ADAPTATION OF HUMAN SKELETAL MUSCLE TO NINE WEEKS OF INTERMITTENT RESISTANCE TRAINING

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ABSTRACT

Twelve persons were randomly assigned to a training group (n=6) or a control group (n=6). The training consisted of intensive, intermittent elbow extensions three times a week at 55 per cent of 1RM for nine weeks. Needle biopsies were taken from the lateral head of the triceps muscle one week before and 2-3 days after termination of the training period. Following training, the mean percentage of type I fibres in m. triceps brachii had increased from 42.4 per cent to 58.2 per cent ($P < 0.03$) and the mean percentage of type IIB fibres had decreased from 22.8 to 8.1 per cent ($P < 0.03$). There was no change in distribution of type IIA fibres. The mean diameter of type I fibres increased from 56.0 to 64.2 μm (14.6%) ($P < 0.05$), type IIA diameter from 65.3 to 76.5 μm (17.1%) ($P < 0.03$). Type IIB fibre diameter showed no significant change. NADH-TR activity in all fibre types was unchanged following training. We observed no significant changes in the control group. Others [19] have found similar results in the same muscle group after continuous, low intensity training. Taken together, these results suggest that increased amount of contractile of activity may be more important than the type of activity in transforming fast muscle fibres to slower fibres in an untrained non-postural muscle.

INTRODUCTION

The responses of human skeletal muscle to continuous, low intensity training have been extensively studied. Results from several exercise studies with repeated low intensity contractions show that the percentage of type IIB muscle fibres decreases with an concomitant increase in the percentage of either IIAB, IIA, IIC, or type I fibre types [e.g. 8, 10, 19, 21].

On the other hand, studies of the response of human muscles to intermittent, high intensity exercise show equivocal results. Some studies report increased percentage of type I fibres and decreased percentage of type IIB fibres [4, 20]. Jansson et al. [11] and Jacobs et al. [12] however, reported decreased percentage of type I fibres and increased percentage of type II fibres. Such discrepancies may be ascribed to differences in the pretraining status and type characteristics of the exercised muscles, or to the amount and type of activity.

In line with the above cited references [4, 8, 10, 11, 12, 19, 20, 21], several experimental studies using animal models have shown that increased contractile activity may transform a fast muscle to a slow muscle. This effect is quite pronounced when fast muscles (e.g. m. extensor digitorum longus or m. tibialis anterior) are chronically stimulated with a low frequency impulse pattern (for review, see reference 18). Interestingly, also an intermittent impulse pattern results in fast-to-slow fibre type transition, but the effect is less extensive than with chronic electrical stimulation [15, 17]. Both animal and human studies therefore indicate that the impulse pattern or exercise modality may be of less importance than the level of activity in a fast-to-slow muscle fibre transformation process.

So far, most human exercise studies in this field have concentrated on the responses of m. vastus lateralis to a running or cycling training regime, but this approach makes it difficult to separate the effect of the specific training from the effect of daily locomotor and postural activity. By using non postural muscles, one may assume better control over parameters that influence the adaptive processes in skeletal muscle. In addition, there is little information about the effect of longitudinal resistance exercise on non postural/upper body muscles.

Using a previously untrained non postural muscle, Schantz and Henriksson [19] observed fast-to-slow fibre transformation in the m. triceps brachii after low intensity, continuous contractions. In light of this, and the previous cited studies, we wished to investigate the adaptive responses of the m. triceps brachii subjected to an increased amount of high intensity, intermittent contractions.

MATERIAL AND METHODS

Subjects

Following written informed consent and ethics committee approval, five female and seven male students, age 26.6± 1.7 yr., height 172.6±1.4 cm and weight 67.3±3.6 kg (mean ±SE), were randomly assigned to a control group (n=6) or a training group (n=6). All subjects were healthy and untrained in the elbow extensor muscles at the beginning of the study. They were instructed to maintain their habitual level of activity, but not to engage in activities that would otherwise involve extensive use of the m. triceps brachii.

Exercise

The training consisted of series of intensive, intermittent elbow extensions (triceps pushdown). The participants were instructed to keep the pace at one repetition per second. Each series lasted 30 seconds, followed by a 15 second rest period. Four consecutive series (one set) were followed by two minutes rest. The first five weeks the participants performed four sets, while they performed five sets during the last four weeks of the training programme. The training programme was performed three times a week. Total weekly training amounted to 1400 – 1800 repetitions. The training resistance was 55 - 60 per cent of one repetition maximum (1RM) during the training period. 1RM was tested at the first training session each week throughout the nine weeks of training and the resistance was adjusted accordingly.

One week before training needle biopsies [2] were obtained from the upper-middle portion of the lateral head of the non dominant m. triceps brachii. Two to three days after termination of the training period, post training biopsies were obtained from an incision close to the previous biopsy scar. Care was taken to obtain biopsies from the

same depth of the muscle belly. The non-dominant arm was chosen because it was supposed to be the more untrained one at the beginning of the study. The biopsy samples were frozen in isopentane, precooled to its freezing point in liquid nitrogen, and stored at -80 $^{\circ}$C until analysis.

Analyses

Serial cross-sections, 10 µm thick were cut in a Leitz 1720 cryostat and incubated for myofibrillar ATPase at pH 9.4. Before the ATPase incubation the serial sections were sequentially pre incubated for ten minutes in an alkaline buffer followed by four minutes preincubation in an acid buffer [26]. The alkaline buffer was 50 mM 221-AMP buffer with pH 10.1 or pH 10.3, containing 20 and 50 mM $CaCl_2$, respectively. The acid buffer was 50 mM acetate buffer, pH 4.25 or pH 4.6. The pre-incubations took place in a water bath at 23°C. Staining intensities of the different fibretypes after preincubations 10.1/4.25 are in the order of IIB = I > IIA. After preincubations 10.3/4.6 the relative intensities are IIB > IIA > I. After staining, the optical density of individual muscle fibres was measured as described by Dahl and Roald [5] to provide a numerical estimate of the relative reaction intensity in each section. Absorbance values for each fibre after both acid and alkaline treatment were plotted in a two dimensional plot giving rise to clusters of fibres with nearly similar reaction to the treatments. On the average 220 fibres (range 200-350) were classified in each section. The lesser diameter of each muscle fibre was measured on a digitizing tablet [3] on sections stained for NADH-TR [14].

Statistics

The statistical significance of the differences between pre- and post values was tested by Wilcoxon Signed Rank Test. Statistical significance was accepted at $P < 0.05$. Power of test was 52 per cent, mostly due to small test group size. The methodological error, i.e. the coefficient of variation (CV), was calculated from densitometric determinations of two different biopsies from the same incision [6]. The CV of fibre type distribution was 7.8 per cent. The CV of differences in staining intensity (duplicate densitometric determinations of serial sections from the same biopsy), was 2.0 per cent. The CVs of lesser fibre diameter calculated from two biopsies from the same incision and from duplicate determinations from two serial sections from the same biopsy, were 2.3 per cent and 0.9 per cent, respectively. Accordingly, the CVs of NADH-TR activity was 6.8 per cent and 4.3 per cent.

RESULTS

A significant increase (P < 0.03) from 42.4 percent to 58.2 percent in type I fibres was observed in the training group after nine weeks of training (table 1). The increase was balanced by a significant reduction (P < 0.03) from 22.8 to 8.1 percent in the percentage of type IIB fibres. The percentage of type IIA fibres was unchanged. No significant differences were found between the first and the last biopsy in the control group.
In addition there were no significant differences between the first biopsies of the exercise and the control group. This suggests that the two different groups initially were statistically similar with regard to muscle fibre type characteristics, and that the differences between pre and post exercise biopsies are due to the training.

In the training group, the lesser diameter of all fibre types (table 1) was increased in the post training biopsies. The mean diameter of type I fibres increased 14.6% from 56.0 to 64.2 µm (P< 0.05), the mean diameter of type IIA fibres increased 17.1% from 65.3 to 76.5 µm (P < 0.03). The mean diameter of type IIB fibres was also increased (14.1%), but the difference was not significant. There were no significant differences between the two biopsies in the control group regarding lesser diameter.

Oxidative capacity of the different fibre types, were determined by opical density readings of NADH-TR stained fibres. OD readings were about 40% higher in type I fibres than in type IIA and type IIB fibres, while there was little difference between type IIA and type IIB fibres (less than 10 per cent). There was no statistically significant change in oxidative capacity after exercise in the training group.

DISCUSSION

The major finding in this study is the increased percentage of type I fibres at the expense of type IIB fibres. This is intriguing because the tendency of fibre type transformation in the fast to slow direction also has been shown in the same muscle group after eight weeks of cross country skiing, a typical continuous low force activity [19]. Consequently, one has to question the importance of different training regimes as a stimulus to fibre type transformation. In this regard Simoneau et al. [20] and Cadefau et al. [4] observed transformation of fast fibres to slow fibres in the vastus lateralis muscle after intense intermittent running. Previous experiments also show that continuous low intensity running induce fibre type transformation of type IIB fibres to type IIA fibres in the vastus lateralis muscle [8, 21].

Until recently it was believed that resistance training did not affect the fibre type distribution of the exercised muscles [9]. However, Staron et al. [22, 23] and Hather et al. [7] have shown that resistance training at about 80-85 per cent of 1RM induces fibre type transformation in the fast fibre subgroups. These studies show a decreased percentage of type IIB fibres and an increased percentage of type IIA fibres in the vastus lateralis after training. The observations of Hather et al. [7] have been substantiated by SDS-polyacrylamide gel electrophoresis on the same material [1]. Adams el al. [1] found parallel changes in fibre type distribution observed by traditional ATPase (reduced IIB, increased IIA percentage) as revealed by densitometric quantification of myosin heavy chain composition (reduced MyHC IIB, increased MyHC IIA). This tendency was confirmed in a study of Jürimäe et al. [13] who investigated the effect of resistance exercise on fibre type characteristics in m. triceps brachii. Jürimäe et al. [13] found a significant reduction of the MyHC IIB isoform and a non-significant increase in

MyHC IIA and MyHC I isoforms after 12 weeks "body-builder-type" resistance training.

In summary, it seems that both intermittent and continuous training regimes, applied to postural as well as to non postural muscles may induce fibre type transformation in the fast to slow direction. This may support the notion that the type of training (intermittent or continuous) may be less important than the amount of training in transforming muscle fibre types in the fast to slow direction in untrained muscles. We are currently investigating this hypothesis in a more comprehensive exercise study.

Few studies have investigated the effect of resistance training on fibre size in the triceps muscle, but MacDougall et al. [16] showed significant increases in the area of both type I (15%) and type II fibres (17%) in the male triceps brachii muscle after heavy resistance training. They also found significant increases in mean fibre type II/I area ratio with training, which could indicate a more extensive involvement of type II muscle fibres in the adaptive response to training. The present study, however, revealed the same type II/I diameter ratio before and after training (1.14 and 1.16, respectively). One possible explanation is that both fibre type groups in our study were untrained and equally susceptible to training. This notion is supported by the fact that the mean fibre diameter of type I and and type IIB fibres prior to training was of nearly the same size (56.0 and 52.3 µm, respectively). This implicates that, prior to this study, type IIB fibres have seldom been recruited in a manner that stimulates hypertrophy. Another explanation is that the resistance used in the present study was insufficient to induce a maximal hypertrophy of type II fibres. The training resistance in strength training studies has most often ranged from 70 to 100 per cent of the subjects' 1RM, and heavy resistance (i.e high tension) has been regarded as a prerequisite for hypertrophy. The

present study employed a medium resistance (about 55% 1RM). 1RM increased only by 9.8 per cent (P<0.01) after nine weeks of training (data not shown). This is not surprising considering the medium resistance and the high number of repetitions of the present study.

The present study did not find any significant increase in oxidative capacity after nine weeks of intermittent resistance exercise. This is in accordance with other resistance training studies [e.g. 24, 25] which however employed heavier training loads than the present study. A common feature between the present study and the above cited studies is however significant muscle fibre hypertrophy. In the present study, mean fibre diameter increased 14-17 per cent, while the oxidative capacity was unchanged from the pre-training state. Since NADH-TR is a mitochondrial enzyme, this implies a dilution of mitochondrial concentration in the hypertrophied muscle fibres. In turn, this will cause lower activity of the NADH-TR enzyme expressed per unit of muscle. The results from the present study therefore suggest that intermittent resistance exercise with sub-maximal loads is not beneficial for developing local oxidative capacity.

Taken together the results in this study show that training with medium resistance, but high speed and many repetitions may recruit all major fibre types and stimulate to hypertrophy and possibly fibre type transformation if the muscles in question are sufficiently untrained before the training starts.

ACKNOWLEDGEMENTS

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Table 1. Fibre type percentage, lesser fibre diameter and NADH-TR optical density

(OD) values in m. triceps brachii after nine weeks of intermittent resistance training

	TRAINING GROUP (n=6)			CONTROL GROUP (n=6)		
	Fibre types %	Fibre diam. μm	NADH-TR OD	Fibre types %	Fibre diam. μm	NADH-TR OD
Pre Exercise						
Type I	42.4±2.8	56.0±4.1	25.1±1.8	43.4±4.9	63.2±2.2	22.1±2.9
Type IIA	34.8±3.7	65.3±3.7	15.8±1.5	37.7±5.5	77.2±3.9	13.8±1.6
Type IIB	22.8±2.4	52.3±11.5	14.2±0.6	18.9±5.5	62.4±12.7	12.6±1.3
Post Exercise						
Type I	58.2±2.0*	64.2±4.5**	23.3±1.3	44.7±5.4	65.1±2.7	21.6±3.1
Type IIA	33.6±3.7	76.5±4.4*	15.6±1.2	37.4±5.0	79.6±4.5	13.1±1.8
Type IIB	8.1±3.0*	59.7±13.1	13.6±2.7	17.8±5.5	62.6±12.9	12.3±1.1

LEGENDS

Table 1. Values are mean ± SEM. * P < 0.03, ** P < 0.05. Optical density values (OD) are arbitrary units.