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Highlights

Experimental Gerontology xxx (2013) xxx–xxx

Low- and high-volume strength training induces similar neuromuscular improvements in muscle quality in elderly women

Regis Radaelli [a,*], Cíntia E. Botton [a], Eurico N. Wilhelm [a], Martim Bottaro [b], Fabiano Lacerda [a], Anelise Gaya [a], Kelly Moraes [a], Amanda Peruzzolo [a], Lee E. Brown [c], Ronei Silveira Pinto [a]

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- The decline of the muscle strength is a consequence of the aging process.
- Decline in the muscle quality has been proposed as another consequence of the aging.
- Strength training is an efficient method for mitigating impairments related to the aging.
- Low- and high-volume strength training induced similar improvements in elderly women.
- Low- and high-volume strength training were effectives for improving muscle quality.

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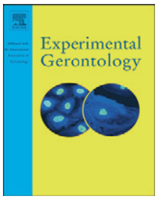

Low- and high-volume strength training induces similar neuromuscular improvements in muscle quality in elderly women

Regis Radaelli [a,*], Cíntia E. Botton [a], Eurico N. Wilhelm [a], Martim Bottaro [b], Fabiano Lacerda [a], Anelise Gaya [a], Kelly Moraes [a], Amanda Peruzzolo [a], Lee E. Brown [c], Ronei Silveira Pinto [a]

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ABSTRACT

The aim of this study was to compare the effects of low- and high-volume strength training on strength, muscle activation and muscle thickness (MT) of the lower- and upper-body, and on muscle quality (MQ) of the lower-body in older women. Twenty apparently healthy elderly women were randomly assigned into two groups: low-volume (LV, $n = 11$) and high-volume (HV, $n = 9$). The LV group performed one-set of each exercise, while the HV group performed three-sets of each exercise, twice weekly for 13 weeks. MQ was measured by echo intensity obtained by ultrasonography (MQ_{EI}), strength per unit of muscle mass (MQ_{ST}), and strength per unit of muscle mass adjusted with an allometric scale (MQ_{AS}). Following training, there was a significant increase ($p \le 0.001$) in knee extension 1-RM (31.8 ± 20.5% for LV and 38.3 ± 7.3% for HV) and in elbow flexion 1-RM (25.1 ± 9.5% for LV and 26.6 ± 8.9% for HV) and in isometric maximal strength of the lower-body ($p \le 0.05$) and upper-body ($p \le 0.001$), with no difference between groups. The maximal electromyographic activation for both groups increased significantly ($p \le 0.05$) in the vastus medialis and biceps brachii, with no difference between groups. All MT measurements of the lower- and upper-body increased similarly in both groups ($p \le 0.001$). Similar improvements were also observed in MQ_{EI} ($p \le 0.01$), MQ_{ST}, and MQ_{AS} ($p \le 0.001$) for both groups. These results demonstrate that low- and high-volume strength training promote similar increases in neuromuscular adaptations of the lower- and upper-body, and in MQ of the lower-body in elderly women.

1. Introduction

The decline of lower- and upper-body isometric and dynamic muscle strength is a consequence of the aging process (Hakkinen et al., 1996; Klein et al., 2001). It is attributed to the loss of muscle mass that results from a decrease in the number of muscle fibers, atrophy of the remaining muscle fibers (sarcopenia) (Aagaard et al., 2010; Andersen, 2003), and reduction in the maximal voluntary activation of the agonist muscle akobi and Rice, 2002). Additionally, the decline in the muscle quality (MQ) of the lower-body has been proposed as another consequence of the aging process (Arts et al., 2010; Lynch et al., 1999).

Originally, MQ was defined as strength per unit of muscle mass, also known as specific tension (MQ_{ST}) (Lynch et al., 1999; Tracy et al., 1999). Thus, MQ may be a superior indicator of muscle function in elderly people than strength alone (Dutta et al., 1997), because it provides an estimate of the contribution of muscle mass and neural factors to strength (Castro et al., 1995). Lynch et al. (1999), after analyzing data from 703 subjects of various ages, observed that the decline in leg MQ_{ST} was modest or nonexistent until the subjects were in their 50s. However, the authors noted an accelerated decline after the fifth decade for both men and women. Likewise, Ivey et al. (2000b) observed that leg MQ_{ST} was significantly less in elderly women than in young subjects. Recently, several authors have utilized another methodology to calculate MQ (Cadore et al., 2012), adjusting units of muscle mass by an allometric scale (MQ_{AS}, $F_m \propto m^{2/3}$), according to the proposal to adjust strength for body size (Jaric et al., 2002). Furthermore, other studies have reported the assessment of MQ without utilizing strength per unit of muscle mass, but have used echo intensity from images obtained via ultrasonography (MQ_{EI}). In one of these studies, Arts et al. (2010), after evaluating the rectus femoris MQ_{EI} of men and women, observed age-related decreases in MQ_{EI}. Similarly, Fukumoto et al. (2012) reported age-related decreases in rectus femoris MQ_{EI}, also indicating significant negative correlations between MQ_{EI} and knee extensor muscle strength and muscle thickness (MT) of the rectus femoris.

A well-designed strength training program is an efficient method for mitigating several impairments related to the aging process via increases in muscular strength, muscle mass, maximal voluntary activation and knee extensor MQ (Cadore et al., 2012; Ivey et al., 2000b; Tracy et al., 1999). Although the benefits of strength training for

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elderly people are well known, there is still some controversy, mainly regarding the ideal training volume (i.e., sets × reps × load) for optimizing neuromuscular gains (Hass et al., 2001; Marshall et al., 2011).

Several previous studies with young individuals have compared the effects of low- and high-volume strength training, indicating that high-volume training results in greater gains in strength, muscle activation and muscle mass than low-volume training (Hanssen et al., 2012; Kemmler et al., 2004). In contrast, other studies have not found any differences between low- and high-volume training gains (Bottaro et al., 2011; Cannon and Marino, 2010; Hass et al., 2000). Although there are many studies comparing the effects of low- and high-volume training, only a few studies have been performed with elderly subjects (Cannon and Marino, 2010; Galvão and Taaffe, 2005). Cannon and Marino (2010) observed that after 10 weeks, low-volume (one-set) and high-volume (three-sets) strength training induced similar increases in strength, muscle volume, agonist activation and MQ of knee extension in elderly women. Nevertheless, the authors did not evaluate the influence of strength training volume on upper-limb neuromuscular adaptations or MQ evaluated by MQ_{AS} and MQ_{EI}. Thus, the aim of our study was to compare the effects of low- and high-volume strength training on neuromuscular adaptations of the lower-and upper-body and on the MQ_{ST}, MQ_{AS} and MQ_{EI} of the lower-body in elderly women.

2. Methods

2.1. Subjects

Twenty healthy elderly women aged 60 to 74 years who had not participated in a resistance-training program for at least 3 months, volunteered for the study. Subjects were carefully informed of the purpose, procedures, benefits, risks and discomfort that might result from this study. Thereafter, subjects gave their written informed consent to participate. All procedures were approved by the Institutional Research Ethics Committee. Included in the study were all volunteers, nonsmokers, free of cardiovascular diseases, and metabolic and musculoskeletal limitations to physical exercise. Elderly women with conditions that could interfere with neuromuscular function and unable to perform some exercises of the training program were excluded from the study. Moreover, subjects were not currently taking antihypertensive, cardiovascular or metabolic medications.

2.2. Experimental design

The total duration of the present study was 13 weeks (i.e. 26 total training sessions). The subjects were tested on two separate occasions, before start of the study (week 0) and after 13 weeks of training, by the same investigators using identical procedures. During the period of this study the subjects were instructed to avoid changes in diet and their recreational physical activities (e.g. walking, jogging and biking) during the course of the study. These activities were similar between both groups.

2.3. Training program

Participants trained for 13 weeks, completing two sessions per week on nonconsecutive days (i.e. 26 total training sessions). They were randomly assigned to either a low-volume (LV; $n = 11$; 64.6 ± 3.1 years; 66.4 ± 5.1 kg; 162.9 ± 5.8 cm) or high-volume (HV; $n = 9$; 63.9 ± 2.3 years; 64.1 ± 7.2 kg; 163.2 ± 4.9 cm) group. Both groups trained according to similar procedures, differing only in the number of sets. The LV group performed one set per exercise, while the HV group performed three sets per exercise. In each workout, they performed the following exercises in this order: bilateral knee extension, lat pull-down, bilateral leg press, elbow flexion, bilateral leg curl, bench press, triceps extension, hip abduction and adduction and abdominal crunch A minimum of 48 h rest was required between workouts. All training sessions were monitored and supervised by at least two trained investigators.

The training intensity was controlled using the number of repetition maximum (RM) as in previous studies (Cadore et al., 2012; Hanssen et al., 2012), thus the heaviest possible weight was used for the designated number of repetitions. During the first 6 weeks both groups trained with an intensity of 20 RM; during weeks 7–10, they trained at 12–15 RM; and during the final three weeks they trained at 10 RM. The training load used per exercise was increased from 2.5 to 5.0 kg for the next workout when subjects were able to perform more repetitions than prescribed. 2-min rest between sets was given for the HV group. All subjects were instructed to perform each repetition with a duration of 2 s concentrically and 2 s eccentrically. During all training program the HV group performed the workouts in a less amount of time than LV group (≃50–60 min for HV group and ≃20–25 min for LV group).

2.4. Maximal dynamic strength

Subjects performed one-repetition maximum (1-RM) tests of knee extension (bilateral) and preacher curl elbow flexion (unilateral) (World-Sculptor, Porto Alegre, Brazil). The same investigator, with identical subject/equipment positioning, conducted the pre- and post-tests. Before 1-RM tests, subjects were carefully familiarized with the testing procedures and performed 10 repetitions with a light resistance as warm-up. Thereafter, resistance was increased until they were unable to lift the additional weight through a full range of motion using proper technique. Muscle action velocity for each repetition (2 s concentric and 2 s eccentric) was controlled by an electronic metronome (Quartz, CA, USA). All 1-RM values were determined within 3–5 attempts, with 3-min rest between each attempt. At post-testing 1-RM was performed 3–5 days after the last training session. Test–retest reliability intraclass correlation coefficients (ICC) for knee extension and elbow flexion 1-RM were 0.96 and 0.90, respectively.

2.5. Lower- and upper-body isometric maximal strength

Bilateral maximal isometric strength of the lower- and upper-body was measured on a leg press machine and an elbow flexion preacher curl bench (World-Sculptor, Porto Alegre, Brazil), respectively, using a load cell (Primax, São Paulo, Brazil) connected to an analog to digital (A/D) converter (Miotol 400, Porto Alegre, Brazil). In the lower-body test, subjects were positioned on the leg press machine with hip, knee and ankle joints at 90°. Subjects were asked to exert maximal force against the leg press platform. The upper-body test was performed with subjects sitting on the machine with both armpits supported on the preacher bench with shoulder and elbow flexion at 60° (90° relative to the floor) and holding a bar with both hands supinated. The bar was attached to the load cell, which was fixed to the floor, and subjects were instructed to exert maximal force against the bar. In both tests, subjects performed three 5-second maximal isometric actions with 3-min rest between actions and 20 min rest between activities. Verbal encouragement was given during both tests. The force–time curve signal was obtained in real-time using Miograph software (Miotec-Equipamentos Biomédicos, Porto Alegre, Brazil) with an acquisition rate of 2000 Hz, recorded on a personal computer (Dell, São Paulo, Brazil) digitized and analyzed with SAD32 software (developed by the Engineering School of the local university, Porto Alegre, Brazil). The highest force value (Kg) of three attempts was utilized for subsequent statistical analyses. After training period, the maximal isometric strength of the lower- and upper-body tests was performed 5–7 days after the last training session.

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2.6. Maximal electromyographic activation

Lower-body maximal electromyographic (EMG) activation was recorded from the vastus lateralis (VL), rectus femoris (RF) and vastus medialis (VM) of the right leg during lower-body isometric maximal strength, whereas upper-body maximal EMG activation was recorded from the biceps brachii (BB) of the right arm during upper-body isometric maximal strength. Before electrode placement, careful skin preparation was performed, including shaving excess hair and cleaning the skin with isopropyl alcohol (to reduce impedance below 2000 kΩ). 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). The electrode position was carefully mapped using a transparent paper to ensure identical positioning for pre- and post-testing. At post-testing, maximal EMG activation was recorded 5–7 days after the last training session. EMG signals were recorded using an electromyograph (Miotool, Miotec-Equipamentos Biomédicos, Porto Alegre, Brazil), amplified by a multiplication factor of 100 and digitized at a sampling frequency of 2000 Hz by a personal computer (Dell Inspiron, São Paulo, Brazil). The EMG signal was filtered with cutoff frequencies of 20 Hz and 500 Hz using a Butterworth band-pass filter. After filtering, the EMG signal from the highest isometric strength (kg) attempt was sliced exactly at the force–time curve plateau and the root mean square (RMS) value of each muscle was calculated during one-second at the force–time curve plateau (Fig. 1).

2.7. Muscle thickness

Muscle thickness (MT) was obtained using a B-Mode ultrasonographic apparatus (Philips-VMI, Ultra Vision Flip, MG, Brazil), with a 7.5 MHz linear-array probe (38 mm). All measurements were performed on the right arm and leg while the subjects were in a supine position with their muscles relaxed. Before MT evaluation, subject rested in the supine position with their arms and legs extended and relaxed for 15 min to allow fluid shifts to occur (Berg et al., 1993). The probe was coated with a water-soluble transmission gel to provide acoustic contact without depressing the dermal surface. Great care was taken in applying minimal pressure during scanning to avoid compression of the muscle. Post-testing MT was performed 3–5 days after the last training session to avoid any swelling. Muscles measured in the lower-body were the RF, VL, and VM vastus intermedius (VI), moreover the overall quadriceps femoris MT (MT QUA_{sum}) was calculated from the sum of the muscles (RF + VL + VM + VI) (Cadore et al., 2012). The muscles involved in upper-body were the elbow flexors (biceps brachii and brachialis), and the sum of their MTs (MT EF_{sum}). All sites of MT measurements have been previously described in other studies (Chilibeck et al., 2004; Korhonen et al., 2009; Kumagai et al., 2000; Miyatani et al., 2000). The sites of MT measurements were mapped using a transparent paper to ensure identical measurements following 13 weeks of training. All images were digitized and later analyzed in Image-J software (National Institute of Health, USA, version 1.37). The subcutaneous adipose tissue–muscle interface and the muscle–bone interface were identified in each image, and the distance between them was accepted as MT. All measurements were made by the same investigator. Baseline test and retest reliability ICC's of MT measurements were 0.95 for VL, 0.93 for RF, 0.90 for VI, 0.85 for VM and 0.89 for EF. The coefficient of variation of knee extensor and elbow flexor MTs was less than 4.0%.

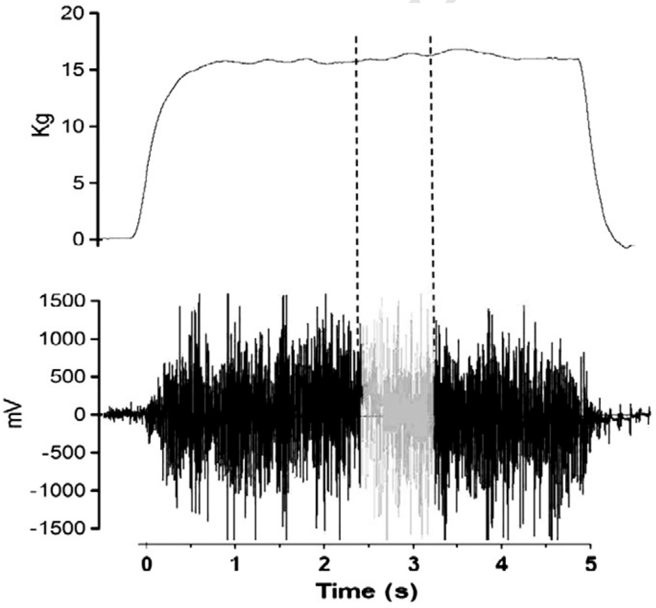

Fig. 1. Strength curve (top trace), raw electromyograph signal (EMG) and the sliced in EMG signal where the root mean square was calculated.

2.8. Muscle quality

MQ_{TE} was calculated from the maximal dynamic strength of the knee extensors divided by MT QUA_{sum}. In this case, MQ_{TE} was calculated from the following formula: unilateral knee extension 1-RM (kg)/MT QUA_{sum} (mm). However, to calculate MQ_{AS}, the MT QUA_{sum} was adjusted (i.e. $F_m \propto m^{2/3}$) following the previous studies' instruction to adjust strength for body size (Cadore et al., 2012; Jaric et al., 2002). Therefore, MQ_{AS} was defined by the following formula: unilateral knee extension 1-RM (kg)/MT QUA_{sum} $(mm)^{0.67}$.

Echo intensity was determined according to previous studies (Arts et al., 2010; Fukumoto et al., 2012) by computer-assisted gray-scale analyses using the standard function of Image-J software (National institute of health, USA, version 1.37). A region of interest was selected in the RF, which included as much of the muscle as possible and avoided surrounding fascia. The depth setting for echo intensity was fixed at 5 cm. The mean echo intensity of the region of interest was calculated as a value between 0 (black) and 255 (white) using the mean value of three images and saved as MQ_{EI}. Test–retest reliability ICC of echo intensity was 0.91.

2.9. Statistical analyses

All data are presented as means ± SD. Normality of the distribution, homogeneity and sphericity for outcome measures were tested using the Shapiro-Wilk, Levene and Mauchly test, respectively. After data was verified for normal distribution and homogeneity ($p \geq 0.05$), the main training effects were assessed by a two-way mixed model (group × time) Analysis of Variance (ANOVA). When a significant F value was identified, a Bonferroni post hoc test was performed to locate pairwise differences between means. The significance level was set at $p \leq 0.05$.

3. Results

3.1. Maximal dynamic strength

There was no statistically significant ($p > 0.05$) difference in dynamic maximal strength between groups at baseline. A significant main effect for time was observed for 1-RM knee extension and elbow flexion in both groups ($p \leq 0.001$) (Table 1). Knee extension 1-RM significantly ($p \leq 0.001$) increased after 13 weeks of training in both groups (31.8 ± 20.5% for LV and 38.3 ± 7.3% for HV). Elbow flexion 1-RM significantly ($p \leq 0.001$) increased after 13 weeks of training in both groups (25.1 ± 9.5% for LV and 26.6 ± 8.9% for HV). There were no main effects for group observed for 1-RM knee extension or elbow flexion ($p > 0.05$).

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Table 1
Bilateral maximal dynamic strength, bilateral isometric maximal strength, absolute values and percentage change (Δ%) after 13 weeks of training. The results represent means ± SD.

Variable	Low-volume (LV, n = 11)			High-volume (HV, n = 9)		
	Pre	Post	Δ%	Pre	Post	Δ%
Knee extension 1-RM (kg)	47.7 ± 15.0	61.1 ± 12.8**	31.8 ± 20.5	46.6 ± 14.7	64.4 ± 20.0**	38.3 ± 7.3
Elbow flexion 1-RM (kg)	6.9 ± 1.5	8.5 ± 1.5**	25.1 ± 9.5	6.6 ± 0.6	8.4 ± 0.5**	26.6 ± 8.9
Lower-body isometric maximal strength (kg)	69.5 ± 28.6	74.9 ± 25.3*	13.9 ± 19.3	67.3 ± 16.4	75.8 ± 16.1*	14.1 ± 10.7
Upper-body isometric maximal strength (kg)	17.3 ± 4.9	20.4 ± 4.5**	20.9 ± 17.5	17.7 ± 2.7	20.6 ± 3.6**	16.3 ± 9.8

1-RM: One-repetition maximum.
* $p \leq 0.05$; significant increase from pre training values.
** $p \leq 0.001$; significant increase from pre training values.

3.2. Maximal isometric strength

There was no statistically significant ($p > 0.05$) difference between groups for lower- or upper-body isometric strength at baseline. There was a significant ($p \leq 0.05$) main effect for time for lower- and upper-body isometric maximal strength in both groups (Table 1). Lower-body isometric maximal strength significantly increased ($p \leq 0.05$) in two training groups (13.9 ± 19.3% for LV and 14.1 ± 10.7% for HV). The upper-body isometric maximal strength significantly increased ($p \leq 0.001$) in both groups (20.9 ± 17.5% for LV and 16.3 ± 9.8% for HV). There was no main effect for the group observed ($p > 0.05$).

3.3. Maximum EMG activity

There were no statistically significant ($p > 0.05$) differences between groups in maximum EMG activity for any quadriceps muscles or for BB at baseline. There was a significant ($p \leq 0.05$) main effect for time for maximum EMG activity recorded from the VM and BB in both groups (Table 2), but no main effect for group ($p > 0.05$). After the training period, both groups had significant increases ($p \leq 0.05$) in the maximum EMG activity of the VM (27.9 ± 40.2% for LV and 22.3 ± 37% for HV) and the BB (24.7 ± 53.9% for LV and 47.4 ± 61.1% for HV).

3.4. Muscle thickness

There were no differences between groups in the MT of lower- or upper-body at baseline ($p > 0.05$). A significant ($p \leq 0.001$) main effect for time was observed in the MT of the knee extensors and elbow flexors, as well as in MT QUA_{sum} in both groups, whereas no main effect for group was observed ($p > 0.05$) for any MT scores (Fig. 2). Significant ($p \leq 0.001$) increases in MT occurred in both groups for RF (8.3 ± 6.5% for LV and 10.9 ± 6.2% for HV), VL (7.9 ± 5.9% for LV and 13.2 ± 4.6 for HV), VM (10.5 ± 8.1% for LV and 14.9 ± 6.1% for HV), VI (9.0 ± 7.1% for LV and 14.6 ± 2.1% for HV) and MT QUA_{sum} (8.6 ± 2.0% for LV and 14.3 ± 4.1% for HV) (Fig. 2). Furthermore, there was a significant increase ($p \leq 0.01$) in the MT of MT EF_{sum} for both groups (11.2 ± 6.0 for LV group and 12.5 ± 5.6% for HV group).

3.5. Muscle quality

There were no significant ($p > 0.05$) differences between groups in MQ_{ST}, MQ_{AS} or MQ_{EI}, at baseline. A significant ($p \leq 0.001$) main effect for time was observed in MQ_{ST}, MQ_{AS} and MQ_{EI} for both groups, but there was no main effect for the group observed for any muscle quality ($p > 0.05$) (Table 3). There was a significant ($p \leq 0.001$) increase after the training period in both groups for MQ_{ST} (22.2 ± 18.1% for LV group and 20.8 ± 19.5% for HV group) and MQ_{AS} (25.6 ± 18.8.1% for LV group and 26.3 ± 8.5% for HV group). Likewise, there was a significant ($p \leq 0.01$) increase in MQ_{EI} for both groups (12.0 ± 9.9% for LV group and 20.9 ± 9.2% for HV group) after the training period.

4. Discussion

The main findings of the present study were that low- and high-volume strength training performed twice a week, induced similar improvements in dynamic and isometric maximal strength, muscular activation and muscle thickness of the lower and upper body of elderly women. Furthermore, both training volumes were similarly effective for improving MQ_{EI}, MQ_{ST} and MQ_{AS} of the lower body.

The increase in force production resulting from a strength training program is related to various mechanisms: supraspinal adaptations (Falvo et al., 2010), changes in maximal motor unit discharge rate (Kamen and Knight, 2004), and changes at the whole-muscle and single-fiber levels (Frontera et al., 2003), among others. The results of the present study suggest that during the first three months of training (13 weeks), a low-volume and high-volume of strength training may induce a similar stimulus under the mechanism related to strength increases in elderly women. To our knowledge, there are only two studies comparing the effects of low- and high-volume training on strength gains in elderly women. Cannon and Marino (2010), after 10 weeks of training, reported that one- and three-sets of each exercise induced similar increases in knee extension 1-RM (27.8% for one-set and 24.7% for three-sets) and in maximal isometric strength of the knee extensors (18.6% for one-set and 17.4% for three-sets). Likewise, Galvão and Taaffe (2005) also observed no differences in elbow flexion 1-RM (39.9% for one-set and 60% for

Table 2
Absolute values and percentage change (Δ%) of maximum EMG activity after 13 weeks of training. The results represent means ± SD.

Variable	Low-volume (LV, n = 11)			High-volume (HV, n = 9)		
	Pre	Post	Δ%	Pre	Post	Δ%
Vastus lateralis (mV)	0.115 ± 0.05	0.132 ± 0.85	15.1 ± 36.7	0.128 ± 0.02	0.132 ± 0.02	24.4 ± 29.6
Rectus femoris (mV)	0.066 ± 0.03	0.062 ± 0.35	34.3 ± 58.7	0.076 ± 0.01	0.088 ± 0.01	43.2 ± 45.4
Vastus medialis (mV)	0.091 ± 0.03	0.112 ± 0.04*	27.9 ± 40.2	0.106 ± 0.06	0.124 ± 0.06*	22.3 ± 37.0
Biceps brachii (mV)	0.206 ± 0.09	0.254 ± 0.15*	24.7 ± 53.9	0.368 ± 0.22	0.461 ± 0.21*	47.4 ± 61.6

* Significant increase from pre training values ($p \leq 0.05$).

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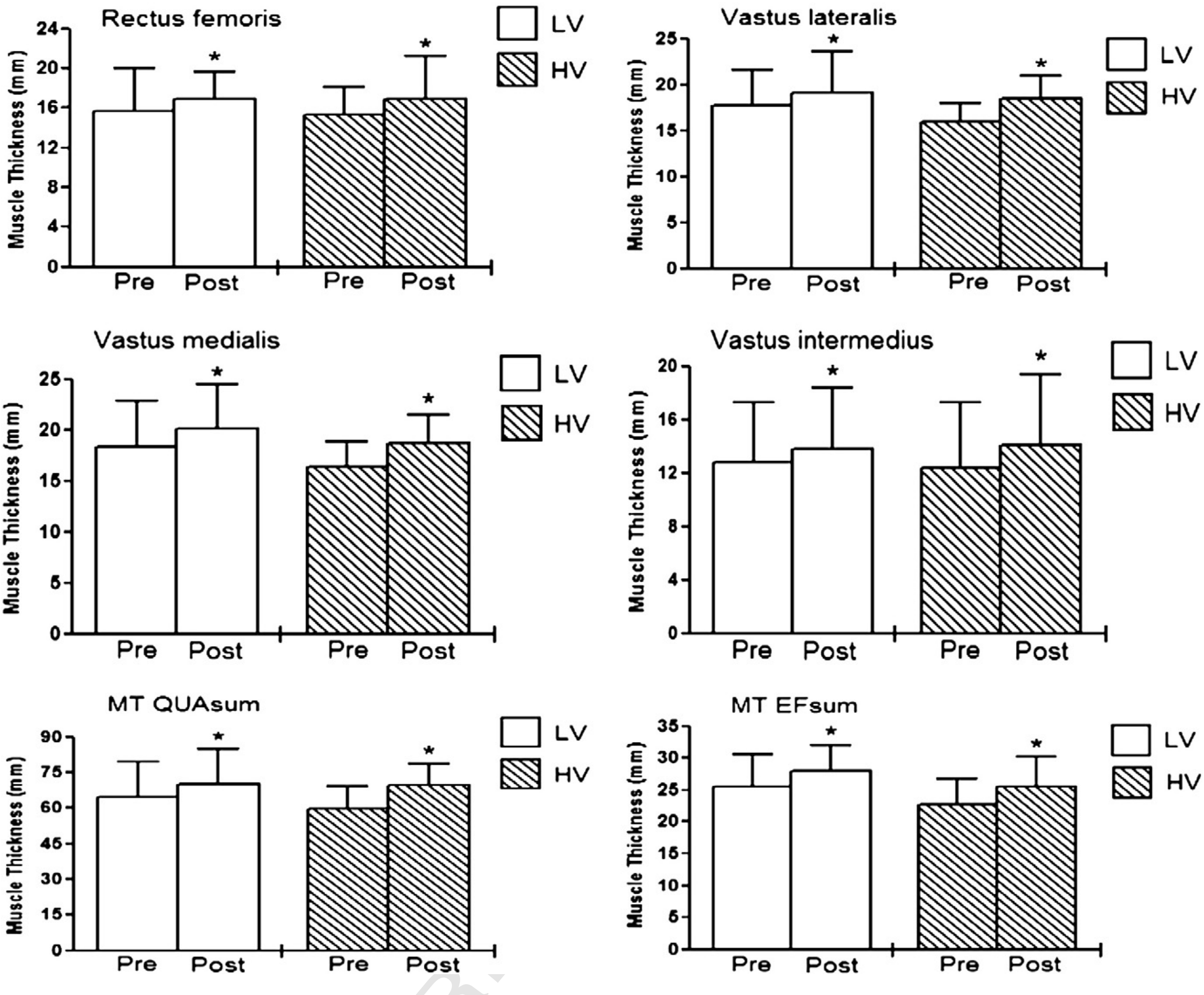

Fig. 2. Absolute values (mean ± SD) of muscle thickness (MT) of the individual quadriceps femoris muscles, MT QUA_{sum} and MT EF_{sum}, before and after 13 weeks of training. *Significant increase from pre training values ($p \le 0.001$).

three-sets) or knee extensor maximal isometric strength (6.3% for one-set and 20.9% for three-set after 20 weeks of training between one- and three-sets). However, three-sets induced greater increases in knee extension 1-RM (20.8% for one-set and 30.9% for three-sets). In contrast to our study, their training groups were not formed exclusively of elderly women (Cannon and Marino used young and elderly women) (Galvão and Taaffe used elderly men and women). This difference makes a detailed comparison with our current results difficult, because the strength gains from the training program may be different for elderly men and women (Beneka et al., 2005; Ivey et al., 2000a) and for young and elderly women (Ivey et al., 2000b; Lemmer et al., 2000). Nevertheless, our results, and the findings of these studies regarding increases in dynamic strength (1-RM), may suggest that during the first 3 months of training, elderly women can significantly increase their lower- and upper-body dynamic strength by utilizing low-volume training. In contrast, after longer periods of training, some muscle groups, such as the knee extensors, may require a greater training volume to provide further strength gains, whereas other muscle groups, such as the elbow flexors, may still show gains with a low training volume (Bottaro et al., 2011; Starkey et al., 1996). Relative to isometric

Table 3
Muscle quality absolute values and percentage (Δ%) change after 13 weeks of training. The results represent means ± SD.

Variable	Low-volume (LV, n = 11)			High-volume (HV, n = 9)		
	Pre	Post	Δ%	Pre	Post	Δ%
MQ_{ST}	0.75 ± 0.19	0.89 ± 0.15	22.2 ± 18.1**	0.77 ± 0.22	0.94 ± 0.26	20.8 ± 19.5**
MQ_{AS}	2.93 ± 0.71	3.57 ± 0.54	25.6 ± 18.8**	2.98 ± 0.87	3.76 ± 1.08	26.3 ± 8.5**
MQ_{EI}	141.3 ± 17.0	123.3 ± 12.7	12.0 ± 9.9*	141.3 ± 20.4	110.4 ± 16.3	20.9 ± 9.2*

MQ_{EI}: muscle quality using the echo intensity images; MQ_{ST}: unilateral knee extension 1-RM (kg)/MT QUA_{sum} (mm); MQ_{AS}: unilateral knee extension 1-RM (kg)/MT QUA_{sum} $(mm)^{0.67}$.

Q3 * $p \le 0.01$; significant increase from pre training values.

** $p \le 0.001$; significant increase from pre training values.

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strength increments, high- and low-volume training appear to promote similar gains in the lower- and upper-body independent of the duration of training. More studies are necessary to elucidate possible mechanisms for this modal difference.

In the present study, the LV and HV groups significantly increased their maximum EMG activity of the BB and VM, with no difference between groups. This increase in maximum EMG activity is related to a higher agonist neural drive caused by changes in the synchronization of motor unit action potentials, motor unit recruitment and firing frequency (Aagaard, 2003). For the quadriceps, we only observed a significant increase in the maximum EMG activity of the VM, corroborating a differential effect of training on individual components of the quadriceps muscle (Rabita et al., 2000). Few studies have analyzed the influence of training volume on maximum EMG muscle activity. Cannon and Marino (2010) observed that one-set and three-sets induced similar increases in maximum EMG activity (average RMS values of the VL and VM) of the quadriceps (19.5 ± 3.5% for one-set and 21.2 ± 5.2% for three-sets). However, this method of summation of the average RMS values from different muscles may complicate the interpretation of the results because the quadriceps muscles show inter-individual variability (Rabita et al., 2000). Additionally, it is desirable to independently consider each component muscle (Rabita et al., 2000). In another study, McBride et al. (2003) examined the effects of low-volume (one-set) and high-volume (six-sets) training on the EMG activity of the VM and BB. After 12 weeks of training, the authors did not observe significant changes in muscle EMG activity for either group. However, our data corroborates that significant neural adaptation may be obtained with low-volume training (Cannon and Marino, 2010).

Using B-mode ultrasound to assess MT is a highly reliable method to measure muscular hypertrophy in response to a strength training program (Abe et al., 2000), mainly when the assessment is performed by the same investigator (Ishida et al., 1992). Although the elderly loses muscle mass with age (sarcopenia), their muscular hypertrophy capacity is retained (Aagaard et al., 2010). Previous studies with elderly subjects comparing upper-body muscle gains using low- and high-volume training are not currently available. However, our findings that corroborate the results of related research with young subjects that indicate low- and high-volume training lead to the development of similar levels of muscular hypertrophy in the upper-body. Ronnestad et al. (2007), found that young men who trained with one-set or three-sets, obtained significant and similar muscular hypertrophy in the trapezius muscle (13.9 ± 2.5% and 9.7 ± 1.4%, respectively) after 11 weeks of training. In a similar study, Bottaro et al. (2011) also observed that one-set and three-sets significantly increased the elbow flexor MT of young subjects (7.2% for one-set and 5.9% for three-sets), with no significant difference between groups. Our data, regarding MT increases in the upper body, confirms the hypothesis that lower training volume per workout may be as efficient as higher volume in developing muscular hypertrophy in the elderly (Ronnestad et al., 2007). There are many published studies regarding muscular hypertrophy in the lower-body related to training volume with young subjects. However, the results are inconsistent. Ronnestad et al. (2007) observed that cross-sectional area (CSA) of the thigh increased significantly greater in the three-set group than in the one-set group (11% vs. 7%, respectively). Recently in a study by Hanssen et al. (2012) the authors found that three-sets induced additional increases in thigh CSA than one-set (12 ± 2% vs. 8 ± 2%, respectively). In addition, they observed that the number of satellite cells in the vastus lateralis, which has a strong relationship with muscle hypertrophy, increased significantly greater in the three-set group (14 ± 7% for one-set and 37 ± 7% for three-sets). In contrast, Starkey et al. (1996) observed a small increase in thigh MT assessed using B-mode ultrasound at 60 and 40% of thigh length, and this increase was similar for the one- and three-set regimens. There is only one study comparing the effects of low- and high-volume strength training on muscular hypertrophy in elderly women. Cannon and Marino (2010) observed that after 10 training weeks, low- and high-volume training produced a similar increase in muscle volume of the quadriceps (7.8 ± 2.0% for one-set and 9.6 ± 2.8% for three-set). However, a comparison with our results is difficult because in their study, the training groups were formed from young and elderly women while our study used exclusively elderly women. Muscle hypertrophy in the upper- and lower-body of elderly women may be associated with different events, such as a reduction in the levels of inflammatory markers and cytokines (e.g., interleukin-6, tumor necrosis factor-α and C-reactive protein) (Ogawa et al., 2010) and a specific increase in the content of Type II muscle fiber satellite cells (Verdijk et al., 2009). In the present study, we did not measure any of the previously mentioned variables. However, our results suggest that low- and high-volume training elicit similar responses in these variables for elderly women during the first three months of training. Thus, additional sets may not induce greater muscle hypertrophy.

The LV and HV training groups in our study, showed significant improvements in MQ_{ST}, MQ_{AS} and MQ_{EI} after the training period, with no difference between groups. Losses in MQ may be related to functional disabilities in the elderly (Tracy et al., 1999), and our results have importance because they suggest that elderly women can significantly improve their lower body muscle quality using a low volume strength training program. There are several studies showing improvement in the MQ of elderly people following a strength training regime (Ivey et al., 2000b; Tracy et al., 1999); however, this study is the first, to our knowledge, to compare the effects of different volumes of strength training on MQ_{AS} and MQ_{EI}. Although MQ_{ST}, MQ_{AS} and MQ_{EI} are all forms of MQ, improvement in each may be related to different mechanisms. Improvements in MQ_{ST} and in MQ_{AS} appear to occur for one of the following reasons: neural adaptation, such as an increase in the activation of synergistic muscles, motor unit recruitment and discharge rate; decreased activation of antagonist muscles (Aagaard, 2003); or alterations in muscle architecture. In our study, both groups demonstrated significant muscle hypertrophy and an increase in muscle EMG activity, which might be responsible for the improvements in MQ_{ST} and MQ_{AS}. Thus, our results reiterate the idea that measuring MQ_{ST} may be a better indicator of muscle function than measuring strength alone (Dutta et al., 1997). Whereas, improvement in MQ_{ST} and MQ_{AS} should result from neuromuscular alterations, improvement in MQ_{EI} may be related to changes in skeletal muscle composition. Previous studies have suggested that age-related increases in the echo intensity of lower muscles are caused by the replacement of contractile tissue by fat and fibrous (Arts et al., 2010). Fat accumulation in the lower-body is harmful, because this may impair the glucose control of elderly people, increasing their exposure to metabolic risk factors (Goodpaster et al., 2003). Previous studies observed a reduction in the relative amount of intramuscular fat in elderly women and an improvement in the MQ_{EI} after a strength-training program (Sipila and Suominen, 1995, 1996). The results of our present study corroborate the findings that strength training can improve MQ_{EI} of the lower-body. Furthermore, our findings demonstrate that low- and high-volume training were similarly efficient in improving MQ_{EI} of the lower-body. Moreover, this change in muscular composition may increase muscular strength and performance in the activities of daily living, because the accumulation of fat in the knee muscle is associated with poor lower-body performance (Visser et al., 2002).

5. Conclusion

In summary, the results of the present study demonstrate that a 13-week progressive strength training regimen, with low- and high-volume, performed only twice a week promoted similar gains in dynamic and isometric maximal strength of the upper- and lower-body, as well as muscle quality of the lower-body in elderly women. These results have important practical applications because the results indicate that low-volume training, which requires less time to complete and thus enhances exercise participation and adherence (Carpinelli and Otto, 1998; Galvão and Taaffe, 2005), can mitigate several important

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impairments caused by the aging process and that this improvement is equivalent to that for high-volume training.

Conflict of interest

There is no conflict of interest.

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