the present and previous studies (Cadore et al. 2012; Fukumoto et al. 2012) supports this speculation.

It has been stated that skeletal muscle power may be equally or even more directly associated to physical performance than maximal strength in older population

(Foldvari et al. 2000; Izquierdo et al. 2001; Suzuki et al. 2001) due to many activities of daily living relying on power instead of maximal strength. Foldvari et al. (2000) reported an inverse correlation between leg press power and self-reported functional status of older women, while Suzuki et al. (2001) demonstrated that ankle power influences functional mobility of older women. In addition, it has been reported that power training (Bottaro et al. 2007) and rapid strength training (Correa et al. 2012) may be more beneficial for improving the functional capacity of older subjects than traditional strength training. Aging appears to exert a greater effect on type II than type I muscle fibers (Andersen 2003; Larsson et al. 1978), causing a selective decrease in type II fiber cross-sectional area (Larsson et al. 1978), which may explain the pronounced decrease in muscle power of older subjects (Izquierdo et al. 2001; Bosco and Komi 1980). In the present study however, negative correlations between EI and both knee extension and CMJ power measurements were observed, suggesting that an increase in the intramuscular proportion of non-contractile elements may also affect skeletal muscle power output. In support of this theory, Cadore et al. (2012) reported that RF EI influences the knee extension PT at high angular velocities. Taken together, these results demonstrate the negative influence of muscle fat and connective tissue deposition over rapid force production and evidence the importance of considering the four quadriceps components in EI analysis.

The ultimate consequence of dynapenia is functional impairment (Clark and Manini 2012), but it was still unknown if muscular EI could be related to functional capacity. In this study, the 30SS test was used as a measure of functional capacity and a significant negative correlation occurred between EI and the number of repetitions completed during the test. The influence of increased non-contractile elements within the skeletal muscle on maximal strength and power levels may explain why EI was also associated with the 30SS test, given that this test depends primarily on lower body maximal muscular performance (Jones et al. 1999). Furthermore, QEI and QMT explained a similar amount of 30SS test variation, suggesting that an increased proportion of non-contractile elements may be a potential factor responsible for the functional status impairment with aging. Interestingly, a recent study demonstrated that strength training may decrease the RF EI while improving maximal strength in older women

(Radaelli et al. 2013), reinforcing the importance of EI on muscular performance.

Although the present results suggest a relevant influence of non-contractile elements accumulation on skeletal muscle performance of older populations, it is also necessary to consider some limitations. First, the participants of the present study were healthy physically independent older men, thus the extrapolation of these results may not be suitable to other populations, such as frail older or subjects under pathological conditions (e.g., rheumatoid arthritis). Secondly, the EI was obtained in a region of interest instead of the entire cross-sectional of the quadriceps muscle, which may affect the correlation coefficients. However, this is an innate limitation of the method, also present in other investigations (Cadore et al. 2012; Fukumoto et al. 2012; Strasser et al. 2013). Finally, it is necessary to note that absolute EI values are not comparable between studies, because they vary from ultrasound device and setups. This technical issue remains a limiting factor for the comparison of absolute EI values across studies and research centers.

In conclusion, the present study demonstrates that EI of the quadriceps femoris muscle is related to maximal strength, power, and functional capacity of older men. The EI of some components of quadriceps femoris were not correlated to RTD at 0.05 s, but QEI was related to all variables investigated. This result demonstrates the importance of considering the whole quadriceps femoris muscle when EI analyses are undertaken. Additionally, QMT and QEI presented similar relationships with performance in a functional task. Beyond muscular quantity, this result suggests that intramuscular deposition of non-contractile elements is an important factor associated to dynapenia development, which may be considered when working with older patients. Therefore, the development of effective interventions and therapies to prevent not only the aging-related muscle wasting, but also the intramuscular accumulation of non-contractile elements in the quadriceps femoris muscle may be worthwhile in a clinical perspective.

Acknowledgments The authors would like to thank the CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) and CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) for their financial support. The ultrasound device used in the present study was supplied by CAPES (Edital Pro-equipamentos institucional Nº 025/2011).

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