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Effects of single vs. multiple-set short-term strength training in elderly women

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Abstract The strength training has been shown to be effective for attenuating the age-related physiological decline. However, the adequate volume of strength training volume adequate to promote improvements, mainly during the initial period of training, still remains controversial. Thus, the purpose of this study was to compare the effects of a short-term strength training program with single or multiple sets in elderly women. Maximal dynamic (1-RM) and isometric strength, muscle activation, muscle thickness (MT), and muscle quality (MQ=1-RM and MT quadriceps quotient) of the knee extensors were assessed. Subjects were randomly assigned into one of two groups: single set (SS; n=14) that performed one set per exercise or multiple sets (MS; n=13) that performed three-sets per exercise, twice weekly for 6 weeks. Following training, there were significant increases ($p \leq 0.05$) in knee extension 1-RM (16.1±12 % for SS group and 21.7±7.7 % for MS group), in all MT ($p \leq 0.05$; vastus lateralis, rectus femoris, vastus medialis, and vastus intermedius), and in MQ ($p \leq 0.05$); 15.0±12.2 % for SS group and 12.6±7.2 % for MS group), with no differences between groups. These results suggest that during the initial stages of strength training, single- and multiple-set training demonstrate similar capacity for increasing dynamic strength, MT, and MQ of the knee extensors in elderly women.

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Introduction

The aging process is characterized by a decline in muscle strength, loss of muscle mass (sarcopenia), an increase in intramuscular fat, and modifications of neural drives (Aagaard et al. 2010; Mitchell et al. 2012). These physiological modifications can potentially contribute to significant impairments in muscle quality (MQ) of the knee extensor muscles (Ivey et al. 2000).

The MQ, also known as specific tension, refers to force per unit of active mass (Ivey et al. 2000; Lynch et al. 1999) and has been suggested as a better indicator of muscle function than muscle strength alone (Dutta et al. 1997), because it provides an estimate of the contribution of muscle hypertrophy and neuromuscular factors to changes in muscle strength (Castro et al. 1995; Tracy et al. 1999). Furthermore, the MQ seems to have a strong association with functional capacity in elderly people (Pinto et al. 2014). A previous study reported that elderly women with lower MQ of lower body were 4.3 to 17.1 times more likely to have functional impairments (Barbat-Artigas et al. 2013). In other study, the authors observed that lower extremity MQ was strongly associated with spatial and temporal gait variability (Shin et al. 2012). Thereby, MQ may represent a meaningful, informative, and sensitive target to monitor functional capacity and sarcopenic status (Barbat-Artigas et al. 2014), and strategies to enhance MQ may help elderly people to maintain their independence. Strength training (ST) has been recognized as an effective intervention for strength and muscle mass loss as well as MQ decline associated with aging (Ivey et al. 2000; Radaelli et al. 2013; Tracy et al. 1999). Thus, several studies have explored the physiological adaptations of ST in elderly subjects.

A study recently completed in our laboratory showed that short-term ST (6 weeks), with two to three sets per exercise, was effective in increasing strength, muscle mass, and improved MQ of the knee extensor muscles in elderly women (Pinto et al. 2014). Although our results showed positive effects with multiple sets, some previous studies have suggested that single and multiple sets promote similar gains in strength and muscle hypertrophy (Fleck and Kraemer 2004; Wolfe et al. 2004). The effects of a number of sets has been investigated previously, whereas some original studies and a recent meta-analysis have asserted that multiple sets may promote greater strength and muscle hypertrophy gains (Krieger 2009, 2010; Paulsen et al. 2003; Rhea et al. 2002), other original studies found no significant difference between single and multiple sets (Hanssen et al. 2013; Hass et al. 2000). Although there are studies investigating the influence of ST volume (product of the number of sets completed of each exercise and the number of repetitions completed in each set), its effect on short-term ST adaptations remains unclear.

In a meta-analysis, Wolfe et al. (2004) suggested that single and multiple sets would provide similar gains in elderly people during the initial periods of ST. Nevertheless, this conclusion was not based on experimental studies comparing the effect of volume in an elderly population. In an experimental study, Cannon and Marino (2010) trained elderly women 3 days a week for a short term (10 weeks), where one group performed single set (one set) and another group performed multiple sets (three sets) of knee extension exercise. Both groups demonstrated significant increases in dynamic and isometric maximal strength, muscular volume, and MQ of the knee extensors, with no significant differences between groups. However, the training groups were composed of both young and elderly women, which limits the application of the results for an elderly population, because strength gains may be affected by age (Lemmer et al. 2000). Furthermore, subjects trained 3 days a week, whereas elderly people appear to adapt better when training 2 days/week (Taaffe et al. 1999). Thus, the impact of volume on strength gains, muscle hypertrophy, and MQ in an elderly population remains unknown.

Training volume has been positively associated with changes in whole muscle volume and in strength capacity (Peterson et al. 2011), two of the most important variables for physical performance in elderly people. Thereby, a better understanding over training volume is necessary for appropriate and effective prescription of ST for elderly individuals. Given the aforementioned limitations and the lack of more studies comparing the impact of a number of sets on lower-body neuromuscular adaptations in elderly people during a short term of ST, the aim of this study was to investigate the effects of single- vs. multiple-set short-term ST (6 weeks) on strength, muscle hypertrophy, muscle activation, and MQ of the knee extensors in elderly women.

Materials and methods

Participants

The number of participants required for the present investigation was calculated by a sample size estimation using G*Power software (ver. 3.0.1), using an α level of 0.05 and power of 0.85, according to a previous recommendation (Beck 2013). Resultant calculations determined that a total of 13 individuals per group were needed to test the effect of number of sets.

Twenty-seven older women aged 60 to 74 years volunteered for this investigation. All women had not participated in regular resistance training for at least 3 months, were post-menopausal, and classified with a normal body mass index (BMI). Exclusion criteria included any musculoskeletal, neurological, or cardiovascular disorder that might compromise involvement in ST. Furthermore, all subjects were not currently taking antihypertensive, cardiovascular, or metabolic medications. All participants received a comprehensive explanation of the proposed study, including benefits and inherent risks. After the explanation, a signed informed consent was obtained prior to testing and training. All procedures performed were approved by the Institutional Human Research Ethics Committee and were conducted in accordance with the Declaration of Helsinki ethical principles for medical research involving human subjects.

Measures

Training program

All subjects performed two training sessions per week on nonconsecutive days for 6 weeks (i.e., 12 total training sessions). Participants were randomly assigned into one of two training groups: single-set group (SS; n=14; 64.7±2.1 years; 67.9±9.2 kg; 163.7±5.2 cm; 24.1±3.7 kg m^{-2}) or multiple-set group (MS; n=13; 64.1±1.8 years; 65.4±8.3 kg; 165.4±4.2 cm; 24.9±4.2 kg m^{-2}). Both training groups performed the following exercises: bilateral leg press, unilateral elbow flexion, bilateral knee extension, lat pull-down, bilateral leg curl, triceps extension, bench press, hip abduction and adduction, and abdominal crunch. The SS group performed only one set per exercise, while the MS group completed three sets per exercise. The MS group rested 2 min between each set. The training intensity was controlled using repetition maximum (RM), according to previous recommendations (Garber et al. 2011) and studies (Cadore et al. 2010, 2012), thus the heaviest possible weight was used for the designated number of repetitions. Subjects performed 15–20 RM during all training sessions, and when they were able to perform more than 20 repetitions, the load was increased from 2.5 to 5.0 kg. This intensity was chosen because it reflects a moderate training intensity and may significantly increase the strength and muscle mass in elderly women (Radaelli et al. 2014). Subjects were instructed to perform each repetition with a 2-s concentric and 2-s eccentric phase. All sessions were supervised by the researchers, and all subjects included in the final analyses completed 100 % of the study sessions. Subjects were instructed to maintain their normal physical activity and dietary habits for the duration of the study.

Maximal dynamic strength

Maximal dynamic strength was measured using one-repetition maximum (1-RM) of the knee extensors (bilateral; World-Esculptor, Porto Alegre, Brazil). Before the maximal test, all subjects were familiarized with the procedures and performed ten repetitions with a light resistance as a warm-up. During the test, repetitions were performed at increasing weights until no additional weight could be lifted using proper technique. 1-RM was defined as the maximum weight that a subject could move through a full range of motion one time (90° to 0°; 0°=knee fully extended). During the 1-RM test, velocity was controlled (2 s for the concentric and 2 s for the eccentric phase) by an electronic metronome (Quartz, USA). The subject's 1-RM was determined with no more than four attempts, with a 3-min rest period between attempts. The 1-RM test–retest intraclass correlation coefficient (ICC) was 0.96. All tests were conducted by the same investigator, with identical subject/equipment positioning before and after 6 weeks of training.

Maximal isometric strength

Lower-body maximal bilateral isometric strength tests were performed on a leg press exercise machine (World Sculptor, Porto Alegre, Brazil). Isometric strength was measured using a load cell (Primax, São Paulo, Brazil) connected to an analog digital (A/D) converter (Miotol 400, Porto Alegre, Brazil). Subjects sat with their hips, knees, and ankle joints at 90°. They were instructed to exert maximal isometric strength against a platform under their feet. They performed three 5-s maximal isometric voluntary actions with a 3-min rest interval between attempts. During the test, verbal encouragement was given. The force-time curve signal was obtained in real time using Miograph software (Miotol 400, Porto Alegre, Brazil), with an acquisition rate of 2000 Hz, recorded on a personal computer (Dell, São Paulo, Brazil), digitized and later analyzed with SAD32 software (developed by the Engineering School of the local university, Porto Alegre, Brazil). The maximal isometric voluntary action with greatest force value (kg) of three attempts was utilized for subsequent statistical analyses.

Maximum electromyographic activation

Maximum electromyographic (EMG) activation of the agonist muscle was recorded during the maximal isometric strength test by surface electromyography. Lower-limb activation was recorded from the vastus lateralis (VL), rectus femoris (RF), and vastus medialis (VM) muscles of the dominant limb. The electrodes, in a bipolar configuration (20 mm interelectrode distance), were positioned along the direction of the muscle fibers on the muscular belly according to SENIAM (www.seniam.org). Before electrode positioning, each site was shaved, cleansed with alcohol, and abraded to reduce impedance below 2000 kΩ. The electrode position was mapped using transparent paper to ensure identical electrode position for pre- and post-testing (Narici et al. 1989). The same investigator performed all electrode positioning for pre- and post-testing. The raw EMG signal was obtained using a four-channel electromyograph (Miotol, Porto Alegre, Brazil) with a sampling frequency of 2000 Hz per channel and amplified by a multiplication factor of 100 by a personal computer (Dell inspiron, São Paulo, Brazil). After recording, EMG signals were analyzed with SAD32 software. EMG signals were filtered using a Butterworth band-pass filter, with cutoff frequencies of 20 and 500 Hz. After filtering, the EMG signal from the greatest maximal isometric voluntary action with highest force value (kg) was sliced exactly at the force-time curve plateau and the root mean square (RMS) values were calculated for 1 s of the force-time curve plateau (Fig. 1).

Muscle thickness

Muscle thickness (MT) of the knee extensors of the right limb were measured using B-mode ultrasound (Philips, VMI), with a 7.5-MHz linear-array probe (38 mm). Measurements on the right leg were taken from each subject, in a supine position, after resting 15 min with their muscles relaxed. The post-test MT was assessed 3–5 days after the last training session to avoid swelling, and the subjects were instructed to hydrate themselves normally 24 h before the tests. The probe was coated with a water-soluble transmission gel to provide acoustic contact without depressing the dermal surface. MT was measured for the VL, RF, VM, and vastus intermedius (VI), with the probe positioned according to descriptions provided in previous studies (Chilibeck et al. 2004; Korhonen et al. 2009; Kumagai et al. 2000; Miyatani et al. 2000). Moreover, the overall quadriceps femoris MT (MT QUA_{SUM}) was calculated from the sum of the four muscles (VL+RF+VM+VI) (Cadore et al. 2012; Radaelli et al. 2013). The sites of MT measurements were mapped using transparent paper to ensure identical measurement positions post-testing. All images were digitized and later analyzed using ImageJ software ver. 1.37 (National Institute of Health, Bethesda, USA). The subcutaneous adipose tissue-muscle interface and the muscle-bone interface were identified from the image, and the distance between them was accepted as MT. The same investigator made all measurements pre- and post-testing. The coefficient of variation for the knee extensors was less than 4.0 %. Test–retest ICC for knee extensor MT was between 0.86 and 0.95.

Muscle quality

To arrive at a value for MQ, the knee extension 1-RM value of the dominant leg was divided by the MT QUA_{SUM} of the dominant leg. Thus, the MQ was determined according to previous studies (Pinto et al. 2014; Radaelli et al. 2013) by the following equation: (MQ= knee extension 1-RM (kg) of the dominant leg/MT QUA_{SUM} (mm) of the dominant leg).

Statistical analyses

All measured values are reported as mean±SD. The normality and homogeneity for outcome measures were tested using the Shapiro–Wilk's and Levene's tests, respectively. The main training effects were assessed by a two-way mixed factor (time×group) analyses of variance (ANOVA). When a significant F value was identified, a Bonferroni post hoc test was performed to identify pairwise differences. Statistical significance was set a priori at $p \leq 0.05$. SPSS software ver. 17.0 was used for all statistical analyses. Effect sizes (the difference between pre- and post-test scores divided by the pre-test SD) were calculated and classified for dynamic strength and MT gains according to Rhea (2004).

Results

Dynamic maximal strength

There were no differences at baseline between groups for knee extension 1-RM ($p>0.05$). There was no time× group interaction or main effect for group, but there was a significant main effect for time ($F=3.9$, $p\leq 0.05$). Both groups significantly increased ($p\leq 0.05$) their knee

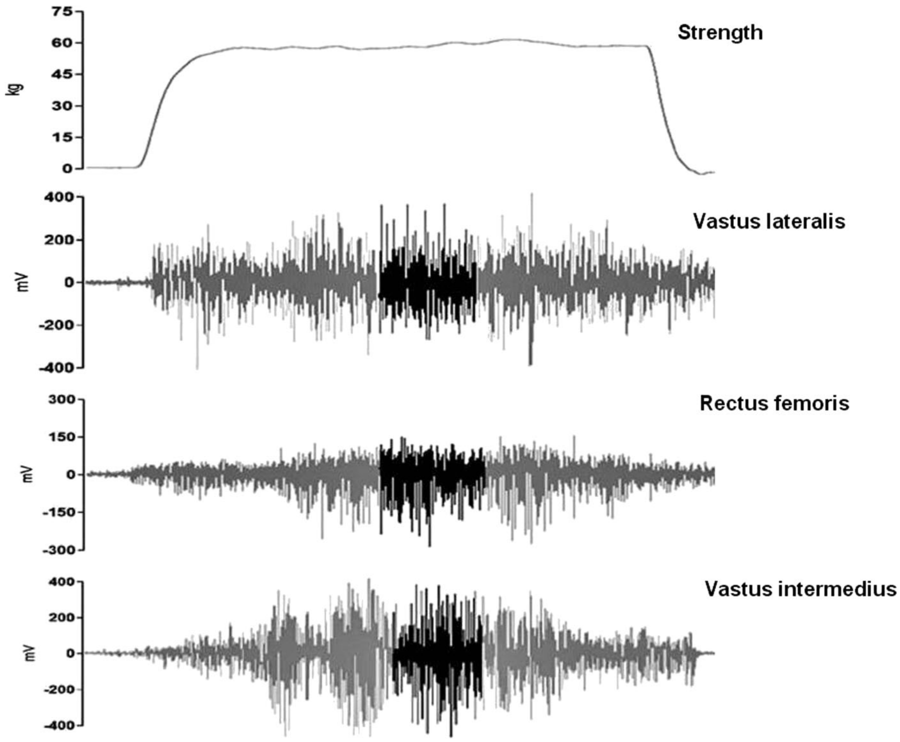

Fig. 1 Strength curve (top race), raw electromyograph obtained in the quadriceps femoris muscles, and the sliced in the EMG signal where the root mean square was calculated

extension 1-RM (16.1±12.0 % for SS group and 21.7±7.7 % for MS group) with no difference between groups ($p>0.05$) (Table 1). The effect size for the change was trivial for the SS group (0.42) whereas for the MS group was small (0.57).

Table 1 Absolute values for maximal dynamic strength and maximal isometric strength pre- and post-training and percent change (mean±SD)

Group	Single set ($n=14$)	Multiple sets ($n=13$)
Knee extension 1-RM (kg)		
Pre	49.5±16.4	50.8±16.4
Post	56.5±15.5*	60.3±17.8*
Δ%	16.1±12.0	21.7±7.7
Lower-body maximal isometric strength (kg)		
Pre	71.6±25.5	74.7±25.6
Post	68.7±16.2	76.8±26.3
Δ%	3.1±5.6	4.3±6.5

1-RM one-repetition maximum, *n* sample size, *Δ%* percentage change

*$p\leq0.05$ significantly different from pre-training within training groups

Lower-body maximal isometric strength

There were no differences at baseline between groups for lower-body maximal isometric strength. There was no significant time×group interaction, main effect for time, or main effect for group ($p>0.05$) (Table 1).

Maximum EMG activation

There were no differences at baseline between groups for maximum EMG activation for any muscle ($p>0.05$). There was no significant time×group interaction, main effect for time, or main effect for group ($p>0.05$) for maximum EMG activation for any muscle (Table 2).

Muscle thickness

There were no significant differences at baseline between groups for knee extensor MTs ($p>0.05$). There was no time×group interaction or main effect for group ($p>0.05$), but there was a significant main effect for time. MT significantly increased for the VL ($F=2.7$, $p\leq0.05$), RF ($F=2.1$, $p\leq0.05$), VM ($F=2.8$, $p\leq0.05$), VI ($F=2.0$, $p\leq0.05$), and in MT QUA_{SUM} ($F=3.1$, $p\leq$

Table 2 Absolute values for maximum EMG activation pre- and post-training (mean±SD)

Variable	Single set (n=14)		Multiple sets (n=13)	
	Pre	Post	Pre	Post
Vastus lateralis (mV)	0.146±0.056	0.144±0.082	0.119±0.023	0.118±0.044
Rectus femoris (mV)	0.066±0.031	0.071±0.034	0.077±0.015	0.083±0.036
Vastus medialis (mV)	0.099±0.031	0.071±0.046	0.122±0.067	0.125±0.048

mV milivolts, *n* sample size

0.05), in both groups (Fig. 2). The effect size for change in the VL (0.21 for SS group and 0.33 for MS group), RF (0.13 for SS group and 0.28 for SM group), VM (0.11 for SS group and 0.37 for MS group), VI (0.14 for SS group and 0.20 for MS group), and MT QUA_{SUM} (0.21 for SS group and 0.45 for MS) were trivial for both groups.

Muscle quality

There was no significant difference at baseline between groups for MQ ($p>0.05$). There was no time×group interaction or main effect for group ($p>0.05$), but there was a significant main effect for time ($F=2.4$, $p\leq 0.05$). Both groups significantly increased their MQ after 6 weeks of training (15.0±12.2 % for SS group and 12.6±7.2 % for MS group), with no difference between groups ($p>0.05$) (Fig. 3). The effect size for the change in MQ in both groups was trivial (0.15 for the SS group and 0.08 for the MS group).

Discussion

The aim of this study was to investigate the effects of single- vs. multiple-set short-term ST on strength, muscle hypertrophy, muscle activation, and MQ of the knee extensors in elderly women. The primary finding was that after 6 weeks of ST, single and multiple sets were similarly effective in promoting gains in maximal dynamic strength and muscle mass, and improving MQ. Furthermore, regarding effect size, the MS group only showed a higher magnitude (0.57) for knee extension 1-RM when compared with the SS group (0.42). These results reinforce the ACSM position stand (ACSM 2009) and corroborate the findings of previous study (Cannon and Marino 2010), which found that single-set training promotes similar strength gains in elderly subjects as those with multiple sets during the early phase of ST. Moreover, the current results suggest that during the initial period of ST, volume is not the primary variable responsible for increases in maximal dynamic strength, muscle mass, and MQ of the knee extensors in elderly women.

Studies on training volume with elderly people are scarce. Galvão and Taaffe (2005), in contrast to the present study, observed that after 20 weeks of ST, multiple sets induced significantly greater gains in knee extension 1-RM than a single-set program in elderly adults. Differences between training duration (20 vs. 6 weeks), intensity (15–20 RM present study and 8 RM in Galvão and Taaffe's study), and the population studied (only women in the present investigated), may explain the difference results. Conversely, Cannon and Marino (2010) observed similar improvements between single and multiple set groups in knee extensor 1-RM after 10 weeks of training, which agrees with the results of the current study. However, in their study, Cannon and Marino (2010) used a combination of young and older women were trained, which can result in differences in strength gains (Lemmer et al. 2000); thus, a detailed comparison with our results is difficult. Nevertheless, the results of the current study and the findings of Cannon and Marino (2010) may suggest that, during the initial period of ST, elderly women may experience similar improvements in maximal dynamic strength of the knee extensors using either a single-set or a multiple-set program.

Although both training groups in our study showed similar increases in maximal dynamic strength, the knee extension 1-RM effect size for the MS group was higher than for the SS group. During daily-life activities, lower-body muscles are exposed to substantially greater total load; as a consequence, some of the growth potential in the lower-limb muscles might have already taken place through daily activities, meaning they are more trained

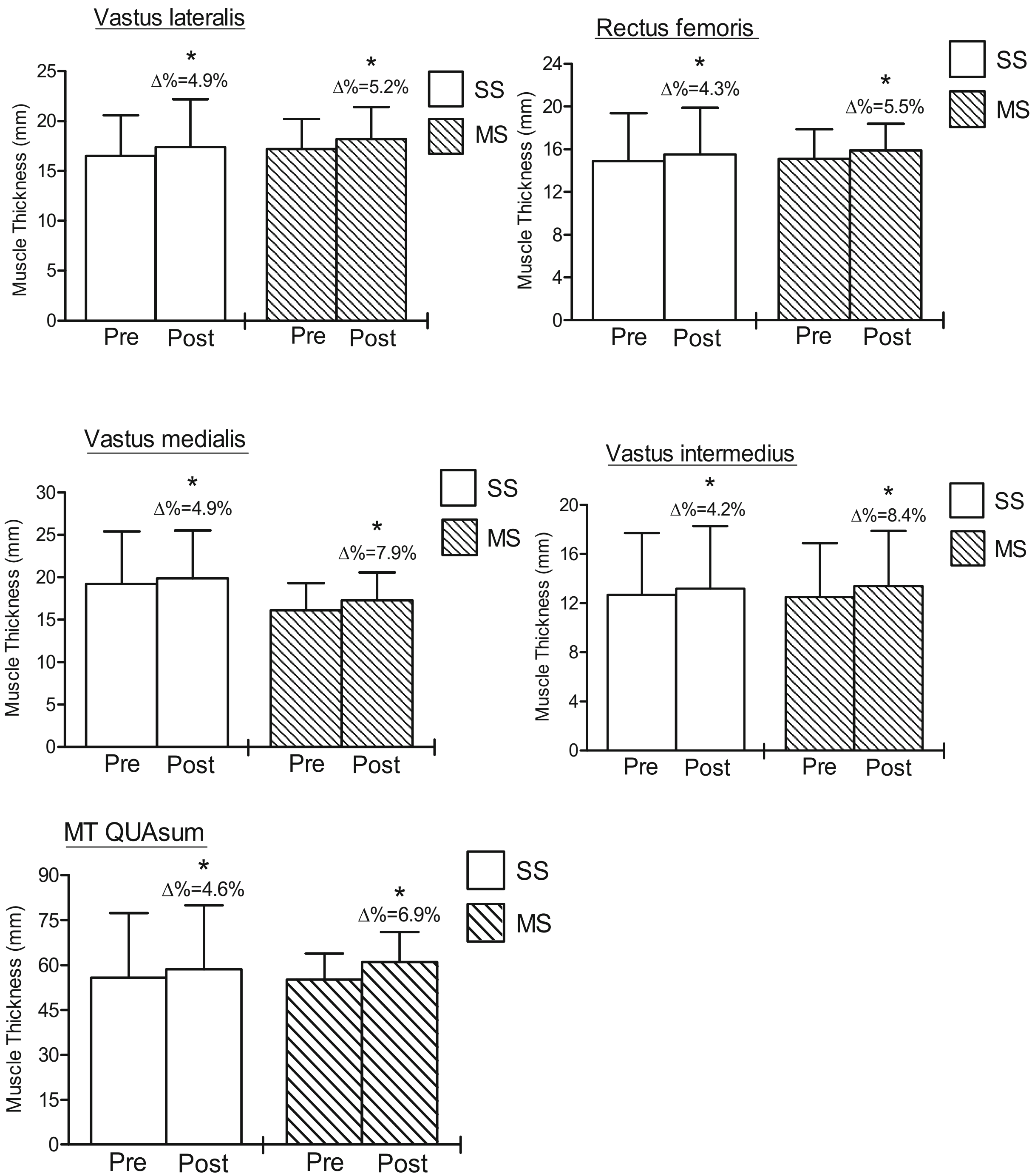

Fig. 2 Absolute values of muscle thickness pre- and post-training (mean±SD); *astersik*, significantly greater than pre-training value; *SS* single-set group, *MS* multiple-set group, *MT* QUA_{SUM} quadriceps femoris muscle thickness (VL+RF+VM+VI), Δ% percentage change

(Paulsen et al. 2003; Ronnestad et al. 2007). Thus, lower-body muscles may require a high volume of training to provide further strength gains and that these are more likely to be long-term rather than short-term gains. Previous studies reported a training volume dose response for lower-body muscles after long periods of training, when multiple sets were more effective than single set for increasing maximal dynamic strength in

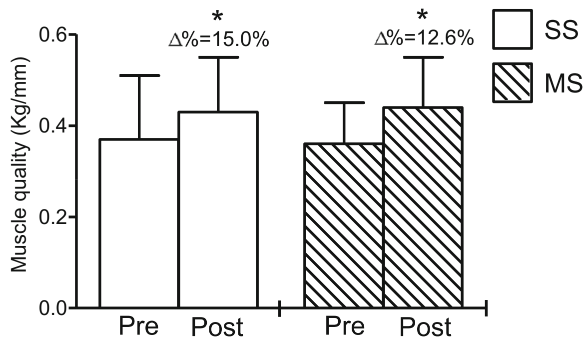

Fig. 3 Absolute values of muscle quality pre- and post-training (mean±SD); *$p<0.05$, significantly greater than pre-training value, *SS* single-set group, *MS* multiple-set group, Δ% percentage change

elderly women (Radaelli et al. 2014; Galvão and Taaffe 2005). However, more studies are necessary to determine the effects of length of training period and ST volume on lower-limb strength gains.

After 6 weeks of training, lower-body maximal isometric strength did not change in either group. This result is in accordance with previous studies that also found no increase in maximal isometric strength after a period of dynamic training (Fry et al. 1992; Sale et al. 1992). However, Cannon and Marino (2010) found significant and similar increases in maximal isometric knee extension strength in single- and multiple-set groups after 10 weeks of training. Differences in training periods (6 vs. 10 weeks) and isometric testing (multi- vs. single joint) may have influenced the results between studies. Increases in isometric strength following ST are not constant across the joint range of motion, because a shift in the optimal angle occurs due to a change in the length-tension properties of the muscle fascicles (Narici et al. 2005; Reeves et al. 2004). Thus, testing isometric strength at just one joint angle, as done in the present study, may have underestimated overall strength gains (Narici et al. 2005).

Maximum EMG activation showed no significant change in either group after 6 weeks of training. This result is supported by previous studies that also found no increase in maximal EMG activation measured under isometric conditions (Cannon and Marino 2010; Marshall et al. 2011; Robbins et al. 2009). The inability of surface electromyography to detect longitudinal changes, at least in part, is due to changes in skin (fat layer) and muscle tissue (muscle fiber pennation) (Aagaard 2003), which may explain the current results. Moreover, ST results in neural adaptations, which may not be perceptible by surface electromyography, such as changes in the organization of the synaptic circuitry in the spinal cord, as well as an increase in cortical excitability (Carroll et al. 2002; Schubert et al. 2008),

Muscle hypertrophy is related to several variables, such as muscle damage (Hill and Goldspink 2003), hormone secretion (Crewther et al. 2006), and activation myogenic pathways (Schoenfeld 2010), and it is believed that multiple sets may be related to greater responses in these variables. However, in the present study, both groups demonstrated similar increases. These results suggest that short-term ST using single set in older women is effective for attenuating the detrimental effects of aging in muscle mass (sarcopenia). Furthermore, the results may suggest that in the initial period of training, a threshold exists beyond which a greater volume of exercise does not have any further effect on MT in elderly women. There is a lack of research specific to the effects of training volume on muscular hypertrophy in elderly people and to our knowledge only one study compared the influence of single and multiple sets on muscle hypertrophy of the quadriceps femoris in elderly women. Cannon and Marino (2010) found similar gains for single- and multiple-set groups in knee extensors lean mass after 10 weeks of training. However, as previously described, they included young and elderly women in training groups, making a detailed comparison with our results difficult. Skeletal muscle hypertrophy is related to muscular protein synthesis, which depends upon several factors including nutrition state (Biolo et al. 1995). Some elderly people, however, have an usual protein intake, consuming less than the recommended protein per kilogram of body weight per day (Roubenoff and Hughes 2000), which may attenuate the muscle hypertrophy. Future studies comparing numbers of sets with dietary supplementation, which have been shown to increase the lean mass in elderly people (Solerte et al. 2008), may provide additional information regarding the influence of numbers of sets in morphological adaptations in this population.

The age-related decline in MQ is associated with alterations in the neuromuscular, contractile, and architecture components (Delmonico et al. 2009; Metter et al. 1999; Tracy et al. 1999). The present results demonstrated that both groups improved similarly in MQ. To our knowledge, this is the first study to compare the effects of volume on MQ of elderly women during short-term ST. The mechanisms responsible for training induced improvements in MQ are still unclear; however, neural adaptations (changes in motor unit recruitment, firing frequency, and summation of motor unit action potential synchronization) as well as enhancement of contractile properties may offer substantial support for the observed increases (Ivey et al. 2000; Tracy et al. 1999). The current results reinforce our previous findings that short-term ST is an effective method to improve MQ of elderly women (Pinto et al. 2014). Furthermore, they suggest that during the early phase of ST, additional sets do not promote greater responses in variables associated with improvement of MQ.

Conclusion

In summary, the results of the present study demonstrated that single and multiple sets resulted in similar increases in maximal dynamic strength, MT, and MQ of the knee extensor muscles in elderly women following 6 weeks of ST. These results suggest that during the initial periods of training, there is no additional benefit to using multiple sets for elderly women, which may increase their adherence to training, since shorter protocols (single-set) are associated with a higher rate of adherence in this population (Hass et al. 2000). These results are important for ST professionals and clinicians who want to design an effective and efficient ST program for elderly women.

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Conflict of interest The authors have no financial or personal conflicts of interest to report which may be perceived to influence the results.

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