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ORIGINAL ARTICLE

Comparison of muscle hypertrophy following 6-month of continuous and periodic strength training

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Abstract To compare the effects of a periodic resistance training (PTR) program with those of a continuous resistance training (CTR) program on muscle size and function, 14 young men were randomly divided into a CTR group and a PTR group. Both groups performed high-intensity bench press exercise training [75 % of one repetition maximum (1-RM); 3 sets of 10 reps] for 3 days per week. The CTR group trained continuously over a 24-week period, whereas the PTR group performed three cycles of 6-week training (or retraining), with 3-week detraining periods between training cycles. After an initial 6 weeks of training, increases in cross-sectional area (CSA) of the triceps brachii and pectoralis major muscles and maximum isometric voluntary contraction of the elbow extensors and 1-RM were similar between the two groups. In the CTR group, muscle CSA and strength gradually increased during the initial 6 weeks of training. However, the rate of increase in muscle CSA and 1-RM decreased gradually after that. In the PTR group, increase in muscle CSA and strength during the first 3-week detraining/6-week retraining cycle were similar to that in the CTR group during the corresponding period. However, increase in muscle CSA and strength during the second 3-week detraining/6-week retraining cycle were significantly higher in the PTR group than in the CTR group. Thus, overall improvements in muscle CSA and strength were similar between the groups. The results indicate that 3-week detraining/6-week retraining cycles result in muscle hypertrophy similar to that occurring with continuous resistance training after 24 weeks.

Keywords Muscle hypertrophy · Frequency of training · Resistance training · Detraining · Retraining

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Introduction

The American College of Sports Medicine and the American Geriatrics Society recommend that to achieve muscle hypertrophy and increased strength, the frequency of progressive resistance training should be 2–3 days (sessions) per week (ACSM 1998, 2009; AGS 2001; Garber et al. 2011). It is believed that the acquired training effects may be maintained by as little as a single session per week of high-intensity exercise (Trappe et al. 2002), while anything below this weekly training session will not maintain the acquired muscle adaptations. Thus, exercise must be continued on a regular basis, at least once a week, to maintain the effects of training.

It is known that the muscle adaptations resulting from resistance training are less likely to increase after several months of continuous training compared with those achieved during the early phase (<3 months) of training. A

review of previous resistance training studies indicated that the relative increase in the cross-sectional area (CSA) of the thigh and upper arm muscles following approximately 3 months of training (mainly 2–3 sessions per week) was, on an average, 0.11 and 0.20 % per day, respectively (Wernbom et al. 2007). After relatively long-term (5–6 months) resistance training, however, the average increase in thigh muscle CSA was about 0.05 % per day (Bemben et al. 2000; Hakkinen et al. 1998, 2000, 2003; Hulmi et al. 2009; Narici et al. 1996). Therefore, the relative increase in muscle CSA after 5–6 months of training is probably half that during the early phase of training.

Interestingly, after short-term (<1 month) cessation of training (detraining), muscle adaptation responses may return to their initial levels, and the effects of retraining after short-term cessation on muscle growth are comparable with those observed during the early phase of training (Ogasawara et al. 2011). During short-term detraining, the rate of decrease (percent change per day) in muscle CSA is similar to (Andersen et al. 2005; Narici et al. 1989) or even less than (Leger et al. 2006; Ogasawara et al. 2011) the increase in muscle CSA during the early phase of training. Thus, if the detraining period is followed by a longer period of retraining, and if the retraining phase has an effect similar to that of the early phase of training, then muscle CSA may improve. For example, assuming that the decrease in thigh muscle CSA during 3 weeks of detraining is 2.1 % (estimated at 0.10 % per day and 21 days) (Narici et al. 1989), and the increase in muscle CSA during 6 weeks of retraining is 5.9 % (estimated at 0.14 % per day and 42 days) (Narici et al. 1989), the increase in muscle CSA during a 3-week detraining/6-week retraining period (estimated at 0.06 % per day during 9 weeks) would be 3.8 %. The estimated value of 0.06 % per day is similar to values obtained in previous studies, where the average increase in thigh muscle CSA was reportedly around 0.05 % per day (Bemben et al. 2000; Hakkinen et al. 1998, 2000, 2003; Hulmi et al. 2009; Narici et al. 1996).

Therefore, we hypothesized that a 3-week detraining/6-week retraining cycle could produce training effects similar to those produced by a relatively long and continuous resistance training program (5–6 months). The present study aimed to compare the effects of a periodic resistance training program with those of a continuous resistance training program on muscle size and function.

Methods

Subjects

Fourteen healthy young men volunteered to participate in this study (age 25 ± 3 years, standing height 1.72 ± 0.06 m, body mass 65 ± 10 kg). All subjects were examined by a physician, and none had any medical problems that would confound the data from these experiments. They were considered to be untrained and had not participated in any regular resistance exercise program for at least 2 years prior to the start of this study. Before participating in the study, the subjects were informed of the methods, procedures, and risks, following which they signed an informed consent document. The study was conducted according to the Declaration of Helsinki and was approved by the Ethics Committee for Human Experiments of the University of Tokyo, Japan. The subjects were randomly divided into either a continuous resistance training group (CTR, $n = 7$) or a periodic resistance training group (PTR, $n = 7$).

Resistance training protocol

Both groups performed high-intensity, free-weight bench press exercise training 3 days per week. The CTR group trained continuously over a 24-week period, while the PTR group performed 2 cycles of a 3-week detraining/6-week retraining period after a 6-week initial training period. Training intensity was set at 75 % of one repetition (rep) maximum (1-RM), and training volume was set at 3 sets of 10 reps (with 2–3 min rest between sets). To ensure an adequate training load, all training sessions were overseen by a supervisor. Training load was renewed every 3 weeks, and, if subjects could perform 12 reps or more at the 3rd set during training sessions, the training load was increased by about 5 % for the next training session. During the detraining period, subjects in the PTR group maintained their normal activities.

1-RM strength tests

Two to 3 weeks before study initiation, all subjects completed two familiarization sessions with submaximum loads (~50 % of predicted 1-RM), where they received instructions on proper lifting technique. As a warm-up 1 week before the study, the subjects performed 5–6 unilateral bench press exercises with a low load (~30–40 % of predicted 1-RM). After warming up, the load was set at ~80 % of the predicted 1-RM. Following each successful lift, the load was increased by ~5 % until the subject failed to lift the load through his entire range of motion. A test was considered valid if the subject used proper form and completed the entire lift in a controlled manner without assistance. On an average, six trials were required to complete a 1-RM test (3–5 min rest between each attempt). 1-RM was also assessed every 3 weeks during training for each subject. During training sessions as well as 1-RM testing, the grip width was set at 200 % of the biacromial

breadth. The coefficient of variation (CV) for these measurements from tests to retests was 1.7 %.

Measurement of maximum voluntary isometric contraction (MVC) of the elbow extensors

MVC of the elbow extensors was determined using an isokinetic dynamometer (Biodex System 3, Biodex Medical Systems Inc., Shirley, NY, USA). A subject sat comfortably on a chair, with the arm positioned on a firm and stable table at chest level and an elbow joint angle of 90° (0° at full extension). The upper arm was maintained in the horizontal plane (at 90°), while the subject's wrist was fixed at the end of the lever arm in a position halfway between supination and pronation. The elbow extension torque was measured with a transducer, while a diagonal strap was secured over the elbow to maintain a stationary position during MVC. Each subject was instructed to contract as rapidly and as forcefully as possible. MVC was measured three times, and the maximum value was used. A 1-min rest was allowed between trials to eliminate the effects of fatigue. The MVC test was performed before and every 3 weeks during the study. The CV for these measurements from tests to retests was 3.1 %.

Electromyography (EMG) measurements

EMG activity during MVC of elbow extensors was recorded. The skin was shaved, abraded with a skin preparation gel (Skinpure, Nihon Kohden, Japan), and cleaned with alcohol wipes. During all experiments, skin impedance was <2 kΩ. The ground electrode was positioned on the lateral epicondyle. Bipolar electrodes (Vitrode F, Ag/AgCl, 1-cm diameter, Nihon Kohden, Tokyo, Japan) were placed over the belly of the muscle with a constant interelectrode distance of 20 mm. The electrodes were connected to a preamplifier of a differential amplifier having a bandwidth of 0 Hz–500 kHz (AB 6216, Nihon Kohden, Tokyo, Japan). EMG signals were collected continuously from the triceps brachii (TB; an agonist muscle) and the biceps brachii (BB; an antagonist muscle) muscles at a sampling rate of 1,024 Hz using a 12-bit analog-to-digital converter (Macintosh, Power PC 750, Apple, Japan). To determine integrated EMG activity (iEMG), signals were fully rectified and integrated (Power Lab Chart 5 software, ADInstruments, Japan). iEMG in the BB muscle was normalized as a percentage of the maximum isometric value of the muscle when it was acting as an agonist, and this value was used to calculate the level of antagonist coactivation during elbow extension. EMG activity was quantified over a period of 1,000 ms around the peak torque of each contraction. The CV for these measurements from tests to retests was 1.9 %.

Rate of force development

The maximum rate of force development (RFD) was calculated during the MVC trials. RFD was equal to the steepest slope calculated for a 20-ms interval, and the maximum value was used. The CV for these measurements from tests to retests was 4.6 %.

Muscle size measurements

Multi-slice magnetic resonance imaging (MRI) of the upper arm and chest was performed using a General Electric Yokogawa Signa 0.2-T scanner (Milwaukee, WI, USA). A T1-weighted, spin-echo, axial plane sequence was generated with a 520-ms repetition time and a 20-ms echo time. The subject rested quietly in the magnet bore in a supine position with his arms extended. The lateral epicondyle of the humerus was used as the point of origin, and continuous transverse images of 1.0-cm slice thickness were obtained from the lateral epicondyle of the humerus to the acromial process of the scapula. All MRI data were transferred to a personal computer for analysis using specially designed image analysis software (TomoVision Inc., Montreal, Canada). For each slice, skeletal muscle CSA was digitized, and the muscle tissue volume (cm^3) per slice was calculated by multiplying muscle tissue area (cm^2) with slice thickness (cm). The CSA at 25, 50, and 75 % from the lateral epicondyle of the humerus to the acromial process of the scapula and the belly of the TB (TB-CSA) and pectoralis major (PM; PM-CSA) muscles was determined for three continuous slices using the same slice number from the point of origin. These were averaged for statistical analysis. Muscle volume of the individual muscle was defined as the summation of the slices of muscle. These measurements were performed before the study and after the training/retraining (weeks 6, 15, and 24) and detraining (weeks 9 and 18) periods in the PTR group. Measurements for the CTR group were performed at the same time points as those for the PTR group. The CV for these measurements was <1 %.

Statistical analysis

Results are expressed as mean and standard deviations (SD). Changes in CSA, 1-RM, MVC, agonist and antagonist iEMG, RFD, and RFD/MVC were compared by two-way ANOVA with repeated measures (group $\times$ time). Post hoc analyses used *t* tests with the Benjamini and Hochberg False Discovery Rate correction for multiple comparisons. All baseline characteristics and relative changes over the 24-week period were compared between groups by Student's *t* test. The magnitude of changes in muscle size and

strength was also compared between the detraining and retraining periods by one-way ANOVA. Significance was set at $P < 0.05$. All analyses were performed using JMP statistical software, version 8.0 (SAS Institute, Cary, NC, USA).

Results

Baseline characteristics

At baseline, there were no significant differences in age and anthropometric variables between the CTR and PTR groups. MVC, dynamic 1-RM strength, and muscle CSA and volume of TB and PM muscle were also similar between the two groups (Table 1).

Effects of initial 6-week training in both groups

There was no difference in training volume (load × reps) after initial 6 weeks of training between groups (CTR 20,385 kg, PTR 19,417 kg). After the initial 6 weeks of training, the increase in muscle strength (1-RM and MVC), TB-CSA, and PM-CSA were similar between the two groups (Fig. 1). The rate of increase in TB-CSA and PM-CSA was similar, i.e., approximately 0.23 and 0.39 % per day, respectively, between both groups (Fig. 2).

Effects of training in the CTR group

MVC, dynamic 1-RM strength, TB-CSA, and PM-CSA gradually increased after the initial 6 weeks of training (Fig. 1). However, the rate of increase in muscle CSA and dynamic strength gradually declined with time throughout the training period; the rate during the initial 0–6 weeks was significantly greater than that during weeks 9–15, weeks 15–18, and weeks 18–24 (Fig. 2). After the 24-week training period, the rate of average increase in TB-CSA and PM-CSA was 0.13 and 0.22 % per day, respectively. The rate of increase in MVC tended to be greater during the initial 0–6 weeks compared with that during weeks 6–9, although these rates were not significantly different (Fig. 2). Although RFD and agonist iEMG gradually increased with training (time effect $P < 0.05$), there were no significant changes in RFD and agonist iEMG between each training period (Figs. 3, 4).

Table 1 Descriptive characteristics and effects of 24 weeks of training on maximal strength (1-RM and MVC) and muscle size (muscle CSA and volume)

	CTR ($n = 7$)			PTR ($n = 7$)		
	Pre	Post	Change (%)	Pre	Post	Change (%)
Age (years)	25.1 ± 3.2			24.3 ± 1.9		
Height (cm)	173 ± 8			170 ± 3		
Body mass (kg)	65.4 ± 6.2	66.6 ± 7.2*		65.1 ± 12.8	66.5 ± 13.2*	
1-RM (kg)	51.1 ± 9.9	77.4 ± 16.9*	51.3	47.1 ± 10.6	70.4 ± 13.6*	50.0
MVC (Nm)	30.8 ± 6.7	39.2 ± 6.7*	28.7	30.0 ± 6.4	38.9 ± 6.8*	31.3
Muscle CSA (cm^2)						
TB						
Belly	22.2 ± 4.3	26.6 ± 3.9*	21.0	20.2 ± 2.3	24.1 ± 2.4*	19.3
25 %	14.3 ± 2.5	17.0 ± 2.9*	19.5	13.0 ± 3.5	15.4 ± 3.1*	20.0
50 %	21.5 ± 3.5	25.8 ± 2.8*	20.9	19.4 ± 2.5	23.2 ± 2.7*	19.7
75 %	19.8 ± 5.3	23.5 ± 5.5*	19.8	16.2 ± 1.7	19.5 ± 2.0*	18.9
PM						
Belly	29.7 ± 6.4	40.6 ± 8.7*	36.9	26.3 ± 4.8	35.5 ± 7.3*	35.0
25 %	15.2 ± 5.7	20.7 ± 7.7*	36.3	15.7 ± 3.9	21.1 ± 15.5*	34.3
50 %	27.7 ± 5.8	38.0 ± 8.3*	37.3	26.8 ± 5.6	36.6 ± 8.8*	36.2
75 %	25.2 ± 3.4	35.1 ± 3.1*	40.0	24.0 ± 4.0	32.9 ± 6.3*	37.3
Muscle volume (cm^3)						
TB	263 ± 65	316 ± 70*	21.4	246 ± 31	293 ± 33*	19.6
PM	276 ± 66	383 ± 96*	39.4	253 ± 51	346 ± 78*	36.1

Values are mean ± SD

CTR continuous training group, *PTR* periodic training group, *CSA* cross-sectional area, *1-RM* one repetition maximum, *MVC* maximal voluntary isometric contraction, *TB* triceps brachii, *PM* pectoralis major

* $P < 0.05$ versus Pre

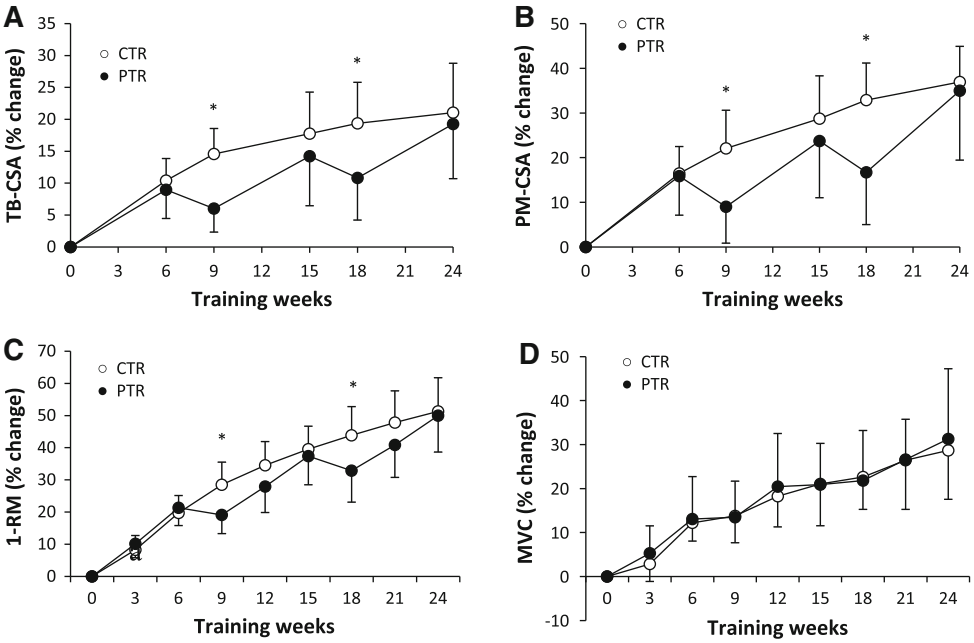

Fig. 1 Time course of changes in cross-sectional area (*CSA*) of **a** the triceps brachii (TB) muscle (*TB-CSA*) and **b** the pectoralis major (PM) muscle (*PM-CSA*), **c** one-repetition maximal (*1-RM*) strength, and **d** maximum voluntary isometric contraction (*MVC*) of the elbow extensors *Significantly different from that in the periodic training group; $P < 0.05$. *CTR* continuous training group, *PTR* periodic training group

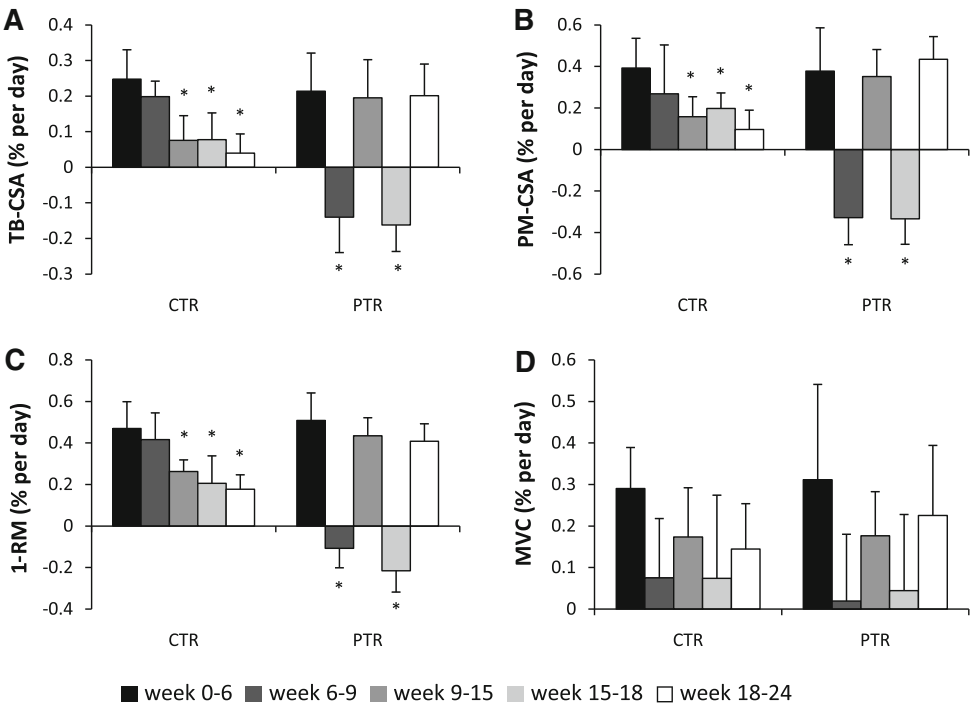

Fig. 2 Rate of change in **a** the cross-sectional area (*CSA*) of the triceps brachii (TB) muscle (*TB-CSA*), **b** CSA of the pectoralis major (PM) muscle (*PM-CSA*), **c** one-repetition maximal (*1-RM*) strength and maximum voluntary isometric contraction (*MVC*) of the elbow extensors, and **d** maximum strength during periodic resistance training (*PTR*) and continuous resistance training (*CTR*). *Significantly different from that during weeks 0–6; $P < 0.05$

Effects of training in the PTR group

During the first (weeks 6–9) and second (weeks 15–18) 3-week detraining periods, the decrease in TB-CSA was 2.6 % (0.14 % per day) and 2.9 % (0.16 % per day), respectively. In contrast, the increase in TB-CSA during the first (weeks 9–15) and second (weeks 18–24) 6-week retraining periods was 7.6 % (0.20 % per day) and 7.5 % (0.20 % per day), respectively. There were no significant differences in the increase in TB-CSA between the initial 6-week training period and the first and second 6-week retraining periods (Fig. 2). Therefore, during the first and second 3-week detraining/6-week retraining cycles, TB-CSA increased by 5.0 and 4.6 %, respectively. The rate of average increase in TB-CSA was 0.11 % per day after the 24-week experimental period. Similar results were observed for the PM muscle; the rate of average increase in PM-CSA was 0.21 % per day after the 24-week period.

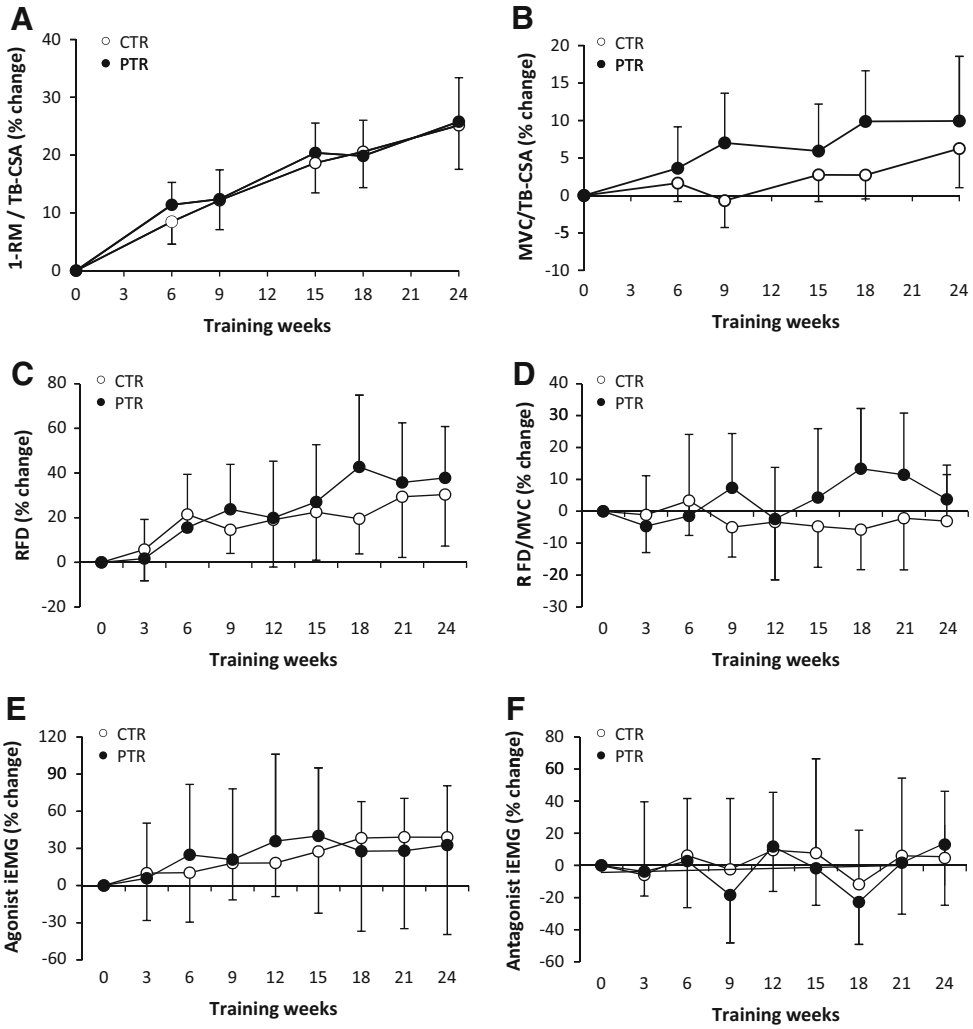

Fig. 3 Time course of changes in **a** relative one-repetition maximal (*1-RM*) strength/cross-sectional area (*CSA*) of the triceps brachii (TB) muscle (*TB-CSA*), **b** relative maximum voluntary isometric contraction (*MVC*) of the elbow extensors/TB-CSA, **c** rate of force development (*RFD*), **d** RFD/MVC, and **e** integrated electromyographic activity (iEMG) of the agonist and **f** antagonist muscles. *CTR* continuous training group, *PTR* periodic training group

Dynamic 1-RM strength decreased slightly (−2.0 % during the first and −3.3 % during the second), whereas MVC remained unchanged during the first and second 3-week detraining periods (Fig. 2). During the first and second 6-week retraining periods, 1-RM strength increased by 15.3 and 12.7 %, respectively, whereas MVC increased by 6.7 and 7.3 %, respectively. The increase in 1-RM strength and MVC was comparable between the initial 6-week training period and the first and second 6-week retraining periods (Fig. 2). Overall, RFD and agonist iEMG increased with PTR program (time effect $P < 0.05$) (Fig. 3). However, there were no significant changes in those during each detraining and retraining period (Figs. 3, 4).

Comparisons between the CTR and PTR groups

After 24 weeks, the total improvement in muscle CSA and volume of TB and PM and maximum strength (1-RM and MVC) were similar between the two training groups (Table 1). There were no significant regional differences in muscle CSA in TB and PM muscle (Table 1). In the PTR group, which included a total of 6 weeks of detraining, there were 25 % fewer total training sessions and 33.5 % fewer total training volume (CTR 96,942 kg, PTR 64,509 kg) throughout the 24-week training period. We calculated the rate of increase in muscle CSA and strength per session (Fig. 5). During the first 3-week detraining/6-week retraining cycle (weeks 6–15), increase in CSA of the TB and PM muscles and strength was similar between the CTR and PTR groups. However, this increase was significantly higher during the second 3-week detraining/6-week retraining cycle in the PTR group than that during the corresponding period in the CTR group, with the exception of MVC.

Discussion

For this study, we hypothesized that the total improvement in muscle CSA would be similar between a continuous resistance group (24 continuous weeks of resistance

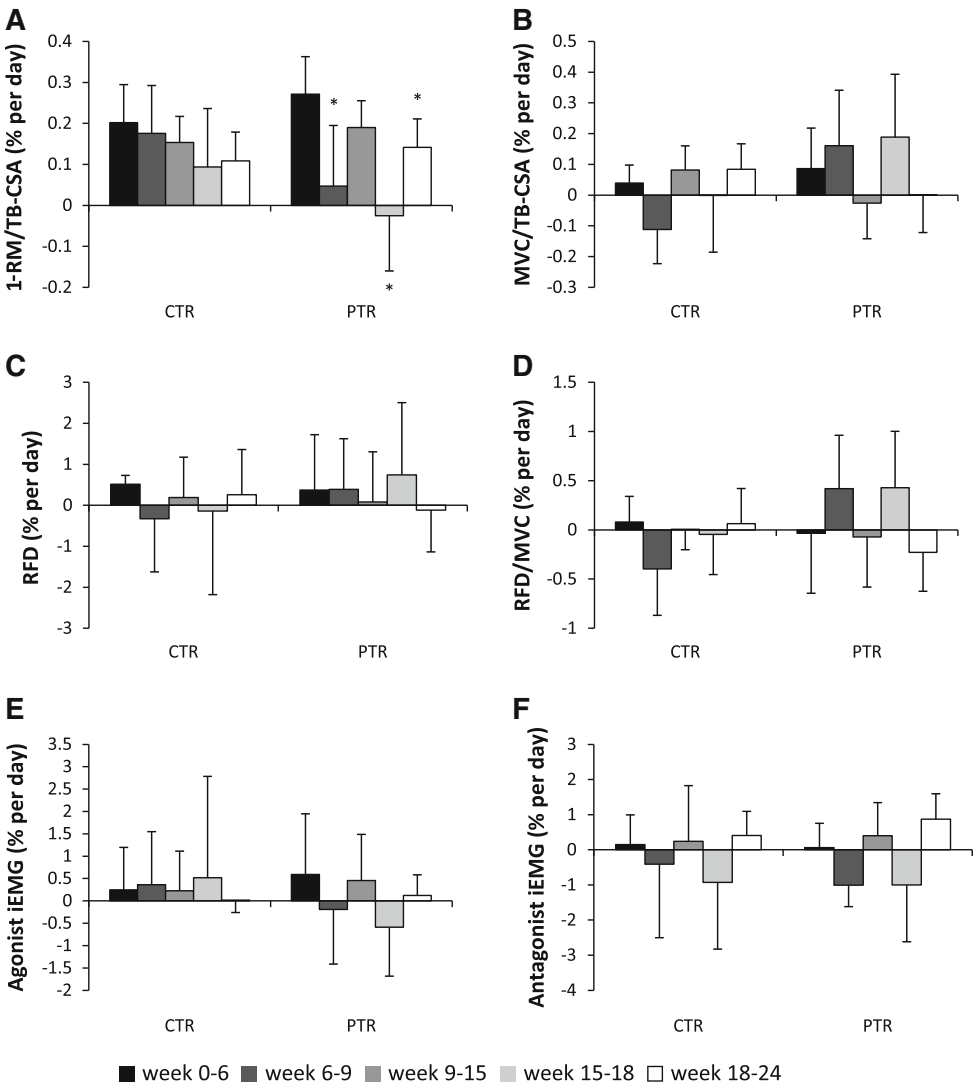

Fig. 4 Rate of change in **a** relative one-repetition maximal (*1-RM*) strength/cross-sectional area (*CSA*) of the triceps brachii (TB) muscle (*TB-CSA*), **b** relative maximum voluntary isometric contraction (MVC)/TB-CSA, **c** rate of force development (*RFD*), **d** *RFD/MVC*, and **e** integrated electromyographic activity (*iEMG*) of the agonist and **f** antagonist muscles during periodic resistance training (*PTR*) and continuous resistance training (*CTR*). *Significantly different from that during weeks 0–6; $P < 0.05$

training) and a periodic resistance group (three 6-week training cycles with two 3-week detraining periods between cycles). The key elements of our hypothesis were whether the muscle adaptation responses would return to their initial levels after short-term training cessation, and whether the effects of retraining on muscle growth after short-term cessation would be comparable to those on muscle growth during the initial phase of training. Our results showed that, in the PTR group, the increase in muscle CSA and 1-RM strength was similar between the initial 6-week training period and the first and second 6-week retraining periods. In contrast, the rate of increase in muscle CSA and 1-RM strength gradually decreased with time throughout the 24 weeks of training in the CTR group. As a result, the increase in TB-CSA, PM-CSA, MVC of the elbow extensors, and 1-RM bench press strength were similar between the CTR and PTR groups, even though the PTR group had 25 % fewer training sessions compared with the CTR group.

It is known that muscle adaptations are less likely to increase after several months of continuous training compared with the increase during the early phase of training. However, there are very few published long-term studies on this issue. In this study, we observed that the increase in TB-CSA was 0.25 % per day during the initial 6 weeks of training and 0.13 % per day during the total 24 weeks of training; the latter value was approximately half the former value. In particular, the increase in muscle CSA was less than 0.10 % per day after 9 weeks of training. Therefore, if the rate of decrease in muscle CSA is similar between detraining and retraining, a twofold longer period of retraining may provide equivalent improvements in muscle CSA when compared with continuous long-term training.

We found that the rate of change in TB-CSA was −0.16 % per day during the 3 weeks of detraining and 0.19 % per day during the 6 weeks of retraining. Our results suggest that training-induced muscle adaptations may recover to the levels observed during the initial phases

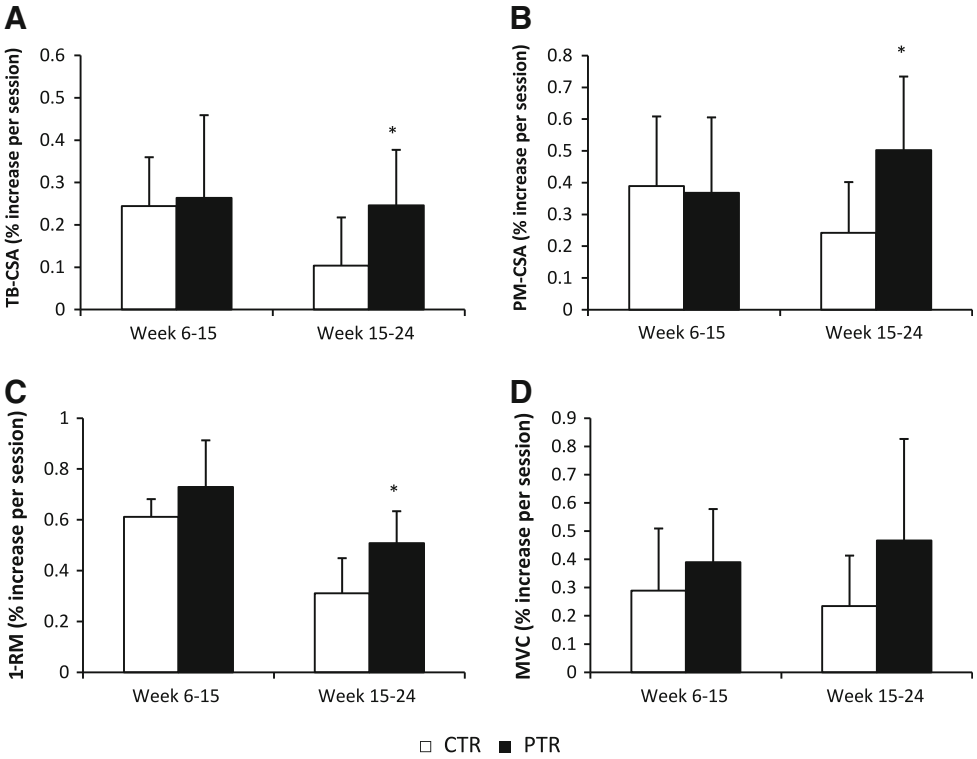

Fig. 5 Potential for increase in hypertrophy and strength (% increase per session) for **a** cross-sectional area (*CSA*) of the triceps brachii (TB) muscle (*TB-CSA*) and **b** the pectoralis major (PM) muscle (*PM-CSA*), **c** one-repetition maximal (*1-RM*) strength, and **d** maximum voluntary isometric contraction (*MVC*) of the elbow extensors during periodic resistance training (PTR *filled square*) and continuous resistance training (CTR *open square*). *Significantly different from that in the CTR group; $P < 0.05$

of training when individuals are subjected to a 3-week detraining period. Therefore, 3-week detraining/6-week retraining cycles for 24 weeks may induce hypertrophic responses similar to those induced by continuous training cycles for 24 weeks. Interestingly, our PTR group exhibited an identical increase in TB-CSA and PM-CSA muscles during the second retraining period (weeks 18–24). If the same retraining effects occurred after 24 weeks of training, and if continuous long-term training induced decreased muscle adaptations, 3-week detraining/6-week retraining cycles may produce greater muscle hypertrophic responses compared with continuous training cycles after 24 weeks.

Our results are in agreement with those of the previous cellular and molecular studies. Chronic muscle contraction induces a variety of metabolic and morphological adaptations in contracted skeletal muscles for maintaining homeostasis and minimizing cellular disturbances during subsequent training sessions (Gordon et al. 2012; Hubal et al. 2008). In the muscle, anabolic mammalian target of rapamycin (mTOR) signaling and protein synthesis responses to resistance exercise are attenuated by chronic resistance training (Coffey et al. 2006; Phillips et al. 1999, 2002; Tang et al. 2008). These results may explain the attenuated muscle hypertrophy response observed during the late phase compared to the early phase of resistance training. In contrast, our results suggest that although greater relative stimulation (i.e., greater intensity, volume, frequency) would be required to sustain anabolic responses for further adaptations, these responses would become *sensitive* again after a short detraining or non-training period. These mechanisms may be responsible for retraining-induced muscle hypertrophy and the advantage of periodic training programs, at least in young individuals. Future studies should address the cellular and molecular mechanisms underlying the changes in sensitivity of the muscle to the training stimulus.

Although it is currently unclear whether satellite cells are necessary for muscle hypertrophy, we know that these cells definitely play an indispensable role in the muscle regeneration process (McCarthy et al. 2011; Pallafacchina et al. 2012; Relaix and Zammit 2012). Since strenuous exercise is considered to cause microtrauma to muscle fibers, satellite cells may be essential especially during the initial phase of training or reuptake of exercise for inducing potent hypertrophy. Some previous studies have reported that regenerative capacity reduces with age, because of reduced satellite cell activation or content (Castets et al. 2011; Day et al. 2010; Renault et al. 2002). Compared to the young individuals, the older individuals showed an attenuated rate and magnitude of increase in muscle mass after 4 weeks of retraining following 2 weeks of immobilization (Suetta et al. 2009). Thus, it is possible that older individuals display an attenuated muscle hypertrophic response to retraining following detraining as well as immobilization. Additional studies are needed for the clinical application of periodic resistance training in older individuals.

A previous study by Kawakami et al. (1995) found that TB-CSA increased by 31.7 % (0.28 % per day) after

16 weeks of high-intensity (80 % of 1-RM, 3 days a week), unilateral elbow extension (French press) exercise training. Kraemer et al. (2004) reported an increase of 17.9 % (0.11 % per day) in TB-CSA after 24 weeks of high-intensity (3–8 RM), upper body (e.g., bench press, triceps pushdown) resistance training. Our results were similar to those of this study (Kraemer et al. 2004) in that the rate of increase in TB-CSA was 0.13 % per day during the 24 weeks of bench press training. By comparison, the percent increase in PM-CSA was greater than that in TB-CSA after 24 weeks of training. Till date, very few studies have reported hypertrophy in muscles of the trunk following high-intensity resistance training. One study by Abe et al. (2000) found that the time course of increase in muscle thickness was greater in the chest than in the upper arm after 12 weeks of total body resistance training. Because chest muscles are probably untrained compared with the arm muscles, especially in previously untrained subjects, the relative increase in chest muscle size may be greater than that in upper arm muscle size.

It is clear that the magnitude of the decline in muscle size is associated with the duration of detraining, although the rate of decline is not constant. Our results showed that a decrease in TB-CSA was 2.6 % (0.14 % per day) and 2.9 % (0.16 % per day) during the first and second 3-week detraining periods, respectively. Andersen et al. (2005) reported a significant increase in CSA of the quadriceps muscle after 3 months of resistance training; however, it decreased to the pretraining level after 3 months of detraining. Leger et al. (2006) investigated muscle adaptations after 8 weeks of both hypertrophy-stimulating resistance training and atrophy-stimulating detraining. They found that half of the training-induced muscle hypertrophy was still present after 8 weeks of detraining. Furthermore, Hather et al. (1991) reported that most of the training-induced increase in muscle fiber area was still maintained after 4 weeks of detraining. Therefore, the rate of detraining-induced muscle atrophy may be lesser than that of training-induced muscle hypertrophy. However, the degree of detraining-induced muscle atrophy is complex and currently unclear.

During the first and second 3-week detraining periods, we found that 1-RM strength decreased slightly (−2.0 and −3.3 %, respectively), while MVC remained unchanged (0.3 and 0.7 %, respectively). Previous studies have reported no significant decrease in muscle strength after short-term (2–6 weeks) detraining (Hortobagyi et al. 1993; Kraemer et al. 2002). Recently, one study found no significant change in the neural activation level after 3 months of detraining because muscle CSA had decreased to its pretraining level (Kubo et al. 2010). Therefore, the relatively short duration of detraining did not affect the increase in training-induced muscle strength. In comparison, there were no significant differences in the rate of increase in 1-RM and MVC between the initial 6-week training period and the first and second retraining periods in the PTR group. There were also no significant changes in agonist and antagonist iEMG activities during the retraining periods. A previous study observed that EMG activity was not significantly changed during 12 weeks of retraining after 24 weeks of detraining (Hakkinen et al. 2003). Therefore, it would appear that increased muscle CSA may contribute primarily to improving muscle strength during retraining.

Previous studies reported that an increase in twitch RFD was observed after 8 weeks or 3 months of detraining (Andersen et al. 2005; Ishida et al. 1990). This phenomenon may be attributed to enhanced muscle excitation–contraction coupling and/or the cross-bridge cycling rate resulting from myosin heavy chain (MHC) transitions to faster-responding isoforms (Andersen et al. 2005). In the present study, however, RFD did not change significantly during the 3 weeks of detraining or the 6 weeks of retraining. The difference between previous studies (Andersen et al. 2005; Ishida et al. 1990) and the present study is the duration of the detraining period; our 3 weeks of detraining may have been insufficient to cause a shift in MHC isoforms and alter RFD independent of MVC changes.

The American College of Sports Medicine (ACSM) and other international organizations have established guidelines for resistance training. In general, it is recommended that a loading range of more than 65 % of 1-RM be used for 8–12 repetitions per set for three sets per exercise for 2–3 days per week (ACSM 2009; Baechle and Earle 2008; Bird et al. 2005; Kraemer and Ratamess 2004). However, evidence suggests that even recreational weightlifters find it difficult to perform these training programs continuously, because of various reasons such as reduced motivation or orthopedic injury (Hass et al. 2000). Therefore, reduced time commitment and exercise volume may decrease physical and psychological strain and lead to greater participation in resistance training programs.

In summary, our results suggest that although improvements induced by periodic training do not appear to exceed those induced by continuous training after a total of 24 weeks, a relatively short detraining period does not attenuate the muscle adaptations that occur over 24 weeks of resistance training and is effective intervention to maintain muscle adaptation during late phase of resistance training.

Conflict of interest None declared.

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