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Effects of periodic and continued resistance training on muscle CSA and strength in previously untrained men

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Summary

To determine muscle adaptations to retraining after short-term detraining, we examined the effects of continuous and interrupted resistance training on muscle size and strength in previously untrained men. Fifteen young men were divided into continuous training (CTr) or retraining (RTr) groups and performed high-intensity bench press training. The CTr group trained continuously for 15 weeks, while the RTr group trained for 6 weeks, stopped for a 3-week detraining period and resumed training at week 10. After the initial training phase, increases ($P<0{\cdot}01$) in one repetition maximum (1-RM) and magnetic resonance imaging-measured triceps brachii and pectorals major muscle cross-sectional areas (CSAs) were similar in both groups. Muscle CSA and 1-RM increased ($P<0{\cdot}05$) continuously for the CTr group, but the muscle adaptations were lower ($P<0{\cdot}05$) after the last 6-week training period than after the initial phase. In the RTr group, there were no significant decreases in muscle CSA and 1-RM after the 3-week detraining period, and increases in muscle CSA after retraining were similar to those observed after initial training. Ultimately, improvements in 1-RM and muscle CSA in both groups were similar after the 15-week training period. Our results suggest that compared with continuous 15-week training, 3-week detraining does not inhibit muscle adaptations.

Introduction

High-intensity resistance training (HIT) is an effective tool for improving muscle size and function. However, the rates of improvement in muscle size and strength are not constant and are dependent on training duration. Previously, several studies demonstrated that HIT-induced muscle adaptations are greater during the early phase (i.e. about the first 10 weeks) of training than during the later phase (Abe *et al.*, 2000; Ikai & Fukunaga, 1970; Sale, 1988; Wernbom *et al.*, 2007). Even if HIT is performed continuously, the improvements in muscle size and strength are small during the later phase of training, and significant muscle size and strength gains are eventually lost (Kondo *et al.*, 1994; Pyka *et al.*, 1994; Taaffe & Marcus, 1997).

Following a relatively long-term (3–8 months) detraining period, HIT resulted in a rapid return to posttraining levels for muscle size (Staron *et al.*, 1991) and function (Henwood & Taaffe, 2008; Staron *et al.*, 1991; Taaffe *et al.*, 2009; Taaffe & Marcus, 1997). These results suggest that muscle adaptations observed after an initial training phase can be restored following rest periods of up to 3 months owing to the high potential of muscle adaptation. Thus, a period of detraining appears to be one way to maintain muscle adaptations during the late phase of HIT. However, the relationship between periodic detraining and its beneficial effect on the recovery of muscle adaptation is unclear. Because similar benefits are seen with relatively short-term (∼1 month) detraining, as with longer-term detraining periods of up to 3 months, a periodic resistance training programme is a more effective tool for improving muscle size and function than a continuous training programme. The aim of this study was to compare the effects of initial resistance training with retraining after a short-term period of detraining on muscle size and strength in previously untrained men.

Methods

Subjects

Fifteen healthy, previously untrained young men volunteered to participate in this study (aged 24·7 ± 2·5 years, height 172·4 ± 6·4 cm, body weight 65·4 ± 9·3 kg). These subjects were randomly divided into either continuous training (CTr, $n = 7$) or retraining (RTr, $n = 8$) groups. All subjects were informed of the procedures, risks and benefits and signed an informed consent document approved by the University of Tokyo. All subjects were considered untrained and had not participated in a regular resistance exercise programme for at least 1 year prior to the start of the study.

Resistance training and maximal dynamic strength

Both groups performed supervised free-weight bench press training 3 days per week. The CTr group trained continuously over a 15-week period, while the RTr group trained for 6 weeks, stopped for a 3-week detraining period and resumed training at week 10 for 6 more weeks. Training intensity and volume were set at 75% of one repetition maximum (1-RM) and 30 repetitions (three sets of 10 repetitions, with 2–3 min of rest between sets), respectively. One-RM was assessed using free-weight bench press every 3 weeks during training, and the training load for each subject was adjusted, as described previously (Abe *et al.*, 2000). During training sessions as well as 1-RM testing, the grip width was set at 200% of the biacromial breadth. The 1-RM was determined by progressively increasing the weight lifted until the subject failed to lift the weight through a full range of motion. Usually about five trials were required to complete a 1-RM test. About a 1·5-min rest was taken between the trials.

Isometric elbow extension strength

The maximal voluntary isometric (MVC) strength of the elbow extensors was measured before and 3 days after the final exercise session at each measurement point using a Biodex dynamometer (Sakai Medical Instrument, Tokyo, Japan). The measurement of elbow extension torque was carried out with the subject seated, with the arm supported on the horizontal plane on a padded table. The axis of rotation of the elbow joint was visually aligned with the axis of the lever arm of the dynamometer. Isometric torque was measured three times at an elbow joint angle of 90 (full extension corresponds to 0), and the maximal value was adopted. About a 1-min rest was allowed between trials to eliminate the effect of fatigue.

MRI-measured muscle cross-sectional area (CSA)

Multislice magnetic resonance imaging (MRI) images of the upper arm and chest were obtained using a General Electric Yokogawa Signa 0·2-T scanner (Milwaukee, WI, USA). A T1-weighted, spin-echo, axial plane sequence was performed with a 520-ms repetition time and a 20-ms echo time (Fig. 1). To prevent the influence of fluid shifts within the muscle, the MRI procedure was performed at around the same time before and 3 days after the final exercise session at each measurement point. Subjects rested quietly in the magnet bore in a supine position with their arms extended. The lateral epicondyle of the humerus was used as the origin point, and continuous transverse images with a 10-mm slice thickness were obtained from the lateral epicondyle of the humerus to the acromial process of the scapula for each subject. All MRI data were transferred to a personal computer for analysis using specially designed image analysis software (TomoVision Inc., Montreal, QC, Canada). For each slice, skeletal muscle tissue CSA was digitized. The triceps brachii (TB) and pectoralis major (PM) muscle CSA of three continuous slices from the muscle belly, the same slice number from the origin point, was averaged for statistical analysis. The coefficient of variation for this CSA measurement was <1%.

Statistical analysis

Statistical analyses were performed by a 2-way analysis of variance (ANOVA) with repeated measures (group × time). When appropriate, Tukey–Kramer *post hoc* testing was performed. All baseline characteristics and percentage changes between groups were tested with a 1-way ANOVA. Statistical significance was set at $P<0{\cdot}05$.

Results

At baseline, there were no significant differences between the two groups for anthropometric variables (height, RTr 171·9 ± 5·8 cm and CTr 172·9 ± 7·5 cm; body weight, RTr 65·3 ± 11·8 cm and CTr 65·4 ± 6·2 kg), 1-RM, isometric MVC and muscle CSA (Table 1). Training volumes (lifting weight × repetition) in the CTr (1280 ± 297 kg) and RTr (1179 ± 230 kg) groups were similar, but total training volume was higher ($P<0{\cdot}01$) in the CTr (57 621 ± 11 112 kg) than in the RTr (42 449 ± 8291 kg) group. After the initial 6-week training phase, increases in 1-RM, isometric MVC, and TB and PM muscle CSAs were similar in both groups (Fig. 1). Following the 3-week detraining period for the RTr group, 1-RM and isometric MVC were maintained (−1·2% and 0·3%, respectively), and TB (−2·2%) and PM (−5·7%) muscle CSAs were not significantly decreased. On the other hand, increases in 1-RM and in TB and PM muscle CSAs in the CTr group were 7·3%, 3·7% and 4·6%, respectively, following the same 3-week (training) period (Table 1).

During the 6 weeks of retraining, increases in TB and PM muscle CSA were similar to those observed after the initial 6-week training phase in the RTr group but were lower ($P<0{\cdot}05$) than those observed after the initial 6-week training period in the CTr group. The increases in TB and PM muscle CSA after the 6 weeks of retraining in the RTr group tended to be higher than those observed in the CTr group (TB muscle: $P = 0{\cdot}06$, PM muscle: $P = 0{\cdot}07$) during the corresponding period. When correcting for the number of training sessions, the magnitude of the hypertrophic potential (percentage increase in muscle CSA divided by total training sessions) during the initial and second 6-week training periods was 0·50% and 0·13% in the TB and 0·92% and 0·29% in the PM for the CTr group, respectively, and 0·51% and 0·40% in the TB and 0·79% and 0·77% in the PM for the RTr group, respectively. On the other hand, the increase in 1-RM strength observed after the 6-week retraining phase was lower ($P<0{\cdot}05$) in both the CTr

Table 1 Effects of training on TB and PM muscle CSA, 1-RM, MVC, 1-RM/TB-CSA, and MVC/TB-CSA (Mean ± SD).

	Training week				
	0 week	6 week	9 week	15 week	Total improvement (%)
TB-CSA (cm^2)					
CTr	22·2 ± 4·3	24·4 ± 4·1*	25·3 ± 4·2*†	25·9 ± 3·8*†	17·7 ± 6·5
RTr	20·7 ± 2·5	22·6 ± 2·7*	22·1 ± 2·8*	23·7 ± 3·0*†‡	14·5 ± 7·2
PM-CSA (cm^2)					
CTr	29·7 ± 6·4	34·6 ± 7·6*	36·2 ± 7·9*	38·1 ± 7·9*†	28·7 ± 9·6
RTr	27·4 ± 5·3	31·3 ± 5·7*	29·5 ± 5·4	33·6 ± 6·7*‡	23·1 ± 11·9
1RM (kg)					
CTr	51·1 ± 9·9	61·2 ± 12·7*	65·7 ± 14·0*†	71·2 ± 14·1*†‡	39·5 ± 7·2
RTr	48·8 ± 10·8	58·4 ± 12·2*	57·4 ± 11·7*	65·9 ± 13·4*†‡	35·8 ± 9·3
MVC (N m)					
CTr	30·8 ± 6·7	34·4 ± 6·5*	34·7 ± 6·0*	37·0 ± 6·7*†‡	21·1 ± 9·5
RTr	30·6 ± 6·2	34·0 ± 5·7*	34·1 ± 11·7*	36·5 ± 6·4*†‡	20·0 ± 9·0
1-RM/TB-CSA (kg cm^{-2})					
CTr	2·33 ± 0·40	2·53 ± 0·47*	2·61 ± 0·48*	2·76 ± 0·47*†‡	18·6 ± 5·2
RTr	2·34 ± 0·35	2·57 ± 0·36*	2·60 ± 0·36*	2·77 ± 0·38*†‡	18·8 ± 6·4
MVC/TB-CSA (N m cm^{-2})					
CTr	1·39 ± 0·17	1·41 ± 0·16	1·38 ± 0·15	1·43 ± 0·19	2·7 ± 3·6
RTr	1·47 ± 0·22	1·51 ± 0·20	1·55 ± 0·23*	1·54 ± 0·21	5·0 ± 6·4

CTr, continuous training group; RTr, retraining 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 0 week, †$P<0·05$ versus 6 week, ‡$P<0·05$ versus 9 week.

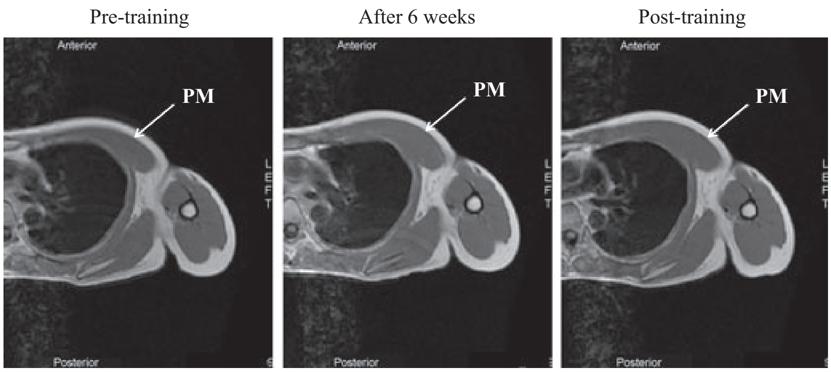

Figure 1 Typical MRI images showing transverse sections of the upper arm and chest taken before (pre), mid (6 weeks), and after (post) 15 weeks of bench press training. The images show identical sections at the site between the 3rd and 4th costae in the same subject (MM). PM, pectoralis major muscle.

and RTr groups than that observed after the corresponding initial 6-week phase, although the increase in the RTr group tended to be higher ($P = 0·06$) than in the CTr group (Fig. 2). The increase in isometric MVC observed after the 6-week retraining period was similar in both the RTr and CTr groups, but was lower ($P<0·05$) than that observed after the corresponding initial 6-week phase in both groups. As a result, in both the CTr and RTr groups, improvements in overall 1-RM strength (39·5% and 35·8%, respectively), isometric MVC (21·1% and 20·0%, respectively) and TB (17·7% and 14·5%, respectively) and PM (28·7% and 23·1%, respectively) muscle CSA were similar.

The change in relative dynamic strength (1-RM or isometric MVC divided by TB muscle CSA) after the initial 6-week training period was similar in both the CTr and RTr groups. Similarly, there was no significant difference in the changes in relative dynamic and isometric strength between the two groups after the 6-week retraining period in the RTr group and after the last 6 weeks of training in the CTr group (Fig. 2).

Discussion

The improvement in muscle CSA observed in the RTr group after the 6-week retraining phase that followed a short-term detraining period was comparable with the improvement observed after the initial 6-week training period, whereas continuous training resulted in a reduced training response after the last 6 weeks of training compared with that observed after

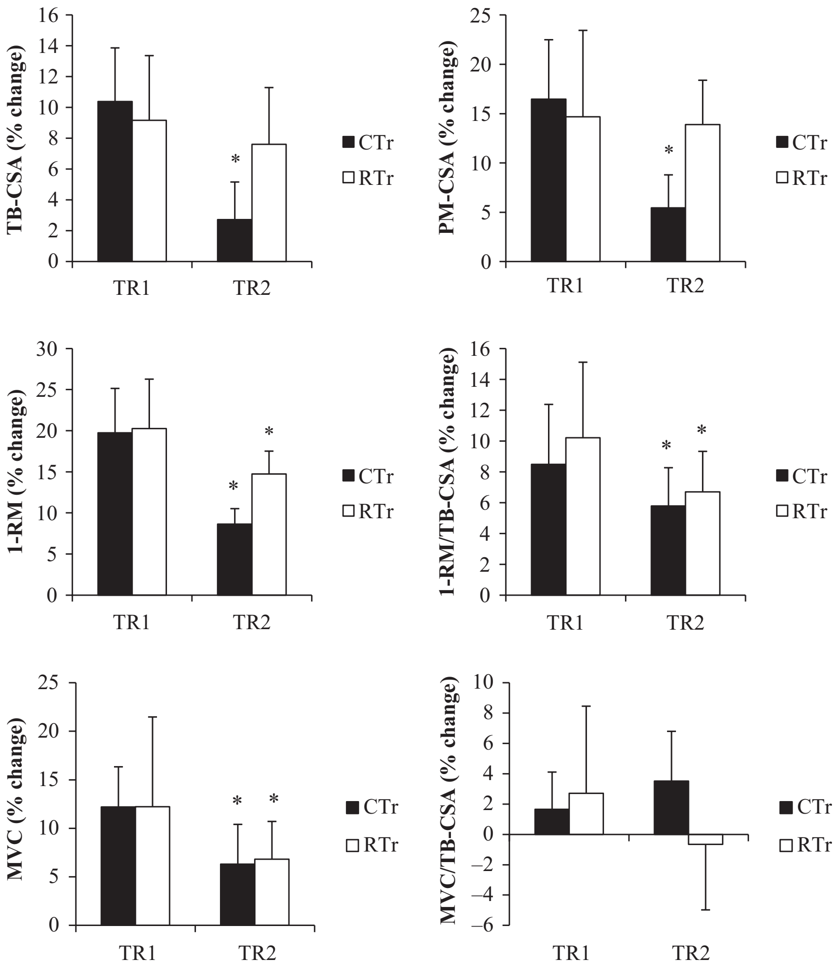

Figure 2 Changes in triceps brachii (TB) and pectoralis major muscle cross-sectional areas (CSA), 1 repetition maximum and isometric maximal voluntary isometric contraction during initial 6 weeks of training (TR1) and final 6 weeks of training (TR2). Values are means ± SD. *$P<0{\cdot}05$ versus TR1.

the initial training phase. The increase in dynamic 1-RM strength during the 6-week retraining phase in the RTr group and the last 6 weeks of training in the CTr group was lower in both training groups but tended to be higher in the RTr group than in the CTr group. As a result, overall training adaptations, such as muscle CSA and strength, were similar in both training groups at the end of the 15-week study.

In standard textbooks of exercise physiology and strength training, it is reported that the peak rate of muscle hypertrophy occurs 8–16 weeks in training (Fleck & Kraemer, 2004; McArdle *et al.*, 1996). However, it has been noted that HIT-induced muscle hypertrophy is greater during the early phase of training than during the later phase (Ikai & Fukunaga, 1970; Wernbom *et al.*, 2007). Moreover, recent studies have investigated the time course of muscle hypertrophic adaptations to resistance training and found that a significant increase in muscle size had occurred 3–4 weeks following the initiation of resistance training (Abe *et al.*, 2000; Seynnes *et al.*, 2007). More recently, DeFreitas *et al.* (2011) reported a significant increase in thigh muscle CSA after 1 week of leg extension and leg press training, with almost all of the increased muscle CSA occurring by 6 weeks into the 8-week training period. The results of the present study and the previously reported studies together suggest that training-induced muscle hypertrophy may occur earlier in a high-intensity resistance training programme, compared with the scenario described in standard textbooks.

A limited number of studies have reported that training adaptations observed after a 6-week period of retraining that followed a 30-week period of detraining are similar to those observed after an initial 6-week round of resistance training performed by other untrained subjects (Staron *et al.*, 1991), although it must be noted that these studies did not compare the same subjects. In the present study, increases in muscle CSA from retraining were similar to those observed during the initial phases of HIT in the same subjects. Following the 3-week detraining period, the TB and PM muscle CSAs tended to be decreased (by 2·2% and 5·7%, respectively) in the RTr group, although these changes were not significant. The second 6-week training (retraining)-induced muscle adaptations may, therefore, have been affected by the changes in muscle size during the detraining period. Previously, it was reported that HIT-induced muscle hypertrophy was associated with increases in muscle protein synthesis after resistance exercise (Burd *et al.*, 2009; Phillips, 2000). Continuous HIT training sessions, however, attenuate muscle protein synthesis in response to an acute bout of resistance exercise (Tang *et al.*, 2008). In the present study, muscle protein synthesis was not measured during the training period. However, our results suggest that metabolic, HIT-induced muscle adaptations may recover to the levels observed after the initial phases of training when subjects experienced a 3-week detraining period. Recently, a study using rodent muscles found that atrophied fibres maintain an overload-induced elevated number of nuclei even after 3 months of subsequent detraining (Bruusgaard *et al.*, 2010). The authors advanced a model for the connection between muscle size and the number of myonuclei during the first training phase and detraining and the retraining cycle phase, suggesting that previously trained individuals are more easily retrained for muscle hypertrophy and improved function owing to the retention of myonuclei.

Our results showed that 1-RM strength as well as muscle CSA did not change significantly after the 3-week detraining period in the RTr group. It is clear that the magnitude of the declines in strength and muscle size is associated with the duration of the detraining, although the rate of the decline is not constant. Andersen *et al.* (2005) reported a significant increase in quadriceps muscle CSA after 3 months of HIT; it decreased to pretraining level following 3 months of detraining. Leger *et al.* (2006) investigated muscle adaptations after 8 weeks of both hypertrophy-stimulating resistance training and atrophy-stimulating detraining, and 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 fibre area was still maintained after 4 weeks of detraining. As a result, the degree of detraining-induced muscle atrophy is complex and is currently unexplained. On the other hand, previous studies also reported that no significant decline in muscle strength was observed after short-term (2–6 weeks) detraining (Hortobagyi *et al.*, 1993; Kraemer *et al.*, 2002). In addition, a study observed no significant change in the neural activation level after 3 months of detraining, because muscle CSA decreased to pretraining levels (Kubo *et al.*, 2010). Therefore, the relatively short duration of detraining did not affect the increase in training-induced muscle strength.

In general, the effects of resistance training, including detraining/retraining cycles, are determined by the balance between retraining-induced increases and detraining-induced decreases in muscle adaptations. In the present study, the muscle hypertrophy response to retraining was similar to that observed after the initial phases of training when subjects experienced a 3-week detraining period. If the muscle hypertrophy response recovers to the initial training level after 3 weeks of detraining and there is no change in muscle size after detraining, the improvements in overall muscle size and function are probably greater with the short-term detraining and retraining programme than with the continuous training programme. Further research is needed to determine the long-term effects of muscle adaptations during resistance training, including short-term detraining/retraining cycles.

Several limitations of this study should be mentioned. First, the terms 'detraining' and 'retraining' refer only to the protocol used in this study, namely 6 weeks of training, followed by 3 weeks of detraining, followed by 6 weeks of retraining. Second, because only one type of exercise – bench press – was performed, we cannot infer similar results for other types of exercise affecting other muscle groups. Similarly, we do not explain the difference between the effects of training on the upper and lower body muscles because only the upper body musculature was studied. Lastly, because our subjects were untrained, it is uncertain if the results pertain to trained subjects as well. Additional research into these issues is needed.

In summary, retraining following a 3-week detraining period induced muscle hypertrophy similar to that observed after an initial 6-week training phase, while continuous training resulted in a reduced training response after the late phase (last 6 weeks) of training compared with that observed after the initial 6 weeks of training. Overall improvements in muscle size and strength in the detraining group were similar to those observed in the continuous training group. These results suggest that a relatively short-term detraining period does not attenuate muscle adaptations over 15 weeks of resistance training.

References

Abe T, DeHoyos DV, Pollock ML, Garzarella L. Time course for strength and muscle thickness changes following upper and lower body resistance training in men and women. *Eur J Appl Physiol* (2000); **81**: 174–180.

Andersen LL, Andersen JL, Magnusson SP, Aagaard P. Neuromuscular adaptations to detraining following resistance training in previously untrained subjects. *Eur J Appl Physiol* (2005); **93**: 511–518.

Burd NA, Tang JE, Moore DR, Phillips SM. Exercise training and protein metabolism: influences of contraction, protein intake, and sex-based differences. *J Appl Physiol* (2009); **106**: 1692–1701.

Bruusgaard JC, Johansen IB, Egner IM, Rana ZA, Gundersen K. Myonuclei acquired by overload exercise precede hypertrophy and are not lost on detraining. *Proc Natl Acad Sci USA* (2010); **107**: 15111–15116.

DeFreitas JM, Beck TW, Stock MS, Dillon MA, Kasishke PR 2nd. An examination of the time course of training-induced skeletal muscle hypertrophy. *Eur J Appl Physiol* (2011), in press.

Fleck SJ, Kraemer WJ. *Designing Resistance Training Programs*, 3rd edn (2004). Human Kinetics, Champaign, IL.

Hather BM, Tesch PA, Buchanan P, Dudley GA. Influence of eccentric actions on skeletal muscle adaptations to resistance training. *Acta Physiol Scand* (1991); **143**: 177–185.

Henwood TR, Taaffe DR. Detraining and retraining in older adults following long-term muscle power or muscle strength specific training. *J Gerontol A Biol Sci Med Sci* (2008); **63**: 751–758.

Hortobagyi T, Houmard JA, Stevenson JR, Fraser DD, Johns RA, Israel RG. The effects of detraining on power athletes. *Med Sci Sports Exerc* (1993); **25**: 929–935.

Ikai M, Fukunaga T. A study on training effect on strength per unit muscle cross-sectional area of muscle by means of ultrasonic measurement. *Int Z Angew Physiol* (1970); **28**: 173–180.

Kondo M, Abe T, Ikegawa S, Kawakami Y, Fukunaga T. Upper limit of fat-free mass: a study on Japanese Sumo wrestlers. *Am J Hum Biol* (1994); **6**: 613–618.

Kraemer WJ, Koziris LP, Ratamess NA, Hakkinen K, Triplett-McBride NT, Fry AC, Gordon SE, Volek JS, French DN, Rubin MR, Gomez AL, Sharman MJ, Lynch JM, Izquierdo M, Newton RU, Fleck SJ. Detraining produces minimal changes in physical performance and hormonal variables in recreationally strength-trained men. *J Strength Cond Res* (2002); **16**: 373–382.

Kubo K, Ikebukuro T, Yata H, Tsunoda N, Kanehisa H. Time course of changes in muscle and tendon properties during strength training and detraining. *J Strength Cond Res* (2010); **24**: 322–331.

Leger B, Cartoni R, Praz M, Lamon S, Deriaz O, Crettenand A, Gobelet C, Rohmer P, Konzelmann M, Luthi F, Russell A. Akt signalling through GSK-3b, mTOR and Foxo1 is involved in human skeletal muscle hypertrophy and atrophy. *J Physiol* (2006); **576**(Pt 3): 923–933.

McArdle WD, Katch FI, Katch VL. *Exercise Physiology* 4th edn (1996). Williams & Wilkins, Baltimore, MD: 440–442.

Phillips SM. Short-term training: when do repeated bouts of resistance exercise become training? *Can J Appl Physiol* (2000); **25**: 185–193.

Pyka G, Lindenberger E, Charette S, Marcus R. Muscle strength and fiber adaptations to a year-long resistance training program in elderly men and women. *J Gerontol* (1994); **49**: M22–M27.

Sale DG. Neural adaptation to resistance training. *Med Sci Sports Exerc* (1988); **5**(Suppl): S135–S145.

Seynnes OR, de Boer M, Narici MV. Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training. *J Appl Physiol* (2007); **102**: 368–373.

Staron RS, Leonardi MJ, Karapondo DL, Malicky ES, Falkel JE, Hagerman FC, Hikida RS. Strength and skeletal muscle adaptations in heavy-resistance-trained women after detraining and retraining. *J Appl Physiol* (1991); **70**: 631–640.

Taaffe DR, Marcus R. Dynamic muscle strength alterations to detraining and retraining in elderly men. *Clin Physiol* (1997); **17**: 311–324.

Taaffe DR, Henwood TR, Nalls MA, Walker DG, Lang TF, Harris TB. Alterations in muscle attenuation following detraining and retraining in resistance-trained older adults. *Gerontology* (2009); **55**: 217–223.

Tang JE, Perco JG, Moore DR, Wilkinson SB, Phillips SM. Resistance training alters the response of fed state mixed muscle protein synthesis in young men. *Am J Physiol Regul Integr Comp Physiol* (2008); **294**: R172–R178.

Wernbom M, Augustsson J, Thomee R. The influence of frequency, intensity, volume and mode of strength training on whole muscle cross-sectional area in humans. *Sports Med* (2007); **37**: 225–264.