Eur J Appl Physiol (1985) 54:250–253

European Journal of
Applied Physiology
and Occupational Physiology

Human skeletal muscle fiber type alteration with high-intensity intermittent training

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Summary. The response of muscle fiber type proportions and fiber areas to 15 weeks of strenuous high-intensity intermittent training was investigated in twenty-four carefully ascertained sedentary (14 women and 10 men) and 10 control (4 women and 6 men) subjects. The supervised training program consisted mainly of series of supramaximal exercise lasting 15 s to 90 s on a cycle ergometer. Proportions of muscle fiber type and areas of the fibers were determined from a biopsy of the vastus lateralis before and after the training program. No significant change was observed for any of the histochemical charactertics in the control group. Training significantly increased the proportion of type I and decreased type IIb fibers, the proportion of type IIa remained unchanged. Areas of type I and IIb fibers increased significantly with training. These results suggest that high-intensity intermittent training in humans may alter the proportion of type I and the area of type I and IIb fibers and in consequence that fiber type composition in human vastus lateralis muscle is not determined solely by genetic factors.

Key words: Human skeletal muscle — Muscle fiber type — Exercise-training

Introduction

Human skeletal muscle adaptation to endurance training has been extensively studied. It has been observed that endurance trained athletes have more type I muscle fibers (Gollnick et al. 1972; Costill et al. 1976) and that regular endurance exercise induces major adaptive changes in skeletal muscle enzyme activities associated with an improved capacity to perform long strenuous exercise (Holloszy and Coyle 1984). Nevertheless, it has not been clearly established yet whether training could elicit fiber type II to fiber type I transformation in humans. Up until recently, the contention was that skeletal muscle fiber type distribution is determined solely by the genotype (Komi and Karlsson 1979). In rat, however, Green et al. (1984) have demonstrated that severe endurance training increased the number of type I fibers to the detriment of the type II fibers in some skeletal muscles. On the other hand, Luginbuhl et al. (1984) have observed that intense interval training can alter the fiber type composition in rat skeletal muscle and to a greater extent than was previously thought. Therefore, the present study was designed to assess the influence of strenuous high-intensity intermittent exercise-training on histochemically determined skeletal muscle fiber type distribution in human subjects.

Methods

Twenty-four healthy experimental subjects (14 women, 10 men), and 10 healthy control subjects (4 women, 6 men), whose ages ranged from 19 to 30 years, gave their written informed consent to participate in this study. They had been selected among individuals who were known to be sedentary at the time of the study and had no history of regular participation in physical activities. Their maximal oxygen uptake was determined on an electromagnetically braked cycle ergometer (Prud'Homme et al. 1984). All procedures were approved by the Human Ethics Committee of the institution.

Muscle biopsies were performed in the morning after an overnight fast, before and following the training program. The sample was extracted from the middle portion of the vastus lateralis, 12—16 cm above the patella and approximately 2 cm away from the epimysium with the percutaneous needle biopsy technique described by Evans et al. (1982).

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Table 1. Descriptive data of pre- and post-training values and of changes in fiber type distribution and areas in control and trained subjects

Variable		Control subjects ($N=10$)			Trained subjects ($N=24$)		
		Pre-training Mean ± SD	Post-training Mean ± SD	Changes Mean ± SD	Pre-training Mean ± SD	Post-training Mean ± SD	Changes Mean ± SD
	%	47 ± 6	48 ± 13	+ 1 ± 13	41 ± 11	47 ± 11**	+ 6 ± 10
Type I	area (μm^2)	4474 ± 864	4390 ± 697	− 84 ± 743	4089 ± 1271	4933 ± 1451**	+ 844 ± 1332
	% area	49 ± 9	49 ± 17	0 ± 13	45 ± 12	52 ± 12**	+ 7 ± 9
	%	38 ± 8	36 ± 12	− 2 ± 13	42 ± 9	42 ± 8	0 ± 11
Type IIa	area (μm^2)	4497 ± 1097	4704 ± 1423	+ 207 ± 962	3794 ± 1191	4266 ± 1196	+ 472 ± 1340
	% area	40 ± 9	37 ± 13	− 3 ± 14	42 ± 10	39 ± 8	− 3 ± 10
	%	14 ± 4	15 ± 10	+ 1 ± 11	17 ± 9	11 ± 6**	− 6 ± 10
Type IIb	area (μm^2)	3572 ± 1334	4008 ± 1381	+ 436 ± 820	2899 ± 1142	3593 ± 1242*	+ 694 ± 1278
	% area	11 ± 3	14 ± 10	+ 3 ± 10	13 ± 8	9 ± 5*	− 4 ± 8

* $p \leq 0.05$; ** $p \leq 0.01$

Specimens for histochemical analysis were orientated in a transverse direction and rapidly frozen in isopentane cooled in liquid nitrogen. Muscle sections (10 μm) were cut on a cryostat at −20° C and stained for ethanol-modified myofibrillar actomyosin ATPase (mATPase) according to the technique described by Mabuchi and Sréter (1980). For each specimen at least 300 fibers were classified. Mean muscle fiber areas were determined by averaging the cross-sectional areas of 20 randomly selected fibers of each type from mATPase stained reaction that have been photographically reproduced at a known magnification. Technical procedures for the analyses of the muscle characteristics were as detailed previously (Simoneau et al. 1985).

The experimental subjects were submitted 4 and later 5 times per week to a 15-week training program on a cycle ergometer which involved both continuous and interval work patterns. Twenty-five continuous, 19 short and 16 long interval sessions were distributed during the program such that half of the continuous sessions were completed by the fifth week of training. The purpose was to minimize problems which could possibly have occurred if high intensity interval work had been frequently imposed at the beginning of the program. The interval pattern consisted of 10 to 15 bouts of 15 to 30 s duration or 4 to 5 bouts of 60 to 90 s duration alternated with recovery intervals allowing the heart rate to return to 120—130 beats per min. The short exercise bouts were initially at an intensity of 60% of the individual's maximal work output in 10 s and increased to 80% during the latter phase of the training program. The long exercise bouts were started at an intensity of 70% of the individual's maximal work output in 90 s and were progressively increased up to 90% of that criterion intensity. This training program has been described in details elsewhere (Boulay et al. in press). Each training session for each subject was carefully controlled to ensure that the pre-determined protocols were maintained so that subjects were submitted to the same standardized training stimulus. The control subjects were requested to maintain their habitual lifestyle during the 15 weeks duration of the training program. Significance of the training effects was assessed through the paired *t*-test.

Results

The descriptive data of pre- and post-training values for fiber type distribution and areas are presented in the table. No significant difference was observed in the control group for the histochemical characteristics as determined before and after 15 weeks. The high-intensity intermittent training induced a significant increase in the proportion of type I fibers of the vastus lateralis. Concomitantly, type IIb fibers decreased significantly while type IIa fibers remained unchanged. Areas of type I and IIb fibers increased significantly with training.

Discussion

Experimental and control subjects had mean $\dot{V}_{O_{2\,max}}$ of 39.8 ± 7.7 and 44.0 ± 8.7 ml $kg^{-1} \cdot min^{-1}$, respectively, which is close to what had been previously reported for sedentary subjects (MacNab et al. 1969). Moreover, their muscle histochemical characteristics were well within the range of values reported for non-active subjects (Mahon et al. 1984; Simoneau et al. 1985).

The present results indicated that sedentary subjects increased the percentage of type I fibers with a decrease in type IIb fibers with high-intensity intermittent training. Variations in muscle characteristics determined from repeated biopsies ot the same muscle may be considered as a factor responsible for these changes. Variability of the muscle needle biopsy technique has previously been assessed and coefficients of variation ranging from 10% to 20% have been reported for fiber type I proportion in repeated samples taken from healthy individuals (Gollnick et al. 1972; Thorstensson 1976; Halkjaer-Kristensen and Ingemann-Hansen 1981; Blomstrand and Ekblom 1982). However, the sampling error effect should become less important in the detection of a mean training effect with increasing number of subjects. The absence of mean change in fiber type composition of control subjects and the similarity of variance observed in pre- and post-training data in control and experimental subjects suggest that problems related to the biopsy technique and muscle sampling were not the cause of the changes observed in experimental subjects.

Our results are in contrast with those from most longitudinal studies on training effects in human muscle (Gollnick et al. 1973; Saltin et al. 1976; Thorstensson 1976; Orlander et al. 1977; Costill et al. 1979), however, these were performed on small numbers and generally used endurance or strength training of shorter duration. Komi and Karlsson (1979) concluded from a twin study with limited sample sizes that heredity was the only factor accounting for the variation observed in type I fiber proportion. This result was quite surprising since the within twin pair variation in fiber type composition was less than the variation obtained between biopsies taken twice from the same muscle of the same individual within 1 to 2 weeks (Blomstrand and Ekblom 1982). In contrast, Lortie et al. (in press) observed intraclass correlations of 0.33 and 0.55 in pairs of brothers ($N=32$ pairs) and monozygotic twins ($N=35$ pairs), respectively, for the proportion of type I fibers of the vastus lateralis suggesting that factors unassociated with the genotype were responsible for a substantial fraction of the variance in muscle fiber type distribution. On the other hand, it is recognized from animal studies that continuous low-frequency activation of the whole muscle, made possible by chronic electrical stimulation, favors the shift from a fast- to slow-type muscle (Pette 1984). Although transformations occurring under normal physiological conditions such as exercise-training are less striking than those induced by chronically increased contractile activity, Green et al. (1984) and Luginbuhl et al. (1984) have detected similar direction of changes in the muscle fiber type proportion following high-intensity exercise training in rats. These results suggest that when the stimulus is appropriate, the potential for conversion of one fiber type to another does exist. Exercise-training studies of longer duration with intermediate testing periods should be undertaken to verify whether transition of fibers can be found to a greater extent than the one observed in the present study.

Some physiological events might explain the change in fiber type proportion induced in response to high-intensity intermittent training as observed in the present study. Pronounced depletion of muscle cell phosphocreatine stores as well as marked accumulation of lactate occur after intensive exercise leading to exhaustion (Hermansen 1979). Sahlin et al. (1979) have shown that the resynthesis of phosphocreatine was limited by the oxidative phosphorylation capacity of the muscle. Since human muscle type I fibers are well suited to remove the circulating lactate (Bonen et al. 1978), generally exhibit a greater oxidative capacity than type II fibers (Reichmann and Pette 1982), are involved in maximal dynamic exercise performed on cycle ergometer (Sjogaard 1978) and are quite depleted of glycogen after intermittent exercise (Green 1979), these fibers were undoubtedly extensively used during the high-intensity intermittent training.

Conflicting evidence has been reported regarding the adaptability of fiber type areas to exercise training. Some reports showed no effects (Constable et al. 1980), whereas others observed increments in fiber areas (Gollnick et al. 1973). Results of the present investigation indicated a significant enlargement in type I and type IIb fiber areas. This observation add evidence to the notion that the apparent disparity observed between studies regarding the adaptation of the fiber type areas could depend on the nature and duration of the training program as well as on the pre-training status of the subjects.

In summary, the results of this study demonstrated that the skeletal muscle fiber type I proportion and fiber areas could be modified by high-intensity intermittent training in adult sedentary humans. These data give support to the notion that the fiber type composition of the human vastus lateralis muscle is not determined solely by genetic factors.

Acknowledgements. Thanks are expressed to Y. D'amours, G. Fournier, C. Leblanc, L. Pérusse, A. M. Simoneau and G. Thériault for their assistance in the course of this study. Research supported by FCAC-Equipe (EQ-1330) and NSERC (G-0850 and A-1850).

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Accepted May 5, 1985