Eur J Appl Physiol 44, 35–42 (1980)

European Journal of
Applied
Physiology
and Occupational Physiology

Maximal Isometric Strength and Fiber Type Composition in Power and Endurance Athletes

Priscilla M. Clarkson, Walter Kroll, and Thomas C. McBride

Department of Exercise Science, Boyden Building, University of Massachusetts, Amherst, MA 01003, USA

Summary. The relationship between maximum isometric strength and muscle fiber type composition was examined in seven endurance and eight power trained athletes. Knee extension strength and ankle extension strength was assessed on 10 separate days and muscle biopsies were taken from the vastus lateralis and gastrocnemius muscles. The percent composition of slow twitch (ST) fibers and fast twitch (FT) fibers was determined from the biopsy samples. Correlation between maximal knee extension strength and percent ST fibers of the vastus lateralis was found to be 0.80 ($n = 8, p < 0.05$) for the power group and 0.63 ($n = 7$, N.S.) for the endurance group. Corresponding correlation coefficients for the relationship between ankle extension strength and gastrocnemius percent ST fibers were −0.94 ($p < 0.01$) and −0.19 (N.S.), respectively. The results suggest that the relationship to be expected between muscle fiber type composition and maximum isometric strength may well depend upon the muscle group under study as well as the type of athlete in terms of specific training adaptations.

Key words: Isometric strength – Fiber types – Athletes

Evidence relating muscle strength output and fiber type composition has been scant and conflicting. Hulten et al. (1975) reported no relationship between maximum isometric strength in a two leg knee extension task and muscle fiber type composition for a group of physical education majors. Thorstensson (1976) similarly found no correlation between fiber type distribution and either one leg or two leg maximum isometric knee extension strength. Other studies, however, have shown significant correlations between isometric strength and fiber type composition. Komi et al. (1977) reported isometric knee extension strength correlated positively with percent FT fibers in the vastus lateralis muscle of male athletes. Tesch and Karlsson (1978), using a group of physical education majors, found a positive correlation between percent FT (fast twitch) fibers and maximal isometric one-leg strength. Significant correlations between

Offprint requests to: P. M. Clarkson (address see above)

0301-5548/80/0044/0035/$ 01.60

peak torque during isokinetic knee extension and percent FT fibers have also been reported by Nilsson et al. (1977) using untrained subjects and by Thorstensson et al. (1977) using athletes as subjects.

In view of the conflicting results concerning strength output and fiber type composition further study seems warranted. It was, therefore, the purpose of the present investigation to examine knee extension and ankle extension isometric strength and correlate these measures with fiber type composition of the vastus lateralis and gastrocnemius muscles. Power and endurance trained athletes were used as subjects in order to contribute additional insight to the problem.

Method

Seven endurance-trained and eight power-trained male athletes volunteered as subjects in the present study. All endurance subjects were actively competing in long distance running events and averaging approximately 60 miles of training per week while power athletes were weight lifters who trained regularly. Strength measurements were assessed on 5 consecutive days in the Motor Integration Laboratory. Several days after the subjects had completed strength testing muscle biopsies were then taken at the University Health Service. All subjects were given medical clearance, fully informed of experimental procedures, and signed an informed consent document as prescribed by university guidelines for the protection of human subjects.

Muscle biopsies were removed from the mid-belly of the vastus lateralis and medial gastrocnemius muscles using a standard needle biopsy procedure (Bergstrom 1962). The muscle samples were mounted in OCT (Ames) and frozen in isopentane cooled with liquid nitrogen. Serial transverse sections (12 μm thick) were cut with a cryostat at −20° C and histochemically stained for myofibrillar adenosine triphosphatase (ATPase) by incubation in a glycine buffer at pH 9.4 after pre-incubation at pH 4.3 and pH 4.6 in an acetate buffer and pre-incubation at 10.3 in a glycine buffer (Padykula and Herman 1955). Photomicrographs were taken of the slides and muscle fibers were classified as ST, FTa, and FTb according to the nomenclature put forth by Saltin et al. (1977). The diameters of 50 fibers of each type per sample were measured using the least diameter method. This method is defined as the maximum diameter across the lesser aspect of the fiber. The least diameter measurement has been shown to be the dimension least affected by possible distortion due to transverse sectioning or compression of the fibers (Brooke 1970; Polgar et al. 1973; Song et al. 1963). The fiber area was calculated, on the assumption that the cells were circular (Stilwell and Sahgal 1977), from the mean diameter ($\bar{x}$) and the variance of the diameter (σ^2) using the formula $\frac{\pi(\sigma^2 + \bar{x}^2)^1}{4}$. This formula provides a better estimate of the square of this normally distributed variable than the square of the mean.

At least two muscle samples were removed from each biopsy site and the fiber type percentage of each determined so that a measure of reliability could be obtained. Also, to assess reliability of the diameter measurements, the scores were split into odd and even categories. Pearson product moment coefficients

---

1 The diameter (D) is a normally distributed variable but its square is skewed. Hence, the arithmetic mean of (D^2) cannot be used in calculation of cell area. The expected value

$$(E) \text{ of } E(D^2) = \int_{-\infty}^{+\infty} (x^2) \left(\frac{e^{\frac{-\frac{1}{2}(x-\bar{x})^2}{\sigma^2}}}{\frac{\sigma^2}{\sigma\sqrt{2\pi}}} \right) dx,\ (D^2) = E(D^2)$$

and where x is the normally distributed variable and $\bar{x}$, σ, σ^2 are respectively, the mean, standard deviation and variance. This resolves to $E(\bar{x}^2) = \sigma^2 + \bar{x}^2$. Thus, the cell area equals $\pi/4\ (\sigma^2 + \bar{x}^2)$

were calculated and separate r values obtained for the percentage and diameter measurements. Analyses of variance were calculated (1) for each group to detect between fiber type difference in area and, (2) to detect between group differences in fiber type percentages and fiber type areas.

Isometric strength was assessed over 10 days with the order of ankle extension and knee extension sequences of 5 days each balanced over subjects; i.e., half the subjects were tested 5 days on ankle extension strength followed by 5 days of knee extension strength testing while the other half of the subjects were administered the knee extension strength series followed by the ankle extension strength series. Two maximum isometric strength contractions (MVC) separated by a one minute rest were administered each day.

Maximum isometric contractions of ankle extension were measured while the subject was in a prone position with the shoulders firmly stabilized by padded blocks bolted to the table to prevent upward movement of the body when the ankle was extended in plantar flexion against an immovable foot plate. The force of the isometric contraction was transduced by a strain gauge unit positioned behind the hinged foot plate with the ball of the foot directly over the strain gauge. For knee extension strength assessment, the subject was seated on a bench with an adjustable back rest in such a manner that the right foreleg was perpendicular to the floor and at a right angle to the upper leg. A seat belt fastened across the waist prevented extraneous movement during knee extension trials. A leather ankle cuff was placed at the level of the malleolus and attached via steel cable to a strain gauge fixed securely to an adjacent wall. Separate Statham Model UC2 Universal Cells coupled to a Beckman Type R Dynagraph recorder were used for ankle and knee extension strength assessments.

Results

Fiber Composition

For vastus lateralis percent ST fibers the corrected split-half reliability coefficient was found to be 0.96 and the r value for the gastrocnemius percent ST fibers was found to be 0.95 (N = 15). For the power group the corrected split half r values of the vastus lateralis ST and FTa diameters and the gastrocnemius ST and FTa diameters were found to be 0.90, 0.96, 0.99, and 0.96 respectively. The corresponding r values for the endurance group were 0.99, 0.99, 0.96, and 0.99, respectively.

In Table 1 can be found the fiber type diameters for each group. For the power group the FTa fibers were significantly larger than the ST fibers and FTb fibers in both the vastus lateralis ($p < 0.01$) and the gastrocnemius ($p < 0.05$) muscles. In contrast, the ST and FTa fibers in the endurance group were similar in size in both muscles. For both the vastus lateralis and the gastrocnemius muscles, the difference in ST diameter between power and endurance groups was not statistically significant. The FTa diameter of the gastrocnemius muscle did not differ significantly between groups but the vastus lateralis FTa diameter in the power group (71.8 μm) was significantly larger than the FTa diameter in the endurance group (57.0 μm), $p < 0.05$.

The fiber type percentages are also presented in Table 1. In both the vastus lateralis and gastrocnemius muscles the endurance group had a significantly ($p < 0.01$) higher percentage of ST fibers (69.8% and 70.6%) compared to the power group (42.8% and 47.0%). Likewise, the power group had significantly ($p < 0.05$) greater percentages of FTa and FTb fibers than the endurance group. An interesting relationship exists between individual fiber type percentages and the two muscle groups studied. The percent area of ST fibers in six of seven endurance subjects was similar in the vastus lateralis and gastrocnemius muscles leading to a significant correlation for the endurance group ($r = +0.81$, $p < 0.05$) but not for the power group ($r = -0.08$, N.S.).

Table 1. Muscle fiber composition and maximum isometric strength in power and endurance athletes

		Power	Endurance
Maximum isometric strength (kg)		(N = 8)	(N = 7)
Ankle extension		212.3 (33.9)	130.3 (47.2)
Knee extension		105.4 (18.8)	65.7 (11.9)
Fiber type percent number/area		(N = 7)[b]	(N = 7)
Gastrocnemius	ST	47.0/41.4 (8.6)	70.6/66.7 (12.0)
	FTa	42.1/47.0 (7.6)	28.5/33.3 (12.6)
	FTb	10.3/9.7 (8.3)	0.5[a] (0.6)
Vastus lateralis	ST	42.8/32.5 (13.2)	69.8/70.7 (19.1)
	FTa	48.5/59.5 (12.1)	27.3/29.3 (15.9)
	FTb	10.9/8.0 (6.2)	2.8[a] (3.9)
Fiber type diameters (μm)			
Gastrocnemius	ST	58.7 (7.1)	61.0 (16.1)
	FTa	68.0 (5.2)	65.2 (14.9)
	FTb	61.7 (10.6)	[a]
Vastus lateralis	ST	57.1 (3.9)	61.7 (11.9)
	FTa	71.8 (8.1)	57.0 (11.2)
	FTb	57.3 (9.7)	[a]

Standard deviations in parentheses
[a] Too few FTb fibers were found for the endurance athletes to make adequate size determination
[b] Fast twitch fibers could not be subclassified into FTa and FTb for one subject

Fiber Composition and Strength Correlation

The maximum isometric strength measures for both groups are presented in Table 1. The power group was approximately one-third stronger than the endurance group in knee and ankle extension ($p < 0.01$).

The r value for knee extension MVC and vastus lateralis percent ST fibers for the endurance group was not significant ($r = +0.63$). However, for the power group the r was $+0.80$ ($p < 0.05$) and this relationship is depicted in Fig. 1. Correlation of MVC and percent area of ST fibers resulted in r values of $+0.60$ (N.S.) for the endurance group and $+0.77$ ($p < 0.05$) for the power group.

Correlation between ankle extension MVC and percent ST fibers of the gastrocnemius muscle for the power group was found to be $r = -0.94$ ($p < 0.01$) while for the endurance group the r value was not significant ($r = -0.19$). The relationship between ankle extension MVC and percent ST fibers for the power group is depicted in Fig. 2. There was no significant correlation between ankle extension MVC and percent area of ST fibers of the gastrocnemius muscle in the endurance group but the r was -0.70 ($p < 0.01$) for the power group.

Discussion

For the endurance athletes, the percent ST fibers in the vastus lateralis correlated highly with the percent ST fibers in the gastrocnemius muscle which was not the case for the

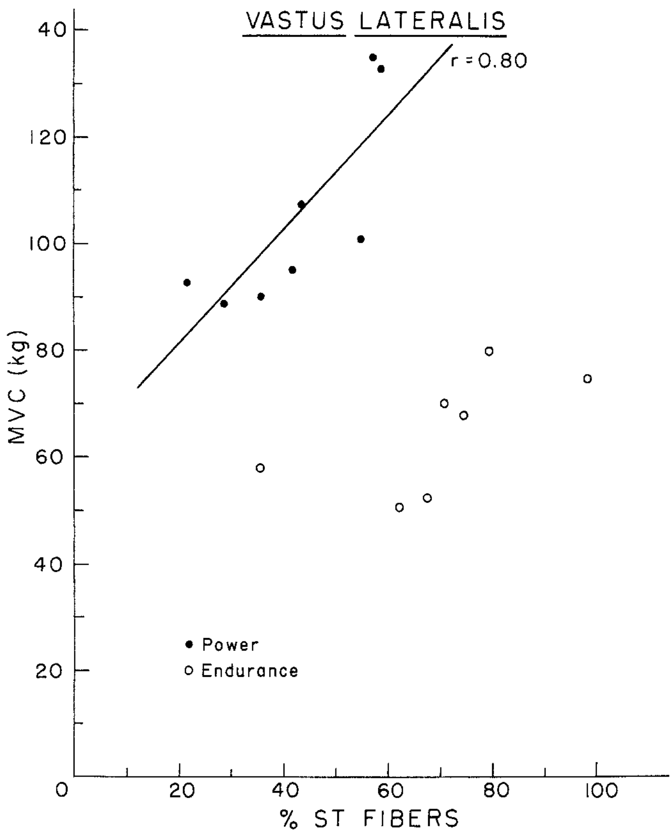

Fig. 1. Knee extension maximum voluntary isometric strength (MVC) and percent slow twitch (ST) fibers of the vastus lateralis muscle in power and endurance athletes. Solid line represents the relationship for the power athletes ($r = 0.80$, $p < 0.05$)

power athletes. It seems that similar and high percentages of ST fibers in both muscles may be important to successful performance in endurance activities. Apparently this is not the case for the power athletes as the percent ST fibers in an individual varies from the vastus lateralis to the gastrocnemius muscle.

While the mean percent fiber type composition within each group was similar in the vastus lateralis and gastrocnemius muscles, a different relationship existed for fiber sizes. For the power group, the area of the FTa fibers in both the vastus lateralis and the gastrocnemius muscles was considerably larger than both the ST fibers and FTb fibers which were similar in size. These data are consistent with previous data for weight lifters (Gollnick et al. 1972; Edstrom and Ekblom 1972). The FTa and ST fibers of endurance athletes were similar in size in the vastus lateralis and in the gastrocnemius muscles. Costill et al. (1976), Jansson and Kaijser (1977), and Nygaard and Nielson (1978) reported that Type I fibers (ST) were somewhat smaller than Type II (FT) fibers in endurance athletes. In the present study, the ST fibers in the vastus lateralis and gastrocnemius of the power and endurance athletes were all similar in size. The FTa fibers in the power athletes, however, were considerably larger than the FTa fibers in the en-

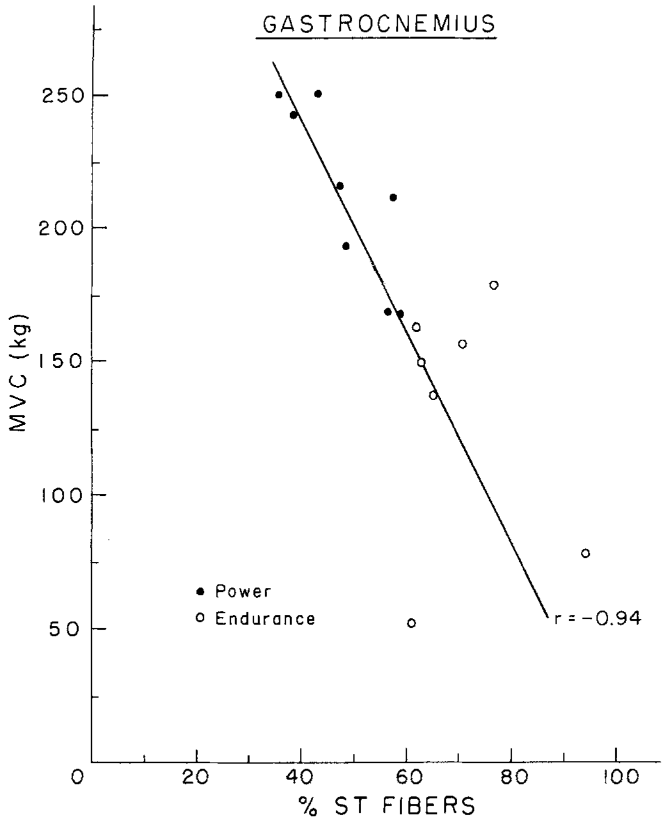

Fig. 2. Ankle extension maximum voluntary isometric strength (MVC) and percent slow twitch (ST) fibers of the gastrocnemius muscle in power and endurance athletes. Solid line represents the relationship for the power athletes ($r = -0.94$, $p < 0.01$)

durance athletes only in the vastus lateralis; in the gastrocnemius the FTa fibers were similar in size in the two groups.

In addition to having a greater percent composition of fast twitch fibers, the power group was also stronger than the endurance group. Maximum isometric strength in the power athletes was significantly higher than in endurance athletes for both muscle groups tested. Correlation of maximum knee extension strength with percent ST fibers of the vastus lateralis resulted in a significant positive correlation for the power group only. Tesch and Karlsson (1978) and Komi et al. (1977) reported a significant positive correlation between one leg isometric strength and percent FT fibers in the vastus lateralis. Physical education students were used as subjects by Tesch and Karlsson (1978) while Komi et al. (1977) studied several athlete groups, as well as a large control group. However, correlations between strength and fiber composition for each group were not presented. Since a positive correlation was found for percent FT fibers and isometric strength in these studies it could be suggested that FT fibers are involved in the production of isometric strength. Yet the opposite was true for the power group in the present study: maximum knee extension isometric strength correlated significantly with percent ST fibers, possibly indicating an involvement of ST fibers in the production of isometric extension strength for these athletes.

Further evidence for specific athlete groups differing in the relationship of fiber composition and strength was provided by Thorstensson et al. (1977) who found that leg peak torque correlated positively with percent FT fibers of the vastus lateralis muscle for several types of athletes pooled together. Examination of their scatterplot where athletes were identified by sport, however, clearly shows that if the groups were analyzed separately the correlations between peak torque and FT percentage would differ depending upon the group. For example, the regression lines for the skiers and for the sprinters would differ from each other and from the other athletic groups.

While studies have examined the relationship of leg strength with fiber type composition of the vastus lateralis muscle, the present study is the first, to our knowledge, to examine the relationship of ankle extension strength and fiber composition of the gastrocnemius muscle. Correlation between gastrocnemius percent ST fibers and ankle extension strength resulted in a significant correlation for the power group ($r = -0.94$) and none for the endurance group. A negative correlation between percentage of ST fibers and strength for the power group suggests a reliance on FT fibers to produce maximum strength.

In summary, for the power group significant correlations were found between percent ST fibers and either knee extension ($r = +0.80$) or ankle extension ($r = -0.94$) maximum isometric strength. Corresponding correlations for the endurance group were not significant suggesting that other factors may affect the relationship of fiber type composition and maximum strength. Thus, the relationship to be expected between muscle fiber type composition and maximum isometric strength may well depend upon the muscle group under study as well as the type of athlete in terms of specific training adaptations.

References

Bergstrom J (1962) Muscle electrolytes in man. Scand J Clin Lab Invest [Suppl] 68:11–13

Brooke MH (1979) Some comments on neural influence on the two histochemical types of muscle fibers. In: Briskey EJ, Cassens RG, Marsh BB (eds) The physiology and biochemistry of muscle as a food, vol 2. University of Wisconsin Press, Madison, pp 131–153

Costill DL, Daniels J, Evans W, Fink W, Krakenbuhl G, Saltin B (1976) Skeletal muscle enzymes and fiber composition in male and female track athletes. J Appl Physiol 40:149–154

Edstrom L, Ekblom B (1972) Difference in sizes of red and white muscle fibers in vastus lateralis of musculus quadriceps femoris of normal individuals and athletes. Relationship to physical performance. Scand J Clin Lab Invest 30:175–181

Gollnick PD, Armstrong RB, Saltin B, Saubert CW IV, Sembrowich WL, Sheperd RE (1972) Effect of training on enzyme activity and fiber composition of human skeletal muscle. J Appl Physiol 33:312–319

Hulten B, Thorstensson A, Sjodin B, Karlsson J (1975) Relationship between isometric endurance and fiber types in human leg muscles. Acta Physiol Scand 93:135–138

Jansson E, Kaijser L (1977) Muscle adaptation to extreme training in man. Acta Physiol Scand 100:315–324

Komi PV, Rusko H, Vos J, Vihko V (1977) Anaerobic performance capacity in athletes. Acta Physiol Scand 100:107–114

Nilsson J, Tesch P, Thorstensson A (1977) Fatigue and EMG of repeated fast voluntary contractions in man. Acta Physiol Scand 101:194–198

Nygaard E, Nielsen E (1978) Skeletal muscle fiber capillarization with extreme endurance training in man. In: Eriksson B, Furberg B (eds) Swimming medicine, vol 4. University Park Press, Baltimore, pp 282–296

Padykula HA, Herman E (1955) The specificity of the histochemical for adensine triphosphate. J Histochem Cytochem 3:170–195

Polgar J, Johnson MA, Weightman D, Appleton D (1973) Data on fiber size in thirty-six human muscles: An autopsy study. J Neurol Sci 19:307–318

Saltin B, Henriksson J, Nygaard E, Andersen P (1977) Fiber types and metabolic potentials of skeletal muscles in sedentary man and endurance runners. Ann NY Acad Sci 301:3–29

Song SK, Shimada N, Andersen PJ (1963) Orthogonal diameters in the analysis of muscle fiber size and form. Nature 200:1220–1221

Stilwill EW, Sahgal V (1977) Histochemical and morphologic changes in skeletal muscle following cervical cord injury: A study of upper and lower motor neuron lesions. Arch Phys Med Rehabil 58:201–206

Tesch P, Karlsson J (1978) Isometric strength performance and muscle fiber type distribution in man. Acta Physiol Scand 103:47–51

Thorstensson A (1976) Muscle strength, fiber types and enzyme activities in man. Acta Physiol Scand [Suppl] 443:1–45

Thorstensson A, Larsson L, Tesch P, Karlsson J (1977) Muscle strength and fiber composition in athletes and sedentary men. Med Sci Sports 9:26–30

Accepted February 6, 1980