

Muscle Fiber Characteristics and Performance Correlates of Male Olympic-Style Weightlifters

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ABSTRACT

Biopsies from the vastus lateralis muscle of male weightlifters (WL; $n = 6$; $\bar{X} \pm SE$, age = 27.0 ± 2.1 years), and non-weight-trained men (CON; $n = 7$; age = 22.0 ± 2.0) were compared for fiber types, myosin heavy chain (MHC) and titin content, and fiber type-specific capillary density. Differences ($p < 0.05$) were observed for percent fiber types IIC (WL = 0.4 ± 0.2 , CON = 2.4 ± 0.8); IIA (WL = 50.5 ± 3.2 , CON = 26.9 ± 3.7); and IIB (WL = 1.7 ± 1.4 , CON = 21.0 ± 5.3), as well as percent MHC IIa (WL = 65.3 ± 2.4 , CON = 52.1 ± 4.2) and percent MHC IIb (WL = 0.9 ± 0.9 , CON = 18.2 ± 6.1). All WL exhibited only the titin-1 isoform. Capillary density (caps·mm⁻²) for all fiber types combined was greater for the CON subjects (WL = 192.7 ± 17.3 ; CON = 262.9 ± 26.3), due primarily to a greater capillary density in the IIA fibers. Weightlifting performances and vertical jump power were correlated with type II fiber characteristics. These results suggest that successful weightlifting performance is not dependent on IIB fibers, and that weightlifters exhibit large percentages of type IIA muscle fibers and MHC IIa isoform content.

Key Words: capillary density, fiber type, myosin heavy chain, power, strength, titin, vertical jump

Reference Data: Fry, A.C., B.K. Schilling, R.S. Staron, F.C. Hagerman, R.S. Hikida, and J.T. Thrush. Muscle fiber characteristics and performance correlates of male Olympic-style weightlifters. *J. Strength Cond. Res.* 17(4):746–754. 2003.

Introduction

Previous studies on muscle fiber characteristics and weight training have often failed to differentiate between the various types of resistance exercise. Each of the competitive weight training sports is characterized by distinctly different goals and training methods (31). One of the principle characteristics of Olympic-style weightlifting is the large power production—almost 7,000 W during the top of the clean pull for an

elite 125-kg lifter (17, 31)—thus exposing these athletes to a unique physical stimulus. On the other hand, powerlifters perform exercises characterized by high forces at low velocities, resulting in relatively low power (17, 31). Body builders train primarily for muscular hypertrophy using exercises and training programs that optimize the anabolic processes, and they focus less on power and force production. Since it is likely that each of the different training methods used by these various athletes result in training-specific muscle adaptations, study of the muscular characteristics of strength-trained athletes needs to differentiate between these different athletes and their unique training methods.

It is well known that athletes in strength or power sports possess greater percentages of fast-twitch (FT) fibers than do proficient athletes in endurance sports (18, 39, 46). Genetic factors can contribute greatly to muscle characteristics, although nongenetic factors, such as neural and endocrine environments and functional demands, can also influence muscle morphology and physiology (22, 40, 43). Skeletal muscle is quite plastic, thus being able to readily respond to current functional demands (43). Various heavy resistance-trained athletes, including weightlifters, have exhibited percentages of FT fibers ranging from 53% to 60% (20, 21, 31, 39, 46–48). Although this ratio between FT and slow-twitch (ST) fibers is not greatly different from proportions observed in untrained individuals, the cross-sectional areas of the FT fibers are considerably larger for competitive lifters and strength athletes (20, 31, 46–48). Many of these previous studies have simply grouped weightlifters with powerlifters, body builders, and other types of strength athletes (e.g., track and field throwers, recreational lifters; 31). To the authors' knowledge, only 1 study has investigated the fiber type composition of muscles from weightlifters alone, but muscle fiber subtypes, contractile protein expression, or their relationships with

physical performances were not analyzed (20). Most studies of fiber characteristics have simply reported the major types (i.e., I, IIA, IIB). It is believed that quantifying the subtypes (i.e., IC, IIC, IIAB) may provide greater sensitivity to training-specific adaptations.

Titin is a large (2,000–3,000 kDa) cytoskeletal protein that extends from the Z line to the M line of the sarcomere (16, 50). This structural protein is elastic and contributes to the passive and active force-producing capabilities of skeletal muscle (26). Two different isoforms of titin have been observed in some humans, whereas others have exhibited only 1 isoform (14). Each isoform is associated with unique force-producing capabilities that could influence the stored elastic energy of muscle. Such alterations in the functional properties of muscle could conceivably affect weightlifting performances. To date, it is not known whether titin isoform expression is regulated by activity patterns, or if it is related to muscular strength and power in humans (14).

Long-term aerobic training results in increased muscle capillarization, whereas such an adaptation is not as critical for many types of long-term anaerobic training. Despite this difference, increased capillarization (caps-fiber⁻¹) has been reported during the initial stages of a resistance-training program (24, 48), even in the presence of increased muscle fiber cross-sectional areas. On the other hand, long-term strength training, such as that used by high-caliber weightlifters and powerlifters, appears to result in attenuated muscle capillarization due to the extremely large muscle fiber cross-sectional areas, especially of the type II fibers (48). It is not currently known whether attenuated capillarity is fiber type-specific or whether it is similarly evident for all muscle fiber types subsequent to long-term weightlifting training. Furthermore, it is also not known whether decreases in capillarity are due primarily to muscle hypertrophy while maintaining the number of capillaries per fiber, or whether there is actually a loss of capillaries, which could lead to future health concerns.

Specific to weightlifting, it is important to closely examine the skeletal muscle characteristics of highly accomplished athletes who are chronically exposed to this unique high-power resistance exercise stimulus. Furthermore, it needs to be determined if these fiber characteristics are related to in vivo muscular performances. The first purpose of this investigation was to determine the skeletal muscle characteristics (i.e., fiber types, fiber type cross-sectional areas, myosin heavy chain [MHC] and titin expression, capillary density) of international- and national-caliber athletes in the Olympic sport of weightlifting. The second purpose was to determine if the fiber characteristics are related to actual competitive performances for the weightlifters, thus providing a structure-function relationship to

Table 1. Subject characteristics ($\bar{X} \pm SE$).

Variable	Weightlifters (<i>n</i> = 6)	Controls (<i>n</i> = 7)
Age (yrs)	27.0 ± 2.1	22.0 ± 2.0
Height (cm)	174.0 ± 12.5	181.1 ± 3.0
Body weight (kg)	95.5 ± 4.5	76.7 ± 4.6
Relative fat (%)	20.4 ± 1.9	17.4 ± 1.9
1RM snatch (kg)*	123.3 ± 4.9	—
1RM clean and jerk (kg)	158.8 ± 6.0	—
Best official total (snatch + clean and jerk; kg)	281.7 ± 10.4	—
Counter-movement vertical jump height (cm)	60.8 ± 3.9	—
Counter-movement vertical jump power (W)	5376.6 ± 180.7	—
Static vertical jump height (cm)	56.7 ± 2.9	—
Static vertical jump power (W)	5127.7 ± 163.4	—
Years trained	10.7 ± 2.4	—
Training sessions/week	5.1 ± 0.1	—
Hours/training session	2.3 ± 0.1	—

* RM = repetition maximum.

explain the fiber characteristics required for this high-power sport.

Methods

Experimental Approach to the Problem

In order to compare physical, physiological, and performance characteristics of weightlifting and untrained control subjects, a quasi-experimental ex post facto study design was used.

Subjects

Six male international- and national-caliber Olympic-style weightlifters (WL) participated in this study. All weightlifters had qualified for national-level competition, with 1 individual being selected for the United States World Championships Team. On average, the most recent competitive performances for these subjects were 68% of the current world record for the 94 kg weight class (417.5 kg). All subjects had previously tested negative via urinalysis for performance-enhancing drugs on numerous occasions. Data for the weightlifters were collected 1 week after the U.S. Senior National Weightlifting Championships, in which most of the subjects had just competed. Seven male exercise science students served as control subjects (CON). None of the CON subjects had performed resistance exercise or aerobic training during the previous year. All subjects provided informed consent following the guidelines of the Institutional Review Board. Descriptive data for the subjects are listed in Table 1.

Physical and Muscular Performance Tests

Anthropometric estimation of body composition was assessed for all subjects using Harpenden skinfold calipers (27). All WL subjects completed a weightlifting history questionnaire, including their most recent actual competitive performances (U.S. National Championships or American Championships). Additionally, vertical jump performances were recorded for the WL to estimate lower-body peak power capacity (23). Jumps were performed both with a preceding counter-movement (CMVJ) and without a counter-movement using a static starting position (SVJ). The SVJ was included to mimic the starting position for both the snatch and the clean and jerk, where typically no counter-movement precedes the lift.

Muscle Biopsies

Muscle biopsies (50–100 mg) were extracted from the vastus lateralis muscle (9), oriented in tragalanth gum, frozen in isopentane cooled by liquid nitrogen to -159°C , and stored at -70°C . To ensure adequate sample sizes, large pieces were obtained using a double-chop method (45) combined with suction (12). The frozen biopsy samples were warmed to -20°C and serially sectioned using 12 μm thick sections for the determination of fiber type composition and MHC or titin content.

Fiber-Type Distribution and Percent Fiber-Type Area

Routine myofibrillar adenosine triphosphatase (m-ATPase) histochemical analysis was performed using preincubation pH values of 4.3, 4.6, and 10.2 (10) to determine the muscle fiber-type distribution. Six fiber types (I, IC, IIC, IIA, IIAB, and IIB) were distinguished based on their staining intensities (42; see Figure 1). A composite photomontage of each mATPase preparation (preincubation at pH 4.6) was made using Polaroid micrographs ($\times 56$ magnification). These were used in combination with the other histochemical preparations (preincubations pH 4.3 and 10.6) to determine fiber type percentages and total fiber number in each biopsy. The cross-sectional areas of at least 50 fibers (35) per major type (I, IIA, and IIB) per biopsy were determined by the use of direct tracings ($\times 200$ magnification) and a digitizing tablet. There were not enough C fibers (i.e., IC, IIC) in any of the biopsy samples to permit cross-sectional analyses for these fibers. In cases where there were too few IIB fibers present, IIAB fibers were included for the cross-sectional area analysis. For the purposes of the present study, we have chosen to use the fiber-type classification scheme (i.e., I, IIA, IIB) originally developed for human muscle (10, 41), as well as the corresponding MHC classification scheme for humans (i.e., I, IIA, IIB).

Myosin Heavy Chain and Titin Analyses

MHC analysis was performed on the muscle biopsies using sodium dodecyl sulfate-polyacrylamide gel elec-

trophoresis (SDS-PAGE). This protocol is based on the procedures of Carraro and Cantani (11) and Perrie and Bumford (37) with modifications used for single human muscle fibers (42). Briefly, 8–10 serial cross-sections (12 μm thick) from each biopsy were placed into 0.5 ml of a lysing buffer containing 10% (w/v) glycerol, 5% (v/v) β -mercaptoethanol, and 2.3% (w/v) sodium dodecyl sulfate (SDS) in 62.5 mM Tris/HCl buffer (pH 6.8) and heated for 10 minutes at 60°C . To determine MHC expression, small amounts of the extracts (3–5 μl) were loaded on 4%–8% gradient SDS polyacrylamide gels with 4% stacking gels (7), run overnight (19–21 hours) at 120 V, and stained with Coomassie blue. MHC isoforms were identified according to their apparent molecular masses compared with those of marker proteins and migration patterns from single fiber analyses (42, 43; see Figure 2). To determine titin expression, 15 μl of muscle extract were loaded on 3%–6% gradient SDS-polyacrylamide gels (pH 8.4) with 3% stacking gels (pH 6.8) and were electrophoresed overnight (21 hours) at 120 V. Due to the low concentrations, the gels were allowed to polymerize >12 hours at 4°C in order to obtain a clear banding pattern (19). Protein bands were visualized using silver staining procedures (36). Semidry Western blots were used to transfer proteins to polyvinylidene difluoride (PVDF) blotting paper. Titin protein bands were visualized using monoclonal antititin clone T11 (T-9030, Sigma, St. Louis, MO); antimouse secondary antibody; and horseradish peroxidase chloro development reagent, 4-chloro-1-naphthol (Bio-Rad, Hercules, CA) to verify the identity of the titin bands. Optical densitometry (Bio-Rad, Hercules, CA) was used to determine relative amounts of either the MHC or the titin isoforms present.

Capillary Density

Capillaries were visualized for each tissue section using a biotinylated Ulex europaeus agglutinin I (UEAI) lectin procedure (25). The surrounding muscle was stained with fast green to provide visual contrast. Capillaries per tissue area (caps- mm^{-2}) and the tissue area served by each capillary (area [$\mu\text{m}^2\text{-cap}^{-1}$]) were determined for all major fiber types. Standardized areas (0.4 mm^2) of each section stained for capillaries were compared with the identical area of the corresponding serial section stained for mATPase, thus permitting fiber type-specific capillary densities to be determined. From these data, the \bar{X} number of capillaries bordering each fiber of the 3 major fiber types (I, IIA, IIB), as well as the number of capillaries bordering each fiber when adjusted for the \bar{X} fiber type area (caps-1,000 $\mu\text{m}^{-2}\text{-fiber type area}^{-1}$) were determined.

Statistical Analyses

Results are reported as $\bar{X} \pm SE$. Due to the dependent nature of the fiber type and MHC data, multivariate

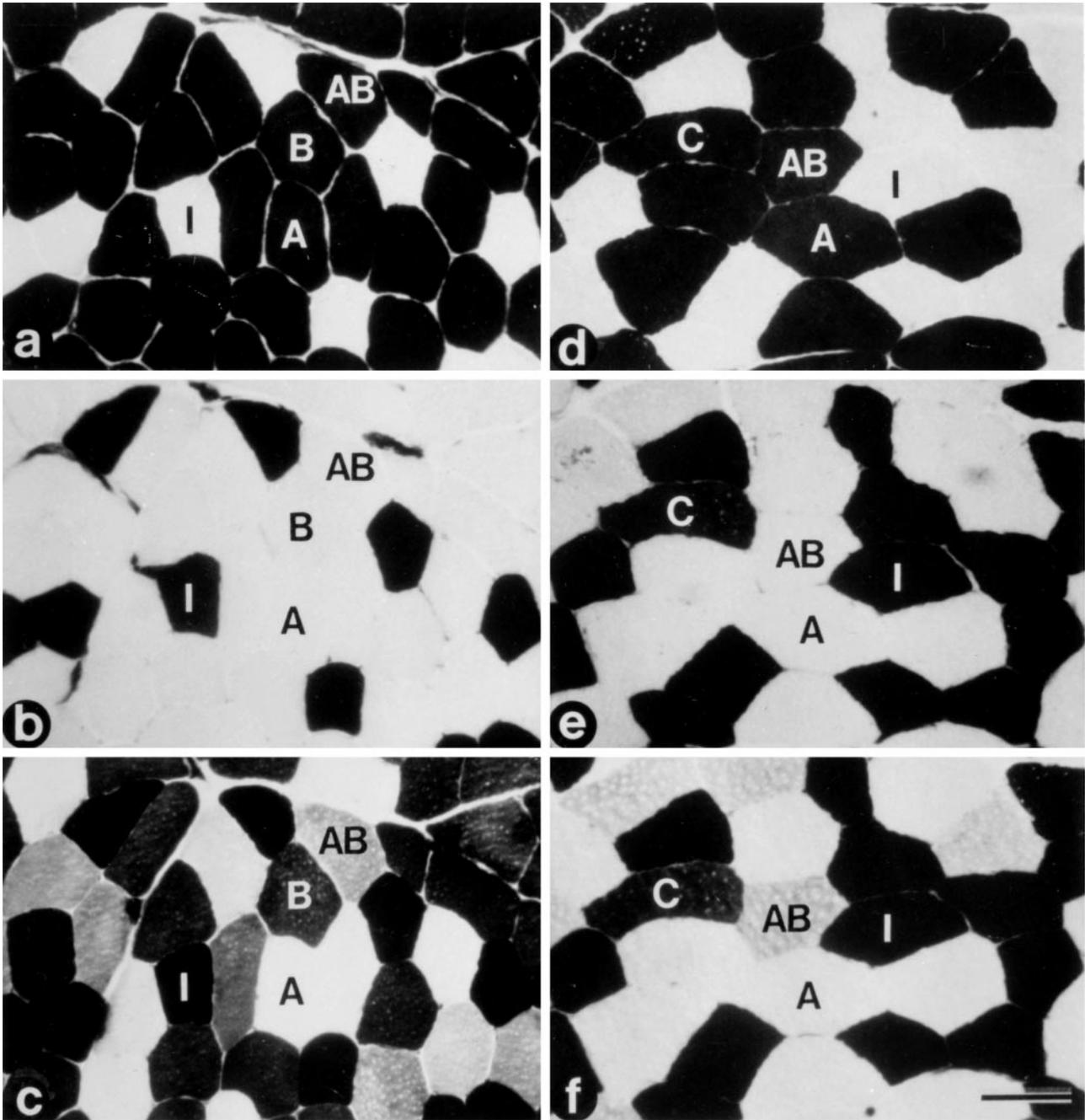


Figure 1. Myofibrillar adenosine triphosphatase (mATPase) histochemical staining for determination of fiber types for a control subject (a, b, and c) and a male weightlifter (d, e, and f) following preincubations at pH 10.2 (a and d), 4.3 (b and e), and 4.6 (c and f). I = type I; C = type IIC; A = type IIA; AB = type IIAB; B = type IIB; bar = 100 μ m.

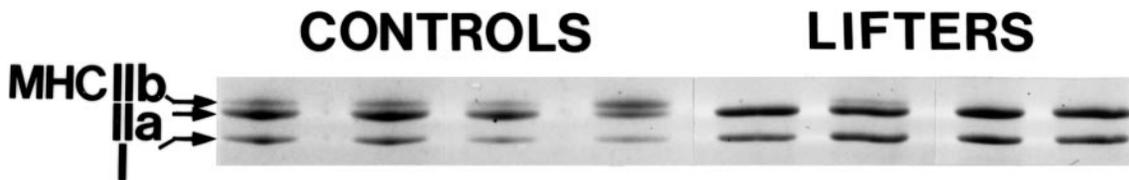


Figure 2. Results of sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE; 4-8% gradient) and Coomassie blue staining for separating myosin heavy chain (MHC) isoforms of 4 representative control subjects and 4 representative weightlifters. MHC IIb = myosin heavy chain IIb; MHC IIa = myosin heavy chain IIa; MHC I = myosin heavy chain I.

Table 2. Muscle fiber type and protein expression characteristics ($\bar{X} \pm SE$).

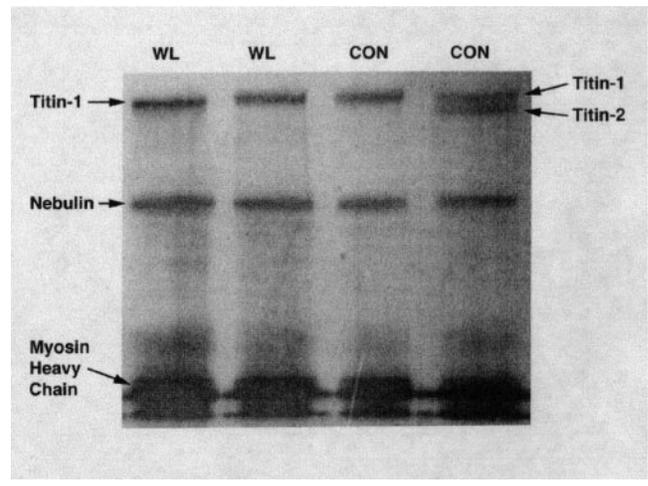
Variable Type	Weightlifters (<i>n</i> = 6)	Controls (<i>n</i> = 7)
% Fiber type		
I	46.5 ± 2.3	43.8 ± 4.6
IC	1.2 ± 0.7	0.2 ± 0.1
IIC	0.6 ± 0.2	2.4 ± 0.8*
IIA	46.5 ± 2.7	26.9 ± 3.7*
IAB	2.8 ± 0.7	5.7 ± 1.2
IIB	2.4 ± 2.0	21.0 ± 5.3*
Cross-sectional areas (μm^2)		
I	6326 ± 704	5488 ± 467
IIA	8735 ± 650	7024 ± 736*
IIB	2561 ± 1626	6234 ± 560*
% Fiber type areas		
I	40.2 ± 2.9	38.6 ± 4.9
IIA	56.7 ± 2.5	36.5 ± 4.0*
IIB	3.1 ± 2.4	24.9 ± 6.2*
% Myosin heavy chain isoform		
I	34.6 ± 2.9	29.7 ± 5.3
Ia	64.0 ± 2.3	52.1 ± 4.2*
Ib	1.4 ± 1.4	18.2 ± 6.1*

* Different from weightlifters ($p < 0.05$).

analyses of variance (MANOVA) were used to compare results for the weightlifters and the control subjects. Independent *t*-tests and 2×3 multivariate ANOVAs were used to compare capillary density results for the WL and CON subjects. Pearson product-moment correlations were calculated for muscle fiber characteristics and weightlifting or vertical jump performances. Significance for this investigation was $p \leq 0.05$ unless otherwise indicated.

Results

The WL were highly trained as indicated by their lifting performances and their training experience and practices (Table 1). Biopsy sizes averaged 618 ± 85 fibers ($\bar{X} \pm SE$) for all subjects. WL subjects exhibited significantly lower percentages of types IIB and IIC fibers, and significantly greater percentages of type IIA when compared with the CON group (Table 2, Figure 1). Cross-sectional areas were not significantly different between groups for type I fibers, whereas type IIA fibers were larger for the WL (Table 2). Although the WL exhibited smaller IIB fibers, there were too few of these fibers for some WL subjects for an accurate cross-sectional area measure. The percent fiber area for IIA fibers were greater for WL than for CON, whereas the percent area for IIB fibers was greater for CON than for WL (Table 2). WL subjects exhibited significantly greater percentages for MHC IIA isoform con-

**Figure 3.** Results of sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE; 3–6% gradient) and silver staining for separating titin isoforms of 2 representative weightlifters (WL) and two representative control (CON) subjects. Overstaining of the lighter proteins was necessary to visualize the titin bands.**Table 3.** Muscle capillary densities ($\bar{X} \pm SE$).

Variable	Fiber type	Weightlifters (<i>n</i> = 6)	Controls (<i>n</i> = 7)
Caps- mm^2	All	192.6 ± 17.4	262.9 ± 26.3*
Area (μm^2)-cap $^{-1}$	All	5611.8 ± 536.5	4014.5 ± 353.0*
Caps-fiber $^{-1}$	I	4.07 ± 0.24	4.40 ± 0.41
	IIA	3.86 ± 0.41	4.66 ± 0.24
	IIB	3.50 ± 0.73	4.18 ± 0.36
Caps-1000 μm^{-2}	I	0.677 ± 0.054	0.828 ± 0.084
	IIA	0.473 ± 0.043	0.705 ± 0.072*
	IIB	0.486 ± 0.032	0.681 ± 0.069

* Different from weightlifters ($p < 0.05$).

tent, and significantly lower percentages for MHC IIB isoform content when compared with the CON group (Table 2, Figure 2). All of the WL exhibited only 1 isoform of titin (titin-1), whereas 3 CON subjects also exhibited only 1 isoform and 4 CON subjects exhibited 2 isoforms (titin-1 and titin-2; Figure 3). WL exhibited a lower capillary density than the CON group, due primarily to a lower density for IIA fibers (Table 3). Although muscle biopsies for the weightlifters were collected 1 week after a major competition, electronmicroscopy analysis determined no evidence of residual muscle disruption or damage (unpublished data). Correlation coefficients indicated muscle fiber characteristics were significantly related to weightlifting and vertical jump performances (Table 4).

Discussion

The weightlifters in this investigation exhibited performance characteristics typical of national-level ath-

Table 4. Correlation coefficients (*r*) for muscle fiber characteristics and weightlifting or vertical jump performances.†

	1RM C&J	1RM snatch	Total	CMVJ height	SVJ height	CMVJ power	SVJ power
% IIA fibers	—	0.94**	0.80*	—	0.79*	0.83**	0.75*
% Area IIA	—	0.83**	—	—	—	0.75*	—
% Area IIB	-0.78*	—	—	—	—	—	—

† 1RM = 1 repetition maximum; C&J = clean and jerk; total = 1RM clean and jerk plus 1RM snatch; CMVJ = counter-movement vertical jump; SVJ = static vertical jump.

* $p < 0.10$.

** $p < 0.05$. — = not significant.

letes as indicated by the 1 repetition maximum (1RM) for the snatch and the clean and jerk (17, 31). Of particular importance to this investigation are the results of the muscle biopsies. Previous data on muscle fiber characteristics of weightlifters have either grouped these athletes with athletes from other strength sports (39, 46, 48), or have only reported percentages of the FT and ST populations of fibers (20, 39, 46, 47), and may have missed potentially subtle differences between these populations.

The percentage of fiber types observed for the WL in the present study are similar to what has been previously reported for other resistance-trained athletes (20, 31, 39, 46–48), including powerlifters (15). The large percentage of IIA fibers in the vastus lateralis m. is also similar to what has been reported for other types of strength training (1, 24, 42, 44); sprint training (28); and endurance-type activities (18, 29). Additionally, a large percentage of IIA fibers has also been reported for other resistance-trained muscles (3, 30, 32, 46). Such large percentages of type IIA fibers are apparent in both strength/power athletes and endurance athletes and appear to be a natural adaptation to the recruitment of the high threshold motor units comprising the type IIB population, ultimately causing an apparent IIB to IIA transformation. Therefore, differences in the performance capabilities for those training for high muscular power or force (i.e., weightlifters and powerlifters) vs. those training for aerobic endurance appear to be due to factors other than mATPase percent fiber-type composition. At this time, although artificial stimulation protocols can induce fiber transformations from type II to type I (38), little support is available for in vivo transformations from either I to IIA or IIA to I in humans using an exercise modality (2, 5, 28, 29). It should be noted that in the present study, the percent fiber type profile for the CON group indicated a similar percent of type I fibers when compared with the WL. These type I percentages are similar to control values previously reported for vastus lateralis m. (1, 15, 24, 44, 45). Differences between the WL and CON for percent fiber type are apparent only when the type II fiber subtypes are analyzed (i.e., IIC,

IIA, IIAB, IIB), thus permitting closer scrutiny of the differences between these groups.

The fiber cross-sectional areas of the WL were similar to what has been previously reported for highly strength-trained individuals (31, 39, 46, 48), although they are greater than what has been reported for short-term resistance-training studies (44, 45, 47). When compared with competitive powerlifters, the WL possess slightly larger fiber areas for all the major fiber types (i.e., I, IIA, IIB; 15). Although numerous reports have indicated that endurance-type exercise may result in a similar percent fiber type distribution, endurance activity is not associated with large fiber cross-sectional areas (18, 29, 46). In the present study, a primary difference between the WL and CON was the considerable difference in area occupied by each major fiber type (Table 2). The net result is a much greater potential contribution from IIA fibers, which appear to make up approximately 60% of the total cross-sectional area for the WL. It should be noted that considerable variability exists in fiber-type profiles (40), and that actual strength performance is not always strongly related to the percent fiber-type characteristics (33). Instead, fiber type and size characteristics are only 2 factors, albeit important ones. The relatively large fiber areas for the CON subjects suggests that although they were not performing any structured exercise programs, they could not be classified as sedentary. As has been observed before for highly competitive lifters and chronically weight-trained subjects (1, 15, 24, 44, 45), the small areas for IIB fibers for the WL may be related to a transformation from IIB to IIA. It has recently been demonstrated that transcription of MHC IIa and MHC IIb proteins are under different regulatory mechanisms (i.e., myogenin and myo-D; 51). It is possible that extreme training regimens such as those used by successful competitive lifters differentially activate these transcription regulatory factors, and ultimately influence the fiber type-specific areas.

Compared with previous reports on powerlifters, the area for the WL were slightly greater for IIA fibers and less for I fibers (15). The greater area for IIA fibers for the WL may be due to the greater power require-

ments for WL when compared with powerlifting; thus this combination of fiber type and area may be an important factor in weightlifting performance. Although it is known that IIB fibers exhibit faster *in vitro* contractile velocities than IIA fibers (49), the IIA fibers make up a disproportionately greater area in the WL, which positively influences force production. Since power is the product of force and velocity, the increased force capability apparently outweighs any possible effects on velocity, thus enhancing power. It should also be noted that it is likely that the contractile velocities of either types IIA or IIB fibers are more than adequate for the velocity requirements of the sport of weightlifting (17).

Longitudinal studies on the effects of resistance exercise have consistently demonstrated a transition from type IIB to IIA fibers (13, 24, 44, 45), and a corresponding change in the phenotypic expression in the MHC protein isoform expression (i.e., MHC IIB to MHC IIA transformation; 1, 13, 24, 44). None of these training studies have reported a transition from slow (type I) to fast (type IIA) fibers as has been suggested as a possible training adaptation (5, 28, 29). Cross-sectional studies on the chronic effects of resistance exercise with elite athletes compared with untrained controls have reported greater percentages of type IIA fibers and little or no presence of IIB fibers (15, 30, 31, 39, 46), whereas the percentage of type I fibers have been quite variable. It should be noted that successful WL and powerlifters both exhibit 46–48% type I fibers, which is not unlike untrained controls (15). As such, it appears that the percent type I fibers is not as critical a variable for the subjects studied as is the percent type IIA fibers and the percent area IIA. Although it has been suggested that IIB fibers may be important for elite sprinters (6), such a fiber profile was not evident in this weightlifting population.

MHC isoform content contributes greatly to the contractile force and velocity of a muscle fiber (43) and is highly related to the mATPase fiber-type profile in humans (13). MHC expression has been shown to readily adapt to a resistance exercise stimulus (1, 13, 24, 44) and is most likely an important factor for enhanced muscular strength and power. It should be noted here that the percent MHC expression is closely associated with the percent fiber type area (13), and most likely represents an important contractile variable for the WL. As shown in Table 3, the WL exhibited a considerably greater percent fiber type area for type IIA fibers when compared with the CON group. The WL exhibited an almost complete lack of MHC IIB and a large percentage of type MHC IIA. Such results closely agree with the fiber type area data (see Table 3), as has been previously reported (13). It appears that IIB fibers and MHC IIB are not essential for elite weightlifting capabilities. Compared with highly trained powerlifters, the WL exhibit slightly greater

MHC IIA and less MHC IIB (15). Although some previous reports have suggested strength training results in an increase in MHC IIB expression (4), or that sprint training induces an MHC I to MHC IIA transition (5), the results of the present study do not support such patterns. Recent data from swimmers has suggested that a precompetition training taper may result in increased expression of fast isoforms of myosin light chains (49). Data from the present study on weightlifters does not indicate appreciable expression of fast protein isoforms (i.e., 1.4% MHC IIB), but further research is necessary to determine expression of other contractile regulatory proteins and their adaptations to training.

As has been previously reported for high-caliber weightlifters and powerlifters (31, 48), the weightlifters in the present study exhibited lower caps·mm⁻² than exhibited by the control subjects. This lower muscle capillarization was also evident when expressed as the cross-sectional area of muscle supplied by each capillary (area [μm²]·cap⁻¹). This was due primarily to a fewer capillaries per fiber-type area for IIA fibers in the WL. This is the first evidence of the fiber-type specificity of the microcirculation of highly trained weightlifters. Although many competitive weightlifters do not perform much, if any, aerobic exercise, it is unlikely that the different capillarity characteristics of the IIA fibers would have much impact on moderate-intensity aerobic exercise, since it is the type I fibers that contribute most to steady-state aerobic exercise. Furthermore, although not measured in the present study, the lower capillary density for the weightlifters most likely does not greatly attenuate aerobic capacity since it has been reported that weight-trained athletes exhibit aerobic capacities comparable with individuals in general fitness programs (31). From a long-term health perspective, the fact that the caps·fiber⁻¹ has been preserved suggests that long-term weightlifting training does not result in loss of capillaries.

All of the WL exhibited only the titin-1 isoform, whereas the CON subjects were more heterogeneous. Two physiological possibilities exist: either those individuals inherently expressing only the titin-1 isoform are more suited to the sport of WL, or titin expression may be influenced by training as has been previously suggested (34). The 2 titin isoforms are known to exhibit different stiffness properties, with titin-1 being less stiff (26). Although not evident in the present study, further study is needed to determine what role, if any, the titin isoforms play in muscle performances such as weightlifting.

Always of interest to the applied muscle physiologist is the relationship between muscle fiber characteristics and actual physical performances. It was interesting to note that 1RM clean and jerk was negatively correlated with percent area IIB fibers, whereas 1RM snatch and the total of the 2 lifts was positively

correlated with percent IIA fibers and percent area IIA fibers (Table 4). The faster of the 2 lifts (snatch) appears to require a large proportion of IIA fibers, whereas the heavier of the 2 lifts (clean & jerk) requires that a smaller percent area for IIB fibers is present. It appears that transitions and proportions of the type II population (i.e., IIA and IIB) are most critical for weightlifting performance, rather than possessing a small percentage of type I fibers. A simple field test of lower-body power, the vertical jump, has been previously used as an indicator of athletic ability (8). In the present study, estimated vertical jump power was correlated to amounts and proportions of the IIA fiber population. It is possible that a simple field test involving vertical jumping could be developed to provide a non-invasive indicator of muscle fiber characteristics. Further research is necessary to more closely examine the efficacy of such a field test.

Practical Applications

The muscle characteristics contributing most to weightlifting performances appear to be the percent IIA fibers and the percent area of IIA fibers. Two points should be made here: (1) type IIB fibers were practically nonexistent in the WL, and (2) the percentage of type I fibers were not significantly different from the CON subjects. This indicates that for the weightlifters used in the present study, the percent of fibers (i.e., type I vs. type II) is not as critical as the percent fiber type area (i.e., percent area type I vs. percent area type IIA vs. percent area type IIB). Rather than possessing a low percentage of type I fibers and a high percentage of type II fibers, successful weightlifting performances are dependent on possessing a high percentage of type IIA fibers and a low percentage of type IIB fibers. Capillary densities of the WL was lower compared with the CON and appeared to be due to a lower density for the fibers most critical for weightlifting performance, the IIA fibers. On the other hand, it should be noted that the number of capillaries for each fiber was preserved. Preliminary data on female weightlifters suggests they exhibit similar fiber characteristics to those of the men reported in the present study (unpublished data), but further research is needed to clarify these comparisons. Weightlifting performance was correlated to characteristics of the type II fiber population, whereas vertical jump power holds promise as a potential field test for fiber characteristics. Collectively, these data will provide comparative information when studying other forms of resistance exercise and high-power activities.

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Acknowledgments

The authors would like to thank Dr. Keith Peterson, DO, and the staff at the Sports Medicine Clinic in Seattle, WA, for their gracious assistance in obtaining the muscle biopsies. Appreciation is also extended to Victoria Thrush, RN, for her assistance with the follow-up care of the weightlifters participating in this project; to Julia Gibson for her assistance with the capillary density analysis; and to Michael H. Stone, PhD, for his assistance with arranging this study. This project was supported by grants from U.S.A.-Weightlifting and the Ohio University Research Committee.

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