Enzyme activities of FT and ST muscle fibers in heavy-resistance trained athletes

Tesch, P. A., A. Thorsson, and H. Essén-Gustavsson. Enzyme activities of FT and ST muscle fibers in heavy-resistance trained athletes. J. Appl. Physiol. 67(1): 83–87, 1989.—Tissue samples were obtained from the vastus lateralis muscle of elite Olympic weight and power lifters (OL/PL, n = 6), bodybuilders (BB, n = 7), and sedentary men (n = 7). Enzyme activities of citrate synthase (CS), lactate dehydrogenase (LD), 3-0H acyl-CoA-dehydrogenase (HAD), and myokinase (MK) were assayed on freeze-dried dissected pools of slow-twitch (ST) and fast-twitch (FT) fiber fragments by fluorometric means. Histochemical analyses were carried out to assess fiber type composition and fiber area. CS and HAD activities were lower (P < 0.05), and LD and MK were higher (P < 0.05) in FT than ST fibers in the entire subject pool (n = 20). CS of FT fibers and HAD of ST fibers were lower in athletes (P < 0.05–0.01) compared with nonathletes, whereas LD of both fiber types was higher (P < 0.05–0.001) in athletes. CS activity of ST fibers and MK activity of FT fibers were higher (P < 0.05) in BB compared with OL/PL. FT and ST fiber area was greater (P < 0.05) in athletes than in nonathletes. BB displayed greater (P < 0.05) fiber size than OL/PL. FT/ST area was greater (P < 0.05) in OL/PL than BB. It is suggested that long-term heavy-resistance training results in specific metabolic adaptations of FT and ST fiber types. These changes appear to be influenced by the type of resistance training.

bodybuilders; hypertrophy; Olympic weight and power lifters; muscle fiber types and size; strength training;

Physiological Training is known to induce substantial alterations in the metabolic profile of human skeletal muscle. Recent reports, utilizing a microanalytic technique and enabling enzyme analyses of single or pooled single slow-twitch (ST) or fast-twitch (FT) fibers (5, 10, 16), show that these changes may occur in both fiber types, although the magnitude of response is influenced by the specific stimuli or mode of training (cf. 20).

The enzymatic adaptations occurring subsequent to heavy-resistance training, in contrast to endurance training, have been poorly examined. Typically, this exercise regimen produces muscle hypertrophy (9, 18, 29, 31), due to an increased incorporation of myofibrillar proteins (17, 19) of mainly FT fibers (8, 9, 21, 24, 25, 29, 31). As a consequence, the skeletal muscle mitochondrial fraction may be reduced (17, 19) and the capillary density decreased (28). These changes do suggest reduced oxidative potential of hypertrophied skeletal muscles. Short-term strength-training programs, varying considerably in design, as well as use of equipment, work load, intensity, types of muscle actions, and populations, produced either increased, decreased, or unchanged activities of enzymes reflecting aerobic-oxidative, anaerobic-glycolytic, or phosphagen metabolism (4, 9, 11, 13–15, 29). A 6-mo strength-training regimen emphasizing high force production, however, demonstrated that a 16% increase in muscle cross-sectional area was accompanied by a decreased activity of enzyme markers for oxidative, glycolytic, or phosphagen metabolism (25). Neither of these cited studies examined the enzyme content of FT and ST fibers. It is therefore not known whether heavy-resistance training induces fiber type-specific changes in enzyme content.

Muscle hypertrophy can be produced through various modes of strength training. Hence, in training for power or Olympic weight lifting, the loads used are near maximal and few repetitions are performed in a sequence, allowing for prolonged recovery and suggesting minute substrate utilization through oxidative or anaerobic-glycolytic metabolism. On the contrary, in training performed by bodybuilders, the load is lower but each exercise consists of a greater number of repetitions followed by shorter recovery periods, the result being a substantial energy turnover through phosphagen breakdown, glycogen, and fat utilization (22, 23). Consequently, the metabolic adaptive response may differ depending on training modality.

In light of paucity of data, it was the purpose of this study to examine the activity of enzymes in FT and ST fibers of quadriceps muscle from strength-trained athletes and nontrained men. A second aim was to compare bodybuilders, on one hand, and power and Olympic weight lifters with regard to enzyme contents of FT and ST fibers.

Materials and Methods

Subjects were 13 national elite Olympic weight lifters (OL), power lifters (PL), and bodybuilders (BB). These athletes had been training systematically in their specific events for a minimum of 4 yr. They were examined during or at the end of their competitive season. The training regimens of OL/PL and BB differ in that the former typically perform a few near-maximal lifts in a sequence, whereas BB may exercise a single muscle group by 20 consecutive sets of 6–12 contractions, each set leading to contraction failure and followed by a short recovery.
period. In addition, seven randomly selected sedentary subjects (controls) of similar age and height volunteered. These controls had never participated in any recreational or competitive sports except for mandatory school sport activities. Body mass index (BMI), calculated as body weight · (height²)⁻¹, was greater (P < 0.01) in OL/PL and BB than in controls. Physical characteristics are given in Table 1. Consent was given by each subject after being informed of the purpose and the potential risks associated with the experiments. The protocol was approved by the Karolinska Institute Human Ethics Committee. Two muscle samples were obtained from the vastus lateralis muscle at a site 13–16 cm proximal to the patella with the percutaneous needle-biopsy technique (1). Samples for enzyme analyses were immediately frozen in liquid N₂, and samples for histochemical analyses were mounted in embedding medium and frozen in liquid N₂-cooled isopentane. Muscle samples were stored at -80° until the analysis.

Enzyme Analysis

Tissue samples were freeze-dried and dissected free from connective tissue, fat, and blood before single muscle fiber fragments were teased apart. A small part of each fiber fragment was stained for myofibrillar adenosine triphosphatase (ATPase) and classified either as ST or FT fibers (5). Subsequently, fiber fragments were pooled into groups of ST and FT fibers. Pools were weighed on a Cahn electrobalance. The weight of pools ranged from 30 to 588 µg. The pools of fragments were homogenized in ice-chilled 0.1 M potassium phosphate buffer (pH 7.3, dilution 1:400) with an ultrasound disintegrator. The activities of citrate synthase (CS, EC. 4.1.3.7), as a measure of citric acid cycle capacity, 3-OH-acyl-CoA dehydrogenase (HAD, EC. 1.1.1.35), reflecting the capacity for lipid oxidation, and lactate dehydrogenase (LD, EC. 1.1.1.27), reflecting the capacity for lactate production from pyruvate, were determined using fluorometric methods and reagents as previously described (6). The activity of myokinase (MK, EC. 2.7.4.3), reflecting the capacity for regeneration of ATP from ADP, was assayed as described elsewhere (16). All analyses were performed at 25°C, and enzyme activities were expressed in µmol · g dry wt⁻¹ · min⁻¹.

Histochemical Analysis

Serial cross sections (10 µm) were cut in a microtome at -20°C and histochemically stained for myofibrillar ATPase, at pH 9.4, after preincubation at pH 10.3, 4.6, and 4.3 (2). For classification, fibers were identified as either FTa, FTb, or ST. The percentage of each fiber type was subsequently calculated. A photograph of the ATPase stain after acid (pH 4.6) preincubation was used for fiber area analyses. The different fibers (ST, FTa, and FTb) were identified on the photograph, and the mean area of 25 randomized fibers of each kind was measured by planimetry with a MOF Digiplan Analyzer. Fiber area measurements were only performed on well-defined cross sections (6).

Statistical Analysis

Means ± SD and SE were calculated with ordinary statistical methods, and analysis of variance (ANOVA) was used for intra- and intergroup comparisons. A "Studentized range" test (12) was used wherever the ANOVA demonstrated statistically significant differences.

RESULTS

In the entire examined sample (n = 20), CS and HAD activities were higher (P < 0.001) in ST compared with FT fibers. Likewise, LD and MK activities were higher (P < 0.001) in FT than in ST fibers. This pattern was present in all three groups.

Citrate synthase. Athletes (OL/PL + BB) displayed lower (P < 0.05) activity of FT fibers than controls. A similar but nonsignificant trend was noticed for ST fibers. The CS activity of ST fibers was lower (P < 0.05) in OL/PL compared with BB and similar in FT fibers of both groups (Fig. 1, Table 2).

Lactate dehydrogenase. LD activity of ST (P < 0.05) and FT (P < 0.001) fibers was higher in OL/PL + BB compared with controls. There were no differences between the two categories of athletes (Fig. 2, Table 2).

3-OH-acyl-CoA-dehydrogenase. HAD activity of ST fibers was lower (P < 0.01) in OL/PL + BB than in controls, whereas HAD activity of FT fibers was similar in these two groups. OL/PL and BB displayed comparable values (Fig. 3, Table 2).

Myokinase. MK activity of FT fibers was higher (P < 0.01) in OL/PL + BB compared with controls, and that of ST fibers was comparable in the two groups. BB had higher (P < 0.05) MK activity of FT fibers compared with controls.
TABLE 2. Activities of CS, LD, HAD, and MK of FT and ST fibers

<table>
<thead>
<tr>
<th></th>
<th>CS</th>
<th>LD</th>
<th>HAD</th>
<th>MK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FT</td>
<td>11.9±3.9</td>
<td>371±119</td>
<td>18.9±2.4</td>
<td>354±111</td>
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<tr>
<td>ST</td>
<td>17.6±5.9</td>
<td>195±61</td>
<td>16.3±3.6</td>
<td>141±5</td>
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<tr>
<td><strong>Controls</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FT</td>
<td>14.8±4.1</td>
<td>264±40</td>
<td>11.4±1.5</td>
<td>278±54</td>
</tr>
<tr>
<td>ST</td>
<td>20.1±6.0</td>
<td>154±55</td>
<td>19.0±3.3</td>
<td>137±30</td>
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<tr>
<td><strong>OL/PL</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FT</td>
<td>9.9±2.8</td>
<td>414±146</td>
<td>9.8±1.4</td>
<td>319±74</td>
</tr>
<tr>
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<td>206±51</td>
<td>15.0±2.4</td>
<td>109±46</td>
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<td><strong>BB</strong></td>
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<td></td>
</tr>
<tr>
<td>FT</td>
<td>10.9±3.0</td>
<td>440±59</td>
<td>11.1±3.6</td>
<td>459±104*</td>
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<tr>
<td>ST</td>
<td>17.9±5.0*</td>
<td>256±57</td>
<td>15.8±2.7</td>
<td>171±64</td>
</tr>
</tbody>
</table>

Values are means ± SD in μmol·g dry wt⁻¹·min⁻¹. CS, citrate synthase; LD, lactate dehydrogenase; HAD, 3-OH-acyl-CoA-dehydrogenase; MK, myokinase; FT, fast-twitch fibers; ST, slow-twitch fibers.

For statistical significance of differences, see RESULTS and legends of Fig. 1–4. * Group differences between BB and OL/PL (P < 0.05). See footnote of Table 1 for definition of other abbreviations.

DISCUSSION

Previous human studies have reported the enzymatic adaptations taking place in different fiber types in response to endurance training (cf. 20). Endurance athletes possess two-to threefold higher mitochondrial enzyme content in both ST and FT fibers but similar LD activity compared with nonendurance-trained subjects (3, 7). In this study, we have produced indirect evidence that long-term heavy-resistance training, associated with muscle fiber hypertrophy, produces metabolic responses that are different from those occurring subsequent to endurance training. Of note is the low activity level of mitochondrial enzymes in both ST and FT fibers in heavy-resistance-trained subjects. This activity level is also lower than that found in nontrained subjects. Furthermore, the LD activity in heavy-resistance-trained subjects is ~1.5 times greater in both fiber types, and the MK activity of FT fibers is 1.5 times higher than in nontrained subjects. The observations described here concerning heavy-resistance-trained athletes are assumed to reflect the effects of long-term training rather than inheritance. The results of this study also show that the different metabolic profile of FT and ST fibers demonstrated in numerous studies (cf. Ref. 20) was established in heavy-resistance-trained athletes. It appears that specific physical training, only to a limited extent, alters this relation-
TABLE 3. Indices of fiber type composition and fiber size

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>%ST</th>
<th>%FTa</th>
<th>%FTb</th>
<th>FT Area, (\mu m^2 \times 100)</th>
<th>ST Area, (\mu m^2 \times 100)</th>
<th>Mean Area, (\mu m^2 \times 100)</th>
<th>FT/ST</th>
<th>%FT Area</th>
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</thead>
<tbody>
<tr>
<td>Controls</td>
<td>7</td>
<td>62±17</td>
<td>22±11</td>
<td>15±8</td>
<td>42.8±9.3</td>
<td>40.4±8.7</td>
<td>41.2±8.1</td>
<td>1.09±0.26</td>
<td>39±18</td>
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<tr>
<td>OL/PL</td>
<td>6</td>
<td>45±7</td>
<td>40±20</td>
<td>15±15</td>
<td>39.1±15.4*</td>
<td>62.6±14.2*</td>
<td>78.5±11.8*</td>
<td>1.54±0.39*</td>
<td>65±25*</td>
</tr>
<tr>
<td>BB</td>
<td>7</td>
<td>39±14*</td>
<td>53±20</td>
<td>8±9</td>
<td>104.6±25.4**</td>
<td>72.3±16.4†</td>
<td>92.8±23.2†</td>
<td>1.44±0.18†</td>
<td>68±14*</td>
</tr>
</tbody>
</table>

Values are means ± SD; n, no. of subjects. FTa, FTb, designated fast-twitch fiber types. Intergroup differences: * P < 0.05, controls vs. OL/PL or BB; † P < 0.05, OL/PL vs. BB. See footnote of Table 1 for definition of other abbreviations.
strated for human skeletal muscle, are also present in heavy-resistance-trained athletes.

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