Muscle capillary supply and fiber type characteristics in weight and power lifters

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TESCH, PER A., A. THORSSON, AND P. KAISER. *Muscle capillary supply and fiber type characteristics in weight and power lifters.* J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 56(1): 35–38, 1984.—Muscle tissue samples were obtained from vastus lateralis muscle of elite weight/power lifters (WL/PL, $n = 8$), endurance athletes (EA, $n = 8$), and nonathletes (NA, $n = 8$). Histochemical stainings for myofibrillar ATPase, NADH-tetrazolium reductase, and amylase-periodic acid-Schiff, respectively, were undertaken to assess relative distribution of fast-twitch (FT) and slow-twitch (ST) muscle fiber types, fiber size, and capillary supply [capillaries per fiber ($cap \cdot fib^{-1}$) and capillaries per mm^2 ($cap \cdot mm^{-2}$)]. Fiber type distribution in WL/PL, EA, and NA averaged 59 ± 6 (SD), 40± 11, and 61 ± 10% FT. Values for mean fiber area and FT/ST area were significantly greater in WL/PL compared with values obtained in EA and NA. Similar values for $cap \cdot fib^{-1}$ were observed in WL/PL (2.06 ± 0.74) and NA (2.16 ± 0.34). EA exhibited greater $cap \cdot fib^{-1}$ (3.11 ± 0.73) than WL/PL (NS) and NA ($P < 0.01$). However, $cap \cdot mm^{-2}$ in WL/PL (199 ± 29) was lower than in EA (401 ± 61, $P < 0.001$) and NA (306 ± 29, $P < 0.01$). It is suggested that heavy resistance training in contrast to endurance training does not result in increased capillary density. Instead, as a consequence of fiber hypertrophy induced by muscle overloading, capillary density is decreased.

endurance athletes; muscle fiber size; fast- and slow-twitch fibers; muscle hypertrophy

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IN PROLONGED HEAVY EXERCISE the capillary supply of the exercising muscle seems to be of utmost importance to provide the muscle with adequate O_2 and blood borne energy substrates (16). Similarly endurance athletes have been found to possess increased skeletal muscle capillary density (1, 4, 14). Also, augmented capillarization has been demonstrated as a response to increased physical activity (2, 20).

In contrast to endurance exercise, strength activities, comprising a single or a few maximal contractions such as in weight lifting, can be effectively executed without increased demand on central and peripheral circulation. It is therefore less likely that capillary proliferation occurs as an adaptive response to strength training. Hypertrophy of individual muscle fibers is a typical response to muscle overloading and has been demonstrated in competitive weight and power lifters (8, 11, 12, 17, 21). Therefore capillary supply, expressed as capillaries per unit muscle cross-sectional area, would, instead, be expected to decrease in these athletes as a response of their training.

Likewise, endurance and strength athletes differ with regard to the relative contribution of fast-twitch (FT) and slow-twitch (ST) fibers and to the cross-sectional area of muscle fibers (11, 21). Regardless of physical activity level of an individual, the FT fiber is typically larger in diameter and surrounded by a lower number of capillaries than the ST fiber (1, 4, 14).

With this background in mind, the purposes of this study were to compare elite weight and power lifters, endurance athletes, and untrained individuals with respect to capillary density, fiber type distribution, and fiber size of vastus lateralis muscle.

MATERIALS AND METHODS

Subjects were national elite weight and power lifters ($n = 8$). Their individual characteristics are described in Table 1. The exercises carried out by these athletes were comprised of heavy slow-speed contractions (power lifters) and combinations of heavy slow- and fast-speed contractions (weight lifters). For comparison, endurance athletes (EA, $n = 8$), including five road-racing cyclists and three runners, and combat pilots ($n = 8$) recruited from the Swedish Air Force and regarded as "nonathletes" (NA) were studied (Table 2). The lifters were significantly heavier and tended to be shorter than both endurance athletes and nonathletes. Athletes were examined when in peak condition. All weight/power lifters (WL/PL) admitted that they had been using anabolic steroids in periods for some years before this investigation. After being informed of the purpose and the potential risks associated with the experiments, consent was given by the subjects. The protocol was approved by the Human Ethics Committee at the Karolinska Institute.

Muscle tissue specimens were obtained from vastus lateralis muscle using the percutaneous needle biopsy technique (3) at a site 13–16 cm proximal basis patella and at a muscle depth of approximately 2 cm. Biopsies were mounted in embedding medium and frozen in isopentane cooled with liquid N_2 and stored at −80°C until analyzed. Serial transverse sections (10 μm) were cut in a microtome at −25°C. Stainings were undertaken for ATPase activity (19) after preincubation at pH 10.3 (9), NADH-tetrazolium reductase (18), and amylase-periodic acid-Schiff (1, 2).

For classification, fibers were identified as FT and ST fibers (9). The percentage of each fiber type was calculated from sections containing at least 200 fibers; an average of 552 (range 285–920) fibers were used for calculation. Muscle fiber area was determined on NADH-tetrazolium reductase-stained fibers using a cutting and weighing procedure (24). At least 10 fibers of each fiber type, subjectively rated as representative for the entire transverse sections, were selected for analysis. Mean muscle fiber area was calculated as absolute FT area $\cdot$ %FT^{-2} + absolute ST area $\cdot$ %ST^{-2}. The relative muscle area occupied by FT muscle fibers was calculated according to a formula described elsewhere (23). Capillary density (cap $\cdot$ mm^{-2}) and capillaries per fiber (cap $\cdot$ fib^{-1}) were determined from magnified photographs of amylase-periodic acid-Schiff stainings (2).

Means ±SD and ±SE were calculated and differences between groups were tested for significance using independent Student's t test. Significance was set at the 0.01 level of confidence.

TABLE 1. *Characteristics of weight and power lifters and information on best performance at time of examination*

Subj No.	Age, yr	Ht, cm	Wt, kg	Best Performance, kg		
				Snatch	Clean and jerk	
Weight lifters						
1	23	171	80	120	165	
2	29	178	96	163	200	
3	20	180	96	125	170	
4	25	183	112	174	207.5	
				Squat	Bench press	Dead lift
Power lifters						
1	30	164	77	237.5	175	260
2	34	164	80	305	200	290
3	25	178	104	267.5	200	295
4	28	165	85	325	192.5	290

TABLE 2. *Physical characteristics of three subject groups examined*

	n	Age, yr	Ht, cm	Wt, kg
WL/PL	8	26.8 ± 4.4	172.9 ± 7.8	91.3 ± 12.7*†
Endurance athletes	8	21.8 ± 2.5	180.8 ± 3.1	68.1 ± 4.9†
Nonathletes	8	26.0 ± 4.0	182.4 ± 6.0	75.9 ± 5.2

Values are means ± SE; n, no. of athletes. WL/PL, weight/power lifters. Significantly different from values obtained in endurance athletes (*$P < 0.01$) and nonathletes (†$P < 0.01$).

RESULTS

Values (±SD) for %FT and %FT area in WL/PL were 59 ± 6 and 70 ± 6%, respectively. Similar values were obtained in NA. %FT area was significantly greater than %FT ($P < 0.001$) in WL/PL but not (NS) in NA. Mean fiber area and FT/ST area averaged 93 ± 26 $\mu m^2 \cdot 100$ and 1.68 ± 0.25, respectively, in WL/PL. These values were significantly greater (72%, $P < 0.01$; 54%, $P < 0.001$) than the values obtained in NA. Capillaries per fiber was equal in WL/PL (2.06 ± 0.74 cap $\cdot$ fib^{-1}) and NA (2.16 ± 0.34), whereas capillary density was 54% ($P < 0.01$) lower in WL/PL (199 ± 29 cap $\cdot$ mm^{-2}) than in NA (306 ± 29). Compared with the values obtained in EA, %FT and %FT area in WL/PL were higher ($P < 0.001$). EA exhibited significantly ($P < 0.01$) smaller mean fiber area and FT/ST area compared with WL/PL. Capillaries per fiber was 51% greater (NS), and capillary density was 102% greater in EA than in WL/PL. For detailed information see Table 3.

DISCUSSION

In accordance with previous reports, muscle fiber hypertrophy and selective FT hypertrophy were noticed in high-caliber WL/PL. The main finding of the present study, however, was the reduced capillary density observed in the trained muscles of lifters. Thus, whereas the number of capillaries surrounding a muscle fiber was the same in WL/PL and NA, capillaries per square millimeter were lower in the former.

Capillary density. The present study apparently shows that heavy resistance training does not alter capillaries per fiber characteristics. Since the number of capillaries per fiber remains unchanged and fiber hypertrophy occurs as a response to training, capillaries per square millimeter are reduced. This finding is consistent with the suggestion, based on studies of myocardial capillary concentrations, that all types of hypertrophy are accompanied by lower capillary density (13). In contrast to our results, it was recently proposed that heavy resistance training performed by bodybuilders could induce capillary growth (22). Whereas capillary density was of the same magnitude, capillaries per fiber were increased in the athletes compared with values reported for untrained

TABLE 3. *Muscle fiber type distribution, fiber size, and capillary density in weight and power lifters, endurance athletes, and nonathletes*

	n	%FT	%FT Area	Mean Fiber Area, $\mu m^2 \cdot 100$	FT/ST Area	cap $\cdot$ fib^{-1}	cap $\cdot$ mm^{-2}
WL/PL	8	59 ± 6*	70 ± 6*	93 ± 26†‡	1.68 ± 0.25†§	2.06 ± 0.74	199 ± 29*‡
		(51–66)	(60–77)	(56–131)	(1.32–2.15)	(1.17–3.22)	(156–241)
EA	8	40 ± 11‡	46 ± 11	65 ± 11	1.31 ± 0.22	3.11 ± 0.73‡	401 ± 61‡
		(30–63)	(36–67)	(46–78)	(0.99–1.74)	(2.05–4.42)	(323–500)
NA	8	61 ± 10	68 ± 9	54 ± 13	1.09 ± 0.17	2.16 ± 0.34	306 ± 29
		(47–72)	(44–74)	(37–78)	(0.88–1.44)	(1.73–2.67)	(280–349)

Values are means ± SD; n, no. of athletes. FT and ST, fast-twitch and slow-twitch fibers, respectively; cap $\cdot$ fib^{-1}, capillaries per fiber; cap $\cdot$ mm^{-2}, capillaries per mm^2; WL/PL, weight/power lifters; EA, endurance athletes; NA, nonathletes. Significantly different from values obtained in endurance athletes (*$P < 0.001$, †$P < 0.01$) and nonathletes (‡$P < 0.01$, §$P < 0.001$).

subjects (2). These deviating findings may be explained by the obviously different training programs executed by lifters and bodybuilders, the latter relying on a higher number of repetetive contractions. It is less attractive to explain the difference in capillary supply by the prolonged and excessive use of anabolic steroids among weight and power lifters, since drug administration is also a typical observation in bodybuilders (25). To the authors' knowledge, there is no evidence suggesting capillary proliferation as a result of anabolic hormones per se (see also Ref. 25).

Our data, then, suggests that the decreased capillary density is caused by an increased number of myofilaments per individual muscle fiber as a result of muscle hypertrophy (10). Similarly, and probably because of the same mechanism, in hypertrophied muscles of athletes low activities of enzymes involved in oxidative metabolism [e.g., succinate dehydrogenase (6, 11) and low mitochondrial fractions] have been observed (17).

It is also interesting to notice that the lower capillary density in WL/PL compared with NA is not due to differences in fiber type distribution. Hence, when the greater FT fiber size in WL/PL was accounted for, the relative area occupied by FT fibers still did not differ.

A decreased vascular density, due to fiber growth, would theoretically increase diffusion distance (16) and reduce the capacity for O_2 delivery to the recruited individual muscle fiber. Therefore WL/PL would be less prone to succeed at aerobic exercise.

Fiber type distribution. Muscle fiber type distribution did not differ when comparing WL/PL and NA. The present finding concerning fiber type distribution is also consistent with previous observations on WL/PL of unknown caliber (8, 11, 12, 17, 21). However, a certain percentage of FT fibers may be required for success in these athletic events, since none of the successful lifters investigated here exhibited a preponderance of ST fibers. On average, 70% of vastus lateralis muscle was occupied by FT fibers in WL/PL, perhaps reflecting the importance of a large relative quantity of FT myofibrillar protein of the contracting muscle for high tension development, such as in competitive lifting. This assumption is in agreement with a recent observation showing a positive correlation between %FT fibers in vastus lateralis muscle and strength improvement in squat in physical education students subjected to a 7-wk strength training program (7). Confirming numerous reports, a high relative proportion of ST fiber was demonstrated in athletes involved in endurance exercise (4, 6, 11, 14, 15).

Fiber size. Mean fiber area was 72% larger in WL/PL than in NA. This difference does not imply a correspondingly greater total muscle mass of the lifters as indicated by the smaller difference in body weight. Instead, it is suggested to be the result of specific hypertrophy of the quadriceps muscle. Earlier Häggmark et al. (12) found a linear relationship between mean fiber area and the cross-sectional area of the vastus lateralis muscle measured by computed tomography, which lead them to suggest the biopsy method and subsequent histochemical procedures to be used as a reliable method to examine for muscle hypertrophy in humans. From the present study it is also apparent that the hypertrophy, to a high extent, is due to selective FT hypertrophy; i.e., a large FT/ST area ratio, which confirms previous observations on strength trained athletes (8, 11, 21, 24). The fact that %FT area was significantly greater than %FT in WL/PL but not in NA is further support for this assumption. Evidently weight lifting stimulates fiber growth in the FT more than ST fibers and this may relate to the recruitment pattern used during lifting. Although lower than in WL/PL, a surprisingly high FT/ST area ratio was observed in endurance athletes. A closer examination of these individuals revealed the presence of a difference between cyclists and runners in that the former possessed larger mean fiber area and greater FT/ST area. From the literature there are reasons to believe that the diameter of individual fibers are larger in cyclists than in middle-distance runners (5, 11). Supporting this thesis is the demonstration that mean fiber area increased as a response to 8 wk of a moderately intense endurance training program on cycle ergometer (2).

In summary, the present data suggests that the adaptive response to long-term weight and power lifting exercise, contrary to endurance exercise, does not include increased skeletal muscle capillarization. As a consequence of the muscle fiber hypertrophy, heavy resistance training results, rather, in reduced capillary density. Also, although selective FT fiber hypertrophy was implied in these athletes, neither fiber type distribution nor the relative area occupied by either of the fiber types were different from the values obtained in nonathletes.

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