Effects of strength training and detraining on knee extensor strength, muscle volume and muscle quality in elderly women

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Abstract Strength training seems to be an interesting approach to counteract decreases that affect knee extensor strength, muscle mass and muscle quality (force per unit of muscle mass) associated with ageing. However, there is no consensus regarding the changes in muscle mass and their contribution to strength during periods of training and detraining in the elderly. Therefore, this study aimed at verifying the behaviour of knee extensor muscle strength, muscle volume and muscle quality in elderly women in response to a 12-week strength training programme followed by a similar period of detraining. Statistical analysis showed no effect of time on muscle quality. However, strength and muscle volume increased from baseline to post-training (33 and 26 %, respectively). After detraining, the knee extensor strength remained 12 % superior to the baseline values, while the gains in muscle mass were almost completely lost. In conclusion, strength gains and losses due to strength training and detraining, respectively, could not

be exclusively associated with muscle mass increases. Training-induced strength gains were partially maintained after 3 months of detraining in elderly subjects.

Keywords Strength training · Knee extensor muscle · Muscular adaptations

Introduction

Muscle weakness observed in older adults is related to the loss of functionality and independence. It also decreases quality of life in the elderly and is closely associated with morbidity and mortality (Doherty 2003; Macaluso and De Vito 2004). It was originally thought that the loss of muscle mass largely explained muscle weakness in the elderly (Grimby and Saltin 1983). However, longitudinal ageing studies indicate a clear dissociation between the loss of muscle mass and strength, as they do not follow the same time course and have different magnitude (Delmonico et al. 2009; Goodpaster et al. 2006; Hughes et al. 2001; Frontera et al. 2000). In addition, cross-sectional studies demonstrated a higher correlation between strength and muscle mass in youngsters compared to the elderly (Hakkinen and Hakkinen 1991; Overend et al. 1992; Macaluso et al. 2002). These findings suggest that other physiological factors (not related to the amount of muscle tissue) play important roles in the strength loss observed in the elderly (Clark and Manini 2008). Therefore, despite the existence of a clear relationship between the phenomena of

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dynapaenia (strength fall) and sarcopaenia (loss of muscle mass), these muscular adaptations to ageing should be investigated separately (Clark and Manini 2008).

The relationship between strength and muscle size has been described as “muscle quality” by several scientists and clinicians (Delmonico et al. 2009; Brooks et al. 2007; Goodpaster et al. 2006; Kostek et al. 2005; Katsiaras et al. 2005; Newman et al. 2003, 2006; Lynch et al. 1999; Metter et al. 1999; Doherty 2003; Russ et al. 2012; Ivey et al. 2000; Hairi et al. 2010). Scientists have assessed muscle strength through tests performed in isometric dynamometers, isokinetic dynamometers and dynamic repetitions with free weights, while muscle mass has been assessed through the muscles’ anatomical cross-sectional area, muscle thickness and muscle volume. Therefore, independent of the tests used, muscle quality is described as the specific force per unit of muscle mass and is considered a better marker of muscle function than absolute strength (Doherty 2003).

Because knee extensor muscle strength is an estimator of elderly survival time (Frontera et al. 2000; Newman et al. 2006), the maintenance and/or improvement of knee extensor muscle functionality has received considerable attention from gerontologists, and strength training for the elderly seems a useful approach (Hunter et al. 2004). Most studies involving strength training in elderly subjects have demonstrated significant increases in knee extensor muscle strength; the magnitudes of the relative increases vary between 10 and 257 % (for a review, see Hunter et al. (2004)). However, the effects of detraining periods on muscle strength in older adults remain unclear. Whereas some studies reported full loss of the training-induced strength gains after 6 (Hakkinen et al. 2000), 8 (Ivey et al. 2000) and 12 months of detraining (Connelly and Vandervoort 1997), other reports suggest that strength gains are partially maintained after 3 (Carvalho et al. 2009), 5 (Harris et al. 2007) and even 12 months (Fatouros et al. 2005) of detraining. Moreover, there is no consensus regarding the change in muscle mass and its contribution to strength during periods of training and detraining in the elderly.

This study aimed at verifying the behaviour of knee extensor muscle strength, muscle volume and muscle quality in elderly women in response to a 12-week strength training programme followed by a period of detraining, as studies on detraining are rare. Our first hypothesis was that knee extensor strength and muscle mass would increase with training, but the relative increment of strength would be higher than the relative

increment of muscle size, leading to higher muscle quality. The second hypothesis was that 3 months of detraining would be insufficient to promote the full loss of strength gains but would be sufficient to completely reverse the training-induced muscle mass gains.

Methods

Subjects

Ten sedentary elderly women aged 67 ± 5 years with a mean height of 158.1 ± 10.2 cm, a mean body mass of 68.7 ± 5.3 kg and a mean body fat composition of 38.0 ± 5.3 % participated in the study. Subjects were not engaged in any type of systematised strength training programme for at least 1 year prior to the study, and they were recruited through an advertisement in a wide-circulation daily newspaper. The authors interviewed all volunteers and included only subjects without any history of severe endocrine, metabolic and neuromuscular diseases. Each selected volunteer was informed about the methodological procedures of the study and agreed to participate by signing an informed consent document, which was approved by the Institutional Ethics and Research Committee (Protocol No. 19322).

Experimental design

This was a longitudinal study with the volunteers performing three knee extensor evaluations with 12 weeks between evaluations. One week before the first evaluation, all subjects were familiarised with the strength training exercise programme and performed a one maximum repetition (1RM) test on a knee extensor exercise machine. In each evaluation session, knee extensor ultrasound images were taken, and the 1RM test was performed on the knee extensor machine. These results were used for subsequent assessments of muscle quality. Between the first and second evaluations, subjects performed the strength training programme, and between the second and the third evaluations, they were instructed to not perform any type of strength exercises for the knee extensor muscles.

Strength training programme

The strength training programme was performed twice a week, with an interval of 48 h between training

sessions. Before the start of the training period, subjects completed a familiarisation session to practise the exercises they would further perform during the training sessions. All subjects performed exercises for the lower limbs (leg press, knee extension and leg curl) and for the upper limbs (biceps curl, triceps extension, lat pull-down, shoulder press, bench press, and abdominal crunch). In each training session, subjects performed specific muscle stretching and a specific warm up (one set of 25 repetitions with very light loads) prior to the exercises. The training programme had a progressive increase of intensity and volume (Cadore et al. 2011a, b; Kraemer and Ratamess 2004), with the subjects performing two sets of each exercise with 15–20 repetitions maximum (RM; i.e. the heaviest possible weight was used for the designated number of repetitions) during weeks 1–3, progressing to three sets of 12–15 RM during weeks 4–6, three sets of 10–12 RM during weeks 7–9 and four sets of 8–10 RM during weeks 10–12. A 120-s time interval was respected between sets and exercises. The duration of each training session lasted approximately 45 min.

Muscle strength evaluation

The knee extensor 1RM test of the dominant lower limb was performed through a knee extensor exercise with the same “extension chair” equipment used for the training sessions (WORLD-ESCUPTOR, Brazil, resolution=1 kg). To control the movement speed during the test, a QUARTZ metronome with a 1-Hz resolution was used (for test details, see Correa et al. 2012). There were no significant differences between the 1RM tests at baseline (test=41.02±7.71 kg; retest=42.52±8.15 kg), and the intraclass correlation coefficient was 0.89.

Muscle volume evaluation

Morphologic changes due to training and detraining were evaluated through images obtained with a B-mode ultrasound device (Philips, VMI, Indústria e Comércio Ltda. Lagoa Santa, MG, Brazil) with a 7.5-MHz transducer. A water-based gel was used to promote acoustic contact between the skin and the transducer, which was positioned on the rectus femoris muscle at two-thirds of the distance from the greater trochanter of the femur to the lateral epicondyle and 3 cm lateral from the limb midline (Abe et al. 2011). The subcutaneous

adipose tissue and bone tissue were identified on the ultrasound image, and the distance between them was defined as the muscle thickness. When thickness reliability was assessed, variations were less than 3 % (Abe et al. 2000; Nogueira et al. 2009). All ultrasound images were acquired from the dominant limb of the subject by the same evaluator, and maps were developed to ensure that images from the three evaluations were obtained at the same location of the muscle belly. Finally, the knee extensor muscle volume was obtained through the method described by Miyatani et al. (2004), where the muscle volume (MV) is calculated by taking into account the muscle thickness (MT) and the thigh length (TL) through the equation: $MV = (MT \cdot 320.6) + (TL \cdot 110.9) - 4437.9$.

Muscle quality evaluation

The 1RM value of the dominant leg was divided by the muscle volume of the dominant leg to determine muscle quality. Therefore, muscle quality was expressed as strength per unit of muscle volume (kg/cm³), as performed by Ivey et al. (2000).

Statistical analysis

Data normality was determined by a Shapiro–Wilk exploratory test. Training and detraining effects on the absolute values of muscle strength, muscle volume and muscle quality were tested through a one-way ANOVA, followed by a Bonferroni post hoc test. Additionally, relative changes (values normalised to the baseline value from each subject) were calculated to determine the training and detraining effects on the knee extensor strength, muscle volume and muscle quality. All tests were performed in SPSS version 17.0. A value of $p < 0.05$ was considered significant for all analyses.

Results

Significant time effects were observed for strength ($p < 0.001$) and muscle volume ($p < 0.001$). Twelve weeks of strength training improved the absolute values of maximal dynamic strength ($p < 0.001$) and muscle volume ($p = 0.002$), whereas the 12 weeks of detraining significantly reduced muscle strength ($p = 0.042$) and muscle volume ($p = 0.002$). There was no time effect ($p = 0.922$) for muscle quality from baseline to post-training and

from post-training to post-detraining. The absolute values of maximal dynamic strength, muscle volume and muscle quality are shown in Table 1.

Figure 1 illustrates the behaviour of knee extensor strength, muscle volume and muscle quality during the 24-week intervention protocol through the values normalised by the baseline evaluation. The knee extensor strength changes due to the training programme were slightly superior to changes in muscle volume, leading to a discrete increase in muscle quality. The detraining period promoted almost full reduction of the muscle volume gains, but the strength remained higher than the baseline values, leading to a higher muscle quality compared to baseline values.

Discussion

The major finding of this study was that a strength training programme promoted a significant increase in knee extensor strength and volume, while both of these parameters decreased with detraining. Although statistical analysis revealed no effect of training or detraining on muscle quality, we observed larger changes in the maximal dynamic strength in relation to muscle volume after training and a smaller strength reduction compared to the loss of muscle volume after detraining (see Fig. 1). In other words, muscle volume gains induced by training were completely lost in the detraining period, but the strength level verified after the detraining remained higher than the strength level observed before the training programme, suggesting higher muscle quality after detraining compared to the baseline evaluation.

Strength adaptations are influenced by several factors, such as subject's characteristics (e.g. gender, age, body composition and conditioning level) and training

Table 1 Absolute values (mean $\pm$ SD) for the one maximum repetition test, muscle volume and muscle quality at baseline, post-training and post-detraining

	Baseline	Post-training	Post-detraining
1RM (kg)	43.60 $\pm$ 6.33	57.90 $\pm$ 7.98 ^a	47.60 $\pm$ 7.78 ^b
MV (cm ³)	656.86 $\pm$ 210.94	820.14 $\pm$ 255.22 ^a	661.12 $\pm$ 182.71 ^b
MQ (kg/cm ³)	0.07 $\pm$ 0.03	0.08 $\pm$ 0.03	0.08 $\pm$ 0.02

1RM one maximum repetition, MV muscle volume, MQ muscle quality

^aSignificant difference from baseline ($p < 0.05$)

^bSignificant difference from post-training ($p < 0.05$)

Fig. 1 Percent change values (mean $\pm$ SEM) for one maximum repetition (1RM) test, muscle volume (MV) and muscle quality (MQ)

periodization (e.g. number of training weeks, weekly frequency, training volume, intensity of exercise and type of exercise) (Kraemer and Ratamess 2004). Although these factors impair comparisons with other studies involving strength training in older subjects, the magnitude of the knee extensor strength gains due to strength training observed in our study agrees with previous findings in this population (Hunter et al. 2004). Similarly, although some studies reported no changes in knee extensor muscle mass (Brooks et al. 2007; Fatouros et al. 2005; Nogueira et al. 2009), our results for muscle volume corroborate previous findings favouring a significant hypertrophic response induced by strength training in the elderly population (Ivey et al. 2000; Hakkinen et al. 2000; Kostek et al. 2005).

Despite the fact that the 1RM test is not considered for functional evaluation (as functionality involves other parameters in addition to maximal muscle strength), a high correlation has been observed between this test and functionality in elderly subjects (Carabello et al. 2010). Moreover, knee extensor muscle strength seems to be a good predictor of independence level and an estimator of elderly survival time (Frontera et al. 2000; Newman et al. 2006). Therefore, the improvements in the 1RM test values after training in our study may be interpreted as an indicator of an improved ability of the elderly to perform their daily life activities, reinforcing the importance of strength exercise in this population.

The strength gains observed in this study were clearly related to increased muscle volume. However, the higher relative change in strength compared with that of muscle volume suggests that other factors are related to training-induced strength gains. Review studies already showed the reduction of knee extensor activation capacity with ageing (Doherty 2003; Macaluso and De Vito 2004),

and the benefits of strength training for activation capacity in elderly subjects have already been reported (Hakkinen et al. 2000). These neuromuscular adaptations are most likely responsible for the improvements in muscle quality observed in our study after the training programme. However, as we did not assess neuromuscular responses to training and detraining, this type of adaptation needs further investigation.

Our findings reinforce the results of previous studies on the maintenance of training-induced strength gains in elderly people (Carvalho et al. 2009; Harris et al. 2007; Fatouros et al. 2005). However, the novelty of our study is that it shows that the partial maintenance of strength after 12 weeks of detraining is not associated with the muscle mass gains induced by the strength training. After detraining, the subjects presented strength capacity that was 12 % higher than that observed before the strength training programme, while muscle volume practically returned to baseline values. In other words, with a very similar amount of muscle mass, the subjects were able to maintain higher levels of strength after 12 weeks of detraining compared to the baseline evaluation, suggesting that other aspects not related to the amount of muscle mass (i.e. neuromuscular adaptations or intrinsic muscular factors) were responsible for the maintenance of strength capacity.

One limitation of this study that should be addressed is related to the methods used to evaluate maximal strength and knee extensor muscle volume. Although 1RM tests and ultrasound evaluations had high reliability, it is possible that tests with higher accuracy, such as isokinetic evaluations and magnetic resonance images, could improve the muscle quality estimation. However, the tests that we chose are more accessible to clinicians, and our results can be compared more closely with measurements made by health professionals on their patients.

Despite the above-mentioned limitations, another important aspect of our study is the applicability of our findings. In addition to reinforcing the body of evidence regarding the effectiveness of strength training for increasing strength and muscle mass (Hunter et al. 2004), this study demonstrated that strength gains induced by strength training can be partially maintained after a detraining period. These findings have important clinical significance for patients and health professionals because: (1) the knee extensor strength, and not the knee extensor muscle volume, is greatly responsible for functionality and lifespan in the elderly (Newman et al. 2006; Frontera et al. 2000); and (2) seniors may have a

higher propensity for training disruptions related to planned or unplanned factors that range from illness to vacations (Nelson et al. 2007).

Conclusion

Twelve weeks of a systematised strength training programme was effective for increasing knee extensor strength and muscle volume. A similar period of detraining fully decreased the muscle volume, but strength was partially maintained. Although muscle quality did not change, the magnitude of the changes in the maximal dynamic strength and muscle volume suggest that adaptations in muscle mass to training and detraining cannot fully explain the strength adaptations. Moreover, our findings suggest that disruptions in training can occur in the elderly without a total loss of muscle strength gains.

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