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Muscle Hypertrophy in Bodybuilders

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Summary. Muscle biopsy samples were obtained from m. vastus lateralis and m. deltoideus of three high caliber bodybuilders. Tissue specimens were analysed with respect to relative distribution of fast twitch (FT) and slow twitch (ST) fiber types and different indices of fiber area. In comparison to a reference group of competitive power/weight-lifters the following tendencies were observed: the percentage of FT fibers was less, mean fiber area was smaller and selective FT fiber hypertrophy was not evident. Values for fiber type composition and fiber size were more similar to values reported for physical education students and non-strength trained individuals. The results suggest that weight training induced muscle hypertrophy may be regulated by different mechanisms depending upon the volume and intensity of exercise.

Key words: Muscle fiber types – Muscle fiber size – Muscle hypertrophy – Muscle strength

Introduction

It is well documented that skeletal muscle hypertrophy, manifested in increased weight or cross-sectional area of muscle, occurs as a result of overloading induced either by surgical manipulation or by training (cf. Goldberg et al. 1975). Is is generally believed that such an increase in muscle volume is due to enlargement of individual muscle fibers (Morpurgo 1897; Goldberg et al. 1975; Gollnick et al. 1981) as a result of an enhanced protein synthesis, increased size and number of myofibrils and addition of sarcomeres within the individual muscle fiber (Goldspink 1964; Denny-Brown 1961). The hypertrophy seen in

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strength trained athletes has been attributed to a supranormal size of individual muscle fibers (Edström and Ekblom 1972; Gollnick et al. 1972; Prince et al. 1976; Häggmark et al. 1978). Recently, however, several reports have proposed hyperplasia, induced by longitudinal fiber splitting, as an alternative mechanism for skeletal muscle hypertrophy (Rowe and Goldspink 1968; Reitsma 1969; Gonyea 1981). To further study the influence of specific long-term exercise stress on over-all muscle hypertrophy, biopsy samples from the muscle of successful bodybuilders were examined with special regard to muscle fiber composition and size. These athletes are characterized by possessing an extraordinary body composition, indicated by gigantic limb circumferences and low percent body fat (Katch et al. 1980; Spitler et al. 1980).

Subjects and Methods

Three bodybuilders volunteered to take part in this study[1]). They were examined the day following a Mr. Scandinavia contest, in which all finished among the top five participants. Age, height, weight and percent body fat as calculated from skinfold measurements (Hermansen and von Döbeln 1971), averaged 25 (20–32) years, 177 (173–183) cm, 84 (80–88) kg and 4 (2–6) %.

Muscle biopsies (Bergström 1962) were obtained from m. vastus lateralis and the lateral portion of m. deltoideus. Cross-sections of the samples were histochemically stained for myofibrillar ATPase and NADH tetrazolium reductase. Individual fibers were identified either as fast twitch (FT) or slow twitch (ST), and fiber type distribution (%FT and %FT area) and fiber area (FT, ST and mean fiber area) were calculated. FT fibers were further subdivided into FTa and FTb (cf. Tesch 1980). Strength measurements were performed during velocity controlled leg extensions at selected constant angular velocities (Hislop and Perrine 1967) using a commercial dynamometer (Cybex II, Lumex Inc., NY, USA). Two reference groups of physical education students, (1) $n = 50$, 23 (19–32) years, 180 (171–190) cm, 72 (62–89) kg, and (2) $n = 12$, 21 (19–26) years, 181 (174–185) cm, 72 (66–80) kg, and one group of national elite power- and weight-lifters, $n = 8$, 26 (19–31) years, 170 (164–178) cm, 85 (75–104) kg, were selected for comparison.

Results

Fiber type distribution in m. vastus lateralis and m. deltoideus averaged 44 (37–49) and 36 (29–41) %FT, respectiveliy. The corresponding values for a reference group, comprising non-strength trained physical education students ($n = 12$), were 53 (29–79) and 50 (36–67) %FT. The percentage of FTa and FTb in m. vastus lateralis averaged 40 (37–49) and 4 (0–6) respectively. Values for m. deltoideus were 33 (27–41) and 3 (0–8) % respectively. Values for mean fiber area were 62 (47–74) and 47 (44–49) $\mu m^2 \cdot 100$ in bodybuilders and 62 (36–92) and 56 (41–70) $\mu m^2 \cdot 100$ in the reference group. Values for fiber type distribution and different indices of fiber area of m. vastus lateralis and m. deltoideus respectively are presented in Table 1. Information on muscle strength of bodybuilders, power- and weight-lifters and physical education students is summarized in Table 2.

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1 The study was approved by the Human Ethics Committee at Karolinska Institutet, Stockholm

Table 1. Mean (range) values for fiber type distribution and fiber area in bodybuilders (n = 3) and physical education students (1) n = 50 and (2) n = 12

	%FT	%FT area	FT area, $\mu m^2 \cdot 100$	ST area, $\mu m^2 \cdot 100$	FT/ST	Mean fiber area, $\mu m^2 \cdot 100$
M. vastus lateralis						
Bodybuilders	44 (37–49)	50 (42–57)	71 (53–84)	54 (44–66)	1.3 (1.2–1.4)	62 (47–74)
Reference group (1)	53 (29–79)	57 (28–77)	67 (37–102)	56 (29–89)	1.2 (0.9–1.9)	62 (32–92)
M. deltoideus						
Bodybuilders	36 (29–41)	42 (32–48)	55 (51–60)	44 (39–47)	1.3 (1.1–1.3)	47 (44–49)
Reference group (2)	50 (36–67)	57 (40–78)	62 (43–81)	48 (38–60)	1.3 (1.1–1.6)	56 (41–70)

Table 2. Mean (range) values for muscle strength in leg extension at two different angular velocities (i. e., peak torque at 30 and $180° \cdot s^{-1}$) in bodybuilders (n = 3), power- and weight-lifters (n = 8) and physical education students (n = 50). Values on fiber type distribution and fiber size of m. vastus lateralis are included for comparison

	%FT area	Mean fiber area, $\mu m^2 \cdot 100$	Muscle strength, $Nm \cdot kg^{-1}$ b.w.	
			$30° \cdot s^{-1}$	$180° \cdot s^{-1}$
Bodybuilders	50 (42–57)	62 (47–74)	3.9 (3.2–4.7)	2.7 (2.5–3.0)
Power- and weight-lifters	69 (62–77)	79 (56–108)	4.5 (3.9–5.1)	2.8 (2.5–3.1)
Physical education students	57 (28–77)	62 (32–92)	2.8 (1.5–3.8)	2.1 (1.3–2.7)

Discussion

We did not observe any sign of individual muscle fiber enlargement in either thigh or shoulder muscles of successful bodybuilders. Thus, despite the considerably greater body weight per height and less body fat in bodybuilders compared to habitually trained and age matched men, mean fiber area did not differ. MacDougall et al. (1980), studying the triceps muscle of bodybuilders, made a similar observation and speculated on an upper limit for the cross-sectional area of fibers undergoing hypertrophy. Accordingly, a greater total number of muscle fibers was suggested to explain the hypertrophied muscles of bodybuilders. In a recent study by Schantz et al. (1981), in which bodybuilders were included, it was concluded that muscle cross-sectional area is reflected in mean fiber area, thus confirming Häggmark et al. (1978). The present finding does not appear to be due either to methodological errors (coefficient of variation) which have ranged from 11–17% (Thorstensson et al. 1977; Tesch 1980), or to errors of interpretation, since the fiber size variation among the six samples was small and in no case were any extremely large fibers observed.

Competitive bodybuilders requires repeated activation and overloading of muscles comprising the entire body, and weight exercises for quadriceps and deltoid muscles are performed extensively, so that the selection of the muscles examined is not open to question.

The use of anabolic steroids among these athletes is recorded (Wright 1980). Typically, athletes take anabolic steroids, which may cause water retention, for a period ending approximately one to two weeks prior to a contest. Subsequently, rigorous diet and fluid restrictions are maintained; intake of salt and carbohydrates is kept at a minimum and fluids are allowed only in small quantities. Carbohydrate intake is increased substantially, beginning 24–48 h before the contest. Hence rehydration, recuperation and normalization of muscle glycogen levels had probably occurred at the time of the present examination, factors which might have affected determination of muscle fiber area. In fact acute glycogen depletion with a concomitant water loss, caused by prolonged heavy exercise, has tended to induce increases in mean fiber area as reflected by histochemical staining procedures (Forsberg et al. 1978). We have therefore ruled out the possibility that drug administration, diet or fluid restrictions have had any impact on our results.

If postnatal skeletal muscle fiber number is constant, as has been suggested (Goldberg et al. 1975), the "normal" muscle fiber size of successful and muscular bodybuilders might be due to an inherited larger number of muscle cells. Recently, a surprisingly great variation in total fiber number of muscle obtained from foetuses and infants was observed (Colling-Saltin 1980), which indicates different muscle growth potentials in humans. Alternatively, our findings may reflect exercise induced formation of new muscle fibers in bodybuilders, either by longitudinal fiber splitting (Reitsma 1969; Gonyea 1981) or due to the development of satellite cells (Salleo et al. 1980). A case report (Etemadi and Hosseini 1968) based on autopsy from an "athletic" subject and demonstrating larger but also 30% more fibers than normal in biceps brachii, do not contradict any of these hypotheses.

The stimuli for fiber splitting are not known, and its occurrence has in fact been questioned (Gollnick et al. 1981). Interestingly, relatively small fibers have also been demonstrated in muscular swimmers (Green et al. 1979; Nygaard and Nielsen 1978). Thus, very intense training consisting of repeated contractions with high tension output might possibly cause longitudinal fiber division (Edgerton 1970; Gonyea 1980, 1981).

In addition to the normal fiber areas observed in bodybuilders, no selective FT hypertrophy was shown as opposed to the pattern previously observed (Edström and Ekblom 1972; Gollnick et al. 1972; Prince et al. 1976) for power/weight lifters, and also confirmed in the present study.

The lack of FT hypertrophy also illustrates that muscle cells adapt differently depending on the intensity and magnitude of exercise. Bodybuilding training involves intense, repetitive contractions. Normally, a certain muscle group is exercised separately by 6–12 contractions until concentric contraction failure. Interspersed with short recovery periods, three sets or more are often repeated. This exercise is usually followed by or combined with additional exercises which activate the same muscle group. Accordingly, as many as 20 consecutive sets stressing a certain muscle may be executed within 30 min. Thus the type of exercise described is distinctly different from the typical training (low repetition system) that competitive weight- and power lifters rely upon. Again without evidence, it is nonetheless tempting to speculate on the occurrence of muscle fiber splitting in bodybuilders as a response to the highly specific type of training. Moreover, all muscle samples examined exhibited a preponderance of ST fibers. Mean values for percentage of FT fibers in m. vastus lateralis and m. deltoideus were considerably lower than even the reference group, comprising physical education studets. According to other reports (Gollnick et al. 1972; Thorstensson et al. 1977; Tesch et al. 1982) fiber type distribution pattern in the present bodybuilders tends to resemble the muscle structural profile of endurance athletes. The bodybuilders did in fact exhibit relatively high muscular endurance (Tesch, pers. observ.), which is consistent with the observed low percentage of high glycolytic, fatiguable FTb fibers. It can therefore be speculated that competitive bodybuilding training is characterized by demands on not only strength but muscular endurance as well, which in turn is favored by a high percentage of ST fibers (cf. Tesch 1980). Whether or not this is indicative of a selective process or due to exercise stress can only be speculated upon.

In summary, the great limb circumferences and muscle mass of bodybuilders was not found to result from enlarged individual muscle fibers. Within the limitation of the small subject sample and even though our data are not conclusive as regards the controversial question of whether overload induced hyperplasia is possible, we have noticed highly trained enlarged muscles in the absence of a corresponding individual fiber hypertrophy.

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