Muscle Fiber Characteristics of Competitive Power Lifters

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ABSTRACT

To examine the skeletal muscle characteristics of power lifters, 5 competitive power lifters (PL; $\bar{X} \pm SE$; age = 31.0 ± 1.5 years, squat = 287.7 ± 15.7 kg, bench press = 170.5 ± 17.7 kg, and deadlift = 284.2 ± 7.5 kg) and 5 untrained control subjects (CON; age = 27.3 ± 3.3 years) served as subjects. Isokinetic squat force and power was greater ($p < 0.05$) for the PL at all bar velocities (0.20, 0.82, and 1.43 m · s⁻¹), as was vertical jump height and estimated power. Muscle biopsies from the vastus lateralis m. revealed significant differences for percent fiber type (PL, IIA = 45.5 ± 1.6%, IIB = 1.3 ± 0.8%; CON, IIA = 33.4 ± 3.1%, IIB = 12.0 ± 2.4%); percent fiber type area (PL, IIA = 51.8 ± 1.6%, IIB = 1.3 ± 0.8%; CON, IIA = 43.5 ± 3.4%, IIB = 12.4 ± 2.6%); and percent myosin heavy chain isoform (PL, IIa = 59.5 ± 6.1%; CON, 46.5 ± 2.5%). Muscle fiber characteristics were significantly correlated ($r = \pm 0.61$) with numerous strength and power measures for the PL. These data illustrate the muscle fiber characteristics necessary for the maximal force production requirements of power lifting.

Key Words: fiber type, cross-sectional area, myosin heavy chain, vertical jump, isokinetic strength

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Introduction

Skeletal muscle adaptations to resistance exercise has become a topic of research interest in recent years, but many studies have failed to differentiate between the various types of resistance exercise. For example, each of the competitive weight-training sports is characterized by distinctly different goals and training methods. Body builders train for maximal skeletal muscle hypertrophy (growth). Power lifters, who compete in the barbell squat, bench press, and deadlift, train to lift maximal loads characterized by high muscular force development, whereas weightlifters, who compete in the snatch and clean and jerk lifts, train to lift maximal loads characterized by high muscular power production. As a result of the unique demands of each activity, the training regimens are quite different for each sport. One of the primary differences between power lifting and weightlifting is the dramatically lower power production observed for power lifters (15, 25), thus exposing these athletes to a unique physical stimulus. Previous research, however, has typically grouped these different strength athletes together despite their different objectives and training styles. Physiological characteristics of skeletal muscle associated with the demands of competition at national and international levels specifically in the sport of power lifting have not been previously identified.

It has long been known that athletes in strength or power sports demonstrate greater percentages of fast twitch fibers than do athletes in endurance sports (16, 31). Genetic factors can contribute greatly to muscle characteristics, although nongenetic factors such as neural, endocrine, and functional demands can also influence muscle morphology and physiology (32, 41). Skeletal muscle is quite plastic, and thus is able to readily respond to current functional demands (37). For example, it has been proposed that fiber-type classifications, based on myosin adenosine triphosphatase (mATPase) histochemistry, actually represent a complex continuum of fiber types that span the functional demands of the muscular system (30): I ↔ IC ↔ IIC ↔ IIAC ↔ IIA ↔ IIAB ↔ IIB.

Fiber-type transitions due to exercise tend to go in the direction from type IIB to type IIA, with little or no change to type I fibers regardless of the modality of exercise (4, 9, 12, 38, 39). The myosin heavy chain (MHC) isoform (I, IIa, or IIb) that the mature human skeletal muscle fiber contains has been shown to significantly correlate with the relative fiber-type areas (I, IIA, or IIB; 12, 34, 36). The MHC is one of the proteins that makes up the myosin filament, forms the cross bridge according to the sliding filament theory (23), and is the site of mATPase activity. The MHC isoform expression changes along with the fiber-type transi-

tions consequent to resistance training (12, 38). The differing isoforms with their unique mATPase activities have been found to correlate with the speed of contraction (3), MHC I being the slowest to contract and MHC IIb being the fastest. With this being the case, it is sometimes suggested that type IIB fibers are desirable for strength and power. However, current literature suggests that these fibers convert to type IIA regardless of what type of physical activity they are engaged in (4, 10, 14, 38, 39, 40).

Previous investigations of competitive lifters (i.e., power lifters and Olympic-style weightlifters) have determined that 53–60% of the muscle fibers in the vastus lateralis are type II, which are sometimes referred to as fast twitch (18–20). Among untrained men, fiber-type percentages are not always related to physical performances (26, 28), which is not unreasonable since many physical performance tasks require contributions from a large number of physiological systems and are not dependent on just fiber-type percentages. On the other hand, isokinetic strength has been successfully used as a predictor of fast- and slow-twitch fiber percentages (45). What may be more important are the actual cross-sectional areas of each of the major fiber types. In men, type II fibers typically comprise a larger cross-sectional area (38). When competitive lifters have been studied, the areas of type II fibers are approximately 8,000 μm^2, whereas type I fibers are approximately 5,000 μm^2 (10, 42–44). It has been suggested that competitive strength performances may be positively affected when the cross-sectional areas of type II fibers equals 60–90% (25). This investigation will determine if such a relationship is present. It is hypothesized that the unique training characteristics of power lifters will produce distinct differences in the physiological characteristics of skeletal muscle when compared with not only untrained subjects, but also to strength athletes in other sports. In this manner, a more complete understanding of proper exercise prescription may be achieved. Such information would be valuable not only for coaches and athletes, but also for those using resistance exercise in a rehabilitative or fitness setting. Since the physiological characteristics of athletes differ according to the specific training modes used, the purpose of the present study was to identify the cellular and molecular characteristics of skeletal muscle in national- and international-caliber power lifters as compared with sedentary controls and to determine if these fiber characteristics are related to isokinetic squat force and power.

Methods

Experimental Approach to the Problem

This study utilized a between-groups design (power lifters vs. untrained controls) in order to describe the muscle performance and muscle fiber characteristics of

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

Variable	Controls ($n = 5$)	Power lifters ($n = 5$)
Height (cm)	180.8 ± 3.5	179.1 ± 7.7
Age (y)	27.3 ± 3.3	31.0 ± 1.5
Body weight (kg)	85.2 ± 6.1	101.8 ± 11.7
Percent fat	22.1 ± 2.9	17.27 ± 2.9
Thigh circumference (cm)	54.8 ± 2.0	62.2 ± 3.5
Vertical jump (cm)	47.5 ± 3.3	58.9 ± 2.3*
Peak vertical jump power (W)	4186.4 ± 313.8	5437.9 ± 337.8*
Bench press 1RM (kg)†		170.5 ± 17.7
Squat 1RM (kg)		287.7 ± 15.7
Deadlift 1RM (kg)		284.2 ± 7.5
Years trained		10.0 ± 3.2

† 1RM = 1 repetition maximum.
* $p < 0.05$.

highly trained power lifters. Inclusion of physical performance tests permitted analysis of relationships between skeletal muscle fiber characteristics and easily administered noninvasive tests.

Subjects

Five national-caliber male power lifters (PL) were recruited for this project. They were actively competing in the American Drug Free Powerlifting Association (ADFPA) and the United States Powerlifting Federation (USPF) at the time of the study. No drug tests were performed in conjunction with this study to verify use or non-use of ergogenic drugs. One power lifter was a 1994 International Powerlifting Federation world champion, and the other 4 power lifters had qualified for national-level championships in their respective organizations. Five recreationally active male controls (CON) were also recruited to serve as controls (see Table 1 for subject characteristics). The power lifters reported their most recent competitive lifts and the number of years trained as a competitive power lifter. Each of the power lifters were in various phases of their training programs, and thus not all of them were in competition shape. All subjects signed informed consent documents approved by The University of Memphis Institutional Review Board.

Anthropometric Measurements

Estimation of body composition (fat mass, fat free mass [FFM], and percent body fat) was made using the 7-site skinfold equation developed by Jackson and Pollock (24) and was measured using Lange skinfold calipers (Country Tech, Gay Mills, WI). Relative fat was estimated using the equation of Siri (33). Thigh circumference was measured at midthigh (7) using a fiberglass tape with a Gulick handle (Country Tech).

Performance Measures

Vertical jump height was measured with a Vertec (Sports Imports, Inc., Columbus, OH) vertical jump tester. Standing reach was subtracted from the highest of 3 vertical jumps to determine vertical jump height. No approach steps were permitted, but a counter-movement was used prior to takeoff. Peak vertical jump power (Watts) was estimated using the Harman (21) equation.

Isokinetic squat peak force and peak power were determined using an Ariel 5000 Multifunction Dynamometer (Ariel Dynamics, Inc., Trabuco Canyon, CA). Calibration was performed prior to each testing session. An intratest and intertest coefficient of variation was calculated for all of these tests (intratest, 54.2 kg = 7%, 101.1 kg = 1%; intertest, 54.2 kg = 0.5%, 101.1 kg = 0.3%). The reproducibility of the force calibration checks were all within acceptable ranges ($<15\%$). Squat performance at similar velocities has been previously reported as very reliable (46). After familiarization, the subject performed a parallel squat (13) for 3 trials at each of 3 velocities (0.20, 0.82, and 1.43 m · s⁻¹ bar velocity). The highest peak power and the highest peak force from each of the velocities was recorded.

Muscle Biopsies

Muscle biopsies (80–160 mg) were extracted from the vastus lateralis muscle (5), oriented in tragacanth gum, frozen in isopentane cooled by liquid nitrogen to −159° C, and stored at −80° C. To ensure adequate sample sizes, large pieces were obtained using the double-chop method (34, 36) combined with suction (11). The frozen biopsy samples were thawed to −20° C and serially sectioned for the determination of muscle protein content (40 μm thick sections) and fiber-type composition (12 μm thick sections).

Fiber-Type Distribution

Routine mATPase histochemical analysis using the methods of Brooke and Kaiser (6) were performed using preincubation pH values of 4.3, 4.6, and 10.2 to determine the muscle fiber–type distribution. Although 7 fiber types (I, IC, IIC, IIAC, IIA, IIAB, and IIB) can be distinguished based on their staining intensities (34, 36), difficulties with the 10.4 pH preincubation resulted in grouping all C fibers (i.e., IC, IIC, IIAC) in 1 group designated IIAC. A composite photomontage of each mATPase preparation (preincubation at pH 4.6) was made using Polaroid photo-micrographs (×56 magnification). These were used in combination with the other histochemical preparations (preincubation pH values of 4.3 and 10.6) to determine fiber-type percentages and total fiber number in each biopsy.

Percent Fiber-Type Area

The cross-sectional areas of at least 50 fibers per major type (I, IIA, and IIB) per biopsy (27) were determined by the use of direct tracings (×200 magnification) that were scanned and analyzed for area using public-domain NIH software. Although 7 fiber types may be distinguished, the "hybrid" fiber types (IC, IIC, IIAC, and IIAB) comprise such a small percentage of the total muscle fibers that it is not possible to identify 50 of these fibers in a typical biopsy sample. As such, fiber-type areas were determined for only the major fiber types.

Myosin Heavy Chain Analysis

MHC analysis was performed using sodium dodecyl-sulfate polyacrylamide gel electrophoresis (SDS-PAGE). This protocol is based on the procedures of Carraro and Cantani (8) and Perrie and Bumford (29) with modifications used for single human muscle fibers (34, 36). Briefly, 3–5 serial cross-sections (40 μm thick) from each biopsy were placed in 0.5–1.0 ml of a lysing buffer containing 10% (w/v) glycerol, 5% (v/v) β-mercaptoethanol, and 2.3% (w/v) SDS in 62.5 mM Tris-HCl buffer (pH 6.8) and heated for 10 min at 60° C. Small amounts of the extracts (3–5 μl) were loaded on 4–8% gradient SDS polyacrylamide gels with 4% stacking gels (12), 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 analysis. Relative MHC content (percent) was determined by densitometric scanning of the resulting gels using NIH Image software.

Statistical Analyses

Results are reported as $\bar{X} \pm SE$. Independent t-tests were used for descriptive and performance data. Due to the correlations between the relative values for the different fiber types and for the different MHC isoform contents, 2×3 multivariate analyses of variance (ANOVAs) were used to compare results for the power lifters and control subjects for these dependent variables. Pearson product moment correlations were calculated for muscular strength and power performances vs. fiber-type characteristics. Significance for this investigation was $p \leq 0.05$.

Results

Descriptive data of the subjects are reported in Table 1. It can be seen that the PL were highly trained as indicated by the number of years trained, their lifting performances, and their jumping and isokinetic squat performances. Compared with the CON, the PL exhibited significantly greater vertical jump height and power (see Table 1). Isokinetic squat peak relative force and peak relative power were also greater for PL at all bar velocities (see Figures 1–4). It should also be noted that peak power for the PL subjects had not begun to decrease at the fastest bar velocity (1.43 m · s⁻¹),
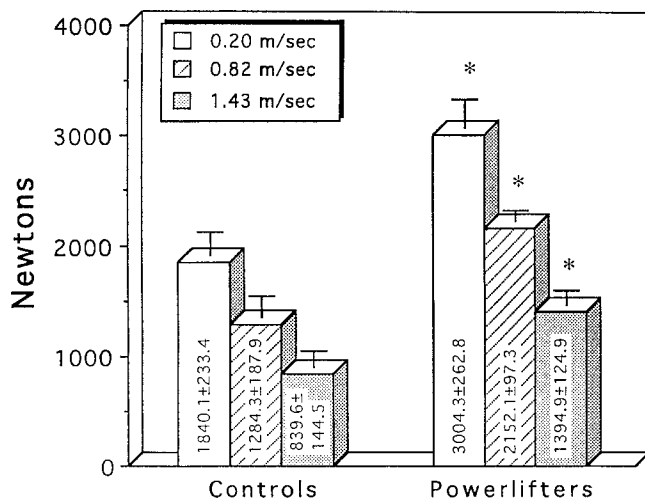
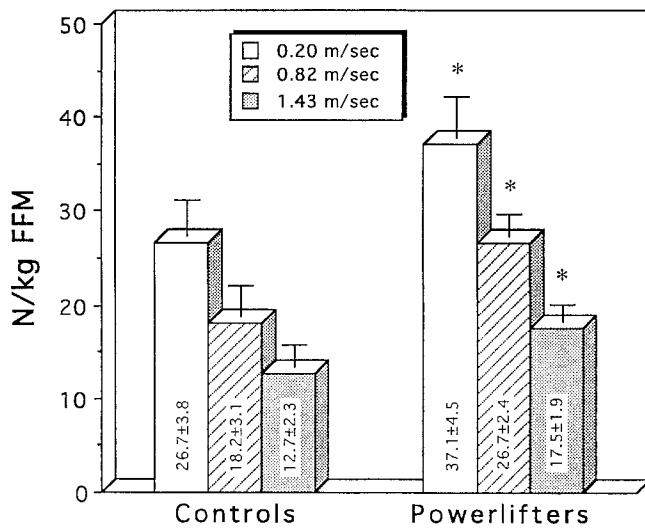**Figure 1.** Absolute (*N*) isokinetic squat force (*p < 0.05).

Figure 2. Relative (*N* · kg FFM⁻¹) isokinetic squat force (*p < 0.05).
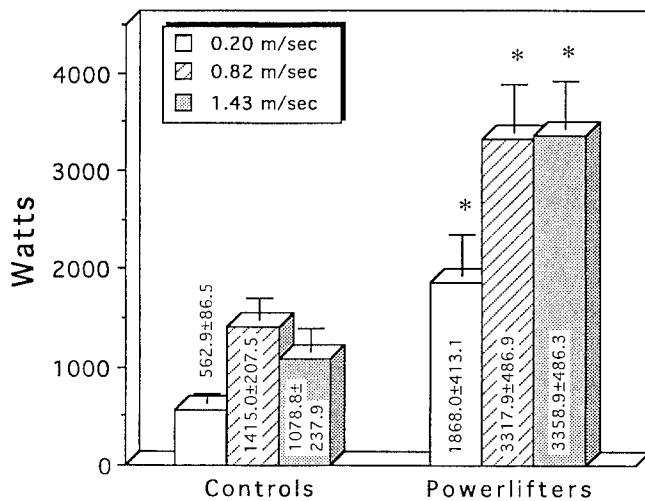
Figure 3. Absolute (W) isokinetic squat power (*p < 0.05).
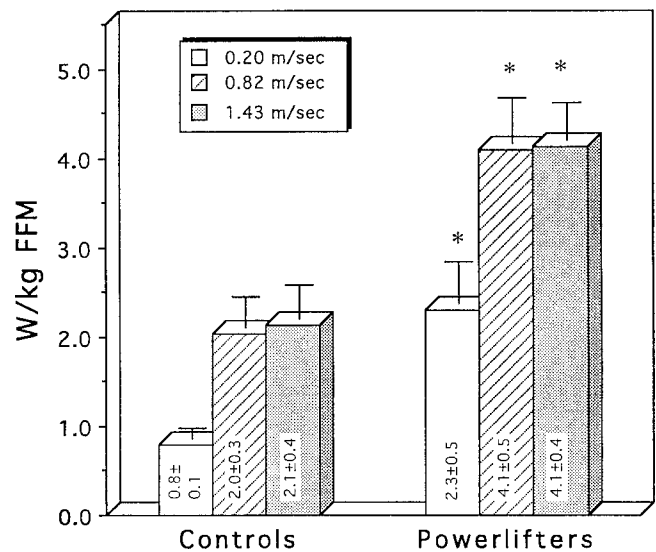
Figure 4. Relative (W · kg FFM⁻¹) isokinetic squat power (*p < 0.05).
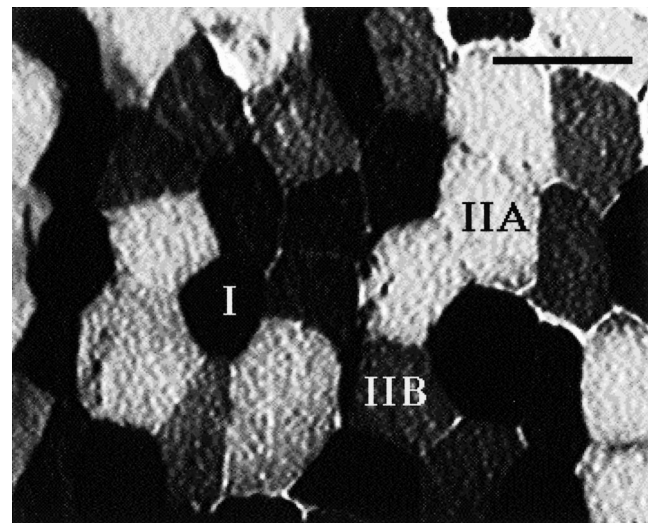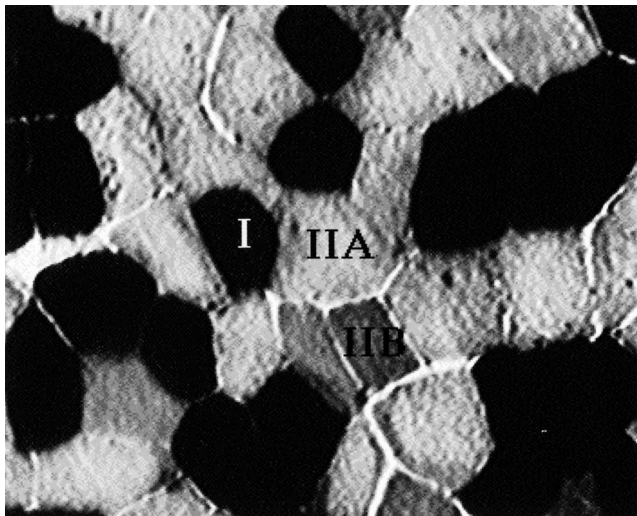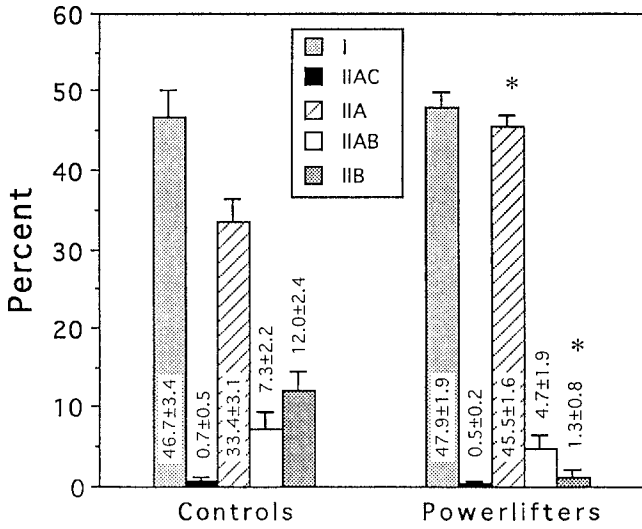

Figure 5. Histochemical stain for mATPase fiber type (pH 4.6) from the vastus lateralis m. of an untrained control subject. I = type I; IIA = type IIA; IIB = type IIB; bar = 100 μm.
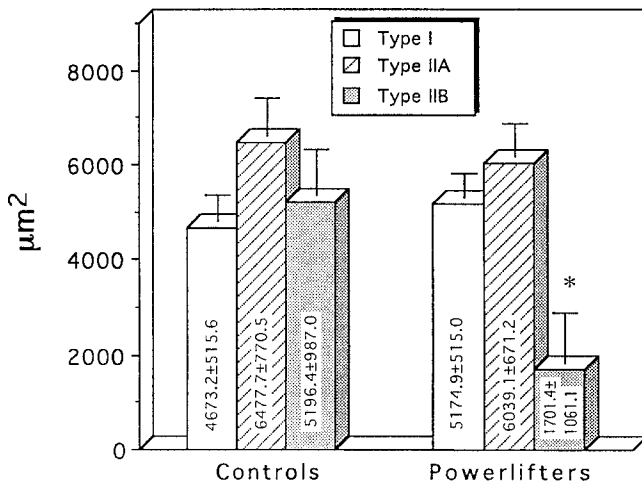
whereas peak power was declining at this velocity for the CON subjects. The PL subjects exhibited a greater percentage of IIA fibers and a lower percentage of IIB fibers compared with the CON subjects (see Figures 5–7). Absolute cross-sectional fiber areas were lower for type IIB fibers for the PL (see Figures 5, 6, 8). Percent cross-sectional areas for the PL were greater for type IIA and lower for type IIB compared with CON (see Figures 5, 6, 9). The PL exhibited a greater percentage of MHC IIa than the controls (see Figure 10), with no between-group differences for the other MHC isoforms. When data for the PL and CON were combined, significant correlations ($r = \pm0.61$) were observed between absolute isokinetic force and power,
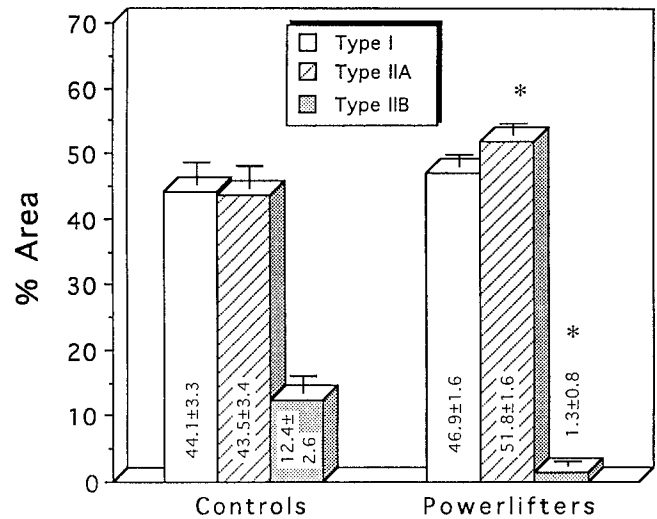
Figure 6. Histochemical stain for mATPase fiber type (pH 4.6) from the vastus lateralis m. of a power lifter. I = type I; IIA = type IIA; IIB = type IIB; scale is the same as Figure 5.
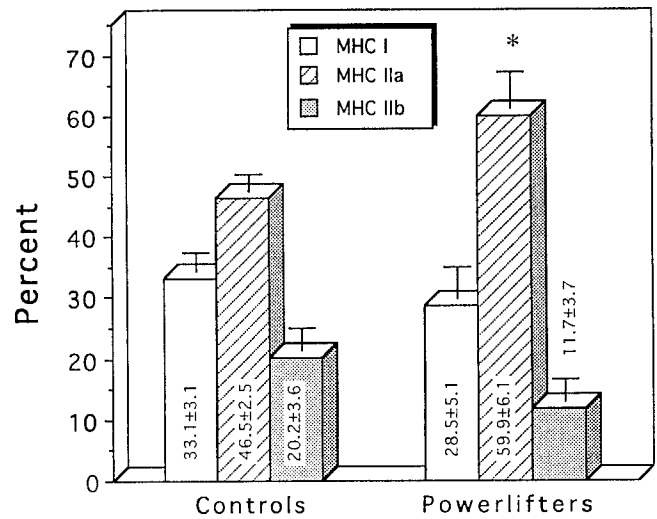

Figure 9. Percent fiber type cross-sectional areas (*$p <$ 0.05).

Figure 7. Percent mATPase fiber types (*$p <$ 0.05).

Figure 10. Percent myosin heavy chain isoform content (*$p <$ 0.05).

Figure 8. Fiber type cross-sectional areas (*$p <$ 0.05).

relative isokinetic force (N/kg FFM) and power (W/kg FFM), or vertical jump height when compared with percent fiber type (see Table 2).

Discussion

The self-reported competition lifts for the PL group were similar to what one would expect for national-caliber power lifters (25; see Table 1). All isokinetic tests indicated greater peak force and peak power for the PL compared with the CON (Figures 1 and 3). This was to be expected because of the high force requirements of power lifting. These differences were still apparent when force and power was adjusted for fat-free mass (Figures 2 and 4), thus suggesting that these performance differences were not simply due to just greater muscle mass, but that the quality of the muscle mass was different as well (e.g., different fiber-type

Table 2. Significant Pearson product moment correlations between performance measures and muscle fiber characteristics.†

Performance variable	% IIA	% IIB	% Area IIA	% Area IIB
Isokinetic squat force				
0.20 m · s^{-1}	0.71	−0.62	0.67	−0.64
0.82 m · s^{-1}	0.67	−0.71	NS	−0.75
1.43 m · s^{-1}	NS	−0.69	NS	−0.70
Isokinetic squat force/FFM				
0.20 m · s^{-1}	NS	NS	0.61	−0.61
0.82 m · s^{-1}	NS	−0.66	NS	−0.70
1.43 m · s^{-1}	NS	−0.62	NS	−0.64
Isokinetic squat power				
0.20 m · s^{-1}	NS	−0.62	NS	−0.61
0.82 m · s^{-1}	0.72	−0.62	NS	−0.63
1.43 m · s^{-1}	0.69	−0.61	NS	−0.61
Isokinetic squat power/FFM				
0.20 m · s^{-1}	NS	−0.67	NS	−0.66
0.82 m · s^{-1}	0.71	−0.69	NS	−0.70
1.43 m · s^{-1}	0.71	−0.71	NS	−0.72
Vertical jump height	0.66	−0.76	0.66	−0.70

† NS = not significant; $n = 10$; $r_{crit} = ±0.61$.
* $p < 0.05$.

profile and protein expression). The isokinetic tests also indicate an ability to produce peak power at a higher velocity compared with the CON (see Figure 3). Despite the fact that power lifting is not a high-velocity activity, high-velocity power is greater for these subjects because of either their power lifting training or their inherent capabilities. The PL also exhibited greater vertical jump height and estimated power compared with the CON (See Table 1). Vertical jump height and power for the PL are similar to those reported for national-caliber weightlifters ($\bar{X} ± SE$; vertical jump = 60.7 ± 3.9 cm; power = 5,378.6 ± 180 W; 14), but vertical jump height was less than that reported for national medal winners in weightlifting (vertical jump = 74.1 ± 2.0 cm; 17). It has been shown that the power production during Olympic-style weightlifting is much greater than for the squat or deadlift in power lifting (15). Considering the differences in training for power lifters and weightlifters, these data suggest that training for maximal muscular force (i.e., power lifting) contributes considerably to vertical jump performance, but training with higher velocity and power (i.e., weightlifting) may augment vertical jump performances to an even greater extent.

Of particular importance to this investigation are the results of the muscle biopsies. Previous data on muscle fiber characteristics of power lifters have either grouped these athletes with athletes from other strength sports (42, 44) or have only reported percentages of the fast- and slow-twitch populations of fibers (31, 42, 43). The primary difference between PL and CON is the greater percentage of IIA and the lower percentage of IIB observed for the PL (see Figure 6). Although the present study is not a longitudinal training study, previous reports of resistance exercise training have reported fiber-type transitions from IIB to IIA (1, 22, 36, 38). It is thus likely that such transformations occurred for the PL in the present study, but it is beyond the scope of this investigation to definitively determine this. Olympic-style weightlifters have also exhibited similar percentages of fiber types (14). As previously mentioned, power lifters and weightlifters appear to differ slightly in muscle performance characteristics. Therefore, differences in the performance capabilities between these 2 types of athletes (i.e., high muscular force vs. high muscular power) appear to be due to factors other than simply mATPase fiber-type composition. It is interesting to note that CON subjects exhibited a similar percentage of I fibers when compared with the PL. Differences between the PL and CON for percentage of fiber type are apparent only when the type II subtypes are analyzed. It appears that the critical variable for successful power lifting performance is not simply a low percentage of I fibers, but is more importantly a high percentage of IIA fibers. Type IIB fibers do not appear to be critical for successful power lifting performance. Furthermore, these data suggest that long-term training for power lifting does not result in a decrease in type I fibers because of a type I to type IIA shift.

It should be noted that we have chosen to classify the IIB fiber population using the fiber classification terminology for human muscle developed by Brooke and Kaiser (6, 35). Although recent trends in the literature have renamed these fibers based on a similarity of human MHC IIB to rodent MHC IID/X, it is important to note that there is ample evidence that these protein isoforms are not identical (35). Therefore, in an attempt to avoid confusion in terminology, we have chosen to utilize the classification system based on human tissue, rather than infuse rodent terminology into the human muscle literature.

The fiber cross-sectional areas of the PL (see Figure 7) were slightly smaller than what has been previously reported for highly strength-trained individuals (14, 25, 31, 42, 44), although they are comparable to what has been reported for short-term resistance training studies (38, 40, 43). Since not all of the PL in the present study were in peak competition shape, it is possible that a detraining effect may have been present to some extent, thus affecting cross-sectional areas. The smaller areas reported for IIB fibers is consistent with previous reports (14). It is possible that the fiber remodeling occurring with the training used by the PL may contribute to this result, with a small subset of

IIB fibers never being recruited and eventually atrophying. It is also possible that these smaller fibers may be developing fibers, again owing to the remodeling process. Although beyond the scope of the present study, the fact that cross-sectional areas for types I and IIA fibers were similar for both the CON and PL, and muscle mass was greater for the PL, the possibility of hyperplasia exists. Unfortunately, the design of this study does not permit a definitive statement on this possibility.

In the present study, a primary difference between the PL and CON was the considerable difference in the relative area occupied by each major fiber type (see Figure 8). The net result is a much greater potential contribution from IIA fibers, which made up almost 52% of the total cross-sectional area for the PL, and a smaller contribution from IIB fibers, which made up slightly more than 1% of the cross-sectional area. The CON subjects exhibited over 12% of the IIB area, indicative of a large portion of fibers seldom recruited. The relative area of type I fibers was comparable for PL and CON, again suggesting that the most important functional contribution for power lifting is the fiber-type distribution and size within the type II fiber population. The combination of fiber type and area exhibited by the PL may be an important factor in power lifting performance. A large percentage of IIB area is not critical to successful power lifting performance. These data suggest that long-term training for power lifting does not result in a decrease in type I fiber area because of a type I to type IIA shift. It is possible that the active lifestyle of the CON subjects may have contributed to larger than expected areas for their fibers.

MHC isoform content influences contractile force and velocity of a muscle fiber (37) and is correlated to the mATPase fiber-type profile in humans (12). MHC expression has been shown to readily adapt to a resistance exercise stimulus (1, 12, 22, 38) and appears to be critical for enhanced muscular strength and power. The PL exhibited a greater percentage of MHC IIa compared with CON, although the percentage of MHC IIb was not significantly different. The PL exhibited a similar percentage of MHC IIa as that of weightlifters but a much larger percentage of MHC IIb (male weightlifters, $\bar{X} \pm SE$; MHC IIa = 64.0 ± 2.3%; MHC IIb = 1.4 ± 1.4%; 14). Such differences could be due to the functional requirements of the respective sports, or due to the training status of the subjects at the time of the biopsy. Given that both groups were highly trained and actively competing in their sport, this is a difference worth investigating further as similar MHC profiles would be expected for resistance-trained athletes. Recruitment patterns due to the speed of contraction for weightlifting could possibly account for this difference. It appears that a large percentage of MHC IIb is not essential for successful power lifting performances, and that long-term training for power

lifting does not result in a decrease in type I MHC due to a type I to a type IIa shift. Although no difference was observed for MHC IIb, the difference in MHC IIa supports earlier findings that have used resistance training, anaerobic training, and aerobic training (2, 4, 9, 22). It has been shown that MHC IIb decreases while MHC IIa increases with resistance training, and the opposite occurs with detraining (39). It cannot be determined from these data whether a fiber-type shift occurred, but the higher MHC IIa in PL is an indicator that a shift may have occurred. The genetic contributions to such an MHC profile cannot be determined in the present study.

Performance capabilities of muscle are dependent on many physiological aspects (25). Although it is overly simplistic to claim all muscle performance properties are dependent on fiber characteristics (26, 28), there is undoubtedly some contribution. Correlational analyses indicate consistent significant negative correlations ($r = -0.61$ to -0.76; $r^2 = 0.37–0.58$) between the percentage of IIB fibers or percentage area of IIB fibers and nearly all performance measures in the present study (see Table 2). In addition, several significant positive correlations were also observed for percentage of IIA fibers or percentage area of IIA fibers and the performance measures. These data suggest that increased strength and power performances are associated with a lower percentage of IIB fibers and a lower percentage area of IIB fibers, again indicative of the fact that IIB fibers are not necessary for successful power lifting performances.

Practical Applications

The competitive PL exhibited the ability to develop their greatest powers at greater velocities than the untrained CON subjects. This greater power capacity may not be as great as that observed for Olympic-style weightlifters based on vertical jump data. Based on the data presented, the muscle characteristics contributing most to successful power lifting performances appear to be (a) greater percentage of IIA fibers, percentage area of IIA fibers, and percentage of MHC IIa, and (b) a lesser percentage of IIB fibers and percentage area of IIB fibers. The fiber characteristics exhibited by the PL were significantly correlated to numerous muscle strength and power measures. Furthermore, long-term training ($\bar{X} = 10.0$ years) for power lifting and successful power lifting performances were not associated with a lower percentage of type I fibers, percentage area of type I fibers, or percentage of MHC I. Although previous reports of strength-trained athletes have not always differentiated different types of resistance exercise, subtle but important differences are apparent when comparing these populations and their training methods. These data will provide compara-

tive data when studying other forms of resistance exercise.

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