Effects of resistance training on elbow flexors of highly competitive bodybuilders

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SEVERAL INVESTIGATIONS have characterized adaptations of skeletal muscle to heavy resistance training in men (4-6, 19, 22, 27, 28), but relatively few studies have examined similar responses in women. The studies that have examined the effects of resistance training in women are largely limited by methodological weaknesses, such as insufficient training duration and intensity. Furthermore, most of such investigations have used indirect methods to predict changes in muscle mass (i.e., percent body fat, limb girth), but these measures do not provide information about changes that might occur at the cellular level. Despite these shortcomings, these studies have been interpreted by many to indicate that women are capable of significant strength gains with minimal or no increase in muscle mass (11, 30). Presumably, increases in muscle strength in women would occur by improvements in neural rather than peripheral mechanisms (20, 21, 30).

Empirical examination of bodybuilders, however, suggests that women may be capable of substantial increases in muscle mass. This idea is supported from our previous work (7, 8) in which both average type I and type II fiber areas, as well as total fiber number, were greater in resistance-trained women than in values reported in the literature for untrained women (22). In addition, recent longitudinal data have demonstrated increases in muscle mass and fiber area in the quadriceps muscles of women after resistance training (25). Thus it now appears appropriate to conclude that skeletal muscle hypertrophy in women is possible.

It is not clear whether type I and type II fibers in men and women respond in identical manners to a similar relative load. We have previously determined that the type II-to-type I area ratio in the biceps brachii of women bodybuilders was 1.1, and this was significantly less than the ratio of 1.5 that was found in men (7). This suggested that female bodybuilders (FB) were unable to achieve a similar degree of preferential hypertrophy in type II fibers, relative to males. This apparent sexual dimorphism was despite similar training experience and similar relative resistance loads in men and women. However, because these were cross-sectional data, we could not be certain that women bodybuilders would not demonstrate selective type II hypertrophy if their training programs were of similar intensity to those of men. This was considered likely because Staron and co-workers (26) found that although all fiber types hypertrophied in the vastus lateralis of women after 20 wk of resistance training, type II fibers were preferentially increased in their subjects. In a subsequent paper, Staron et al. (25) observed that 6 wk of resistance training induced preferential hypertrophy of type II fibers after a 30- to 32-wk detraining period.

The purpose of the present study was to determine the effects of resistance training on characteristics of type I and type II muscle fibers and muscle cross-sectional area (CSA). Specifically, our objective was to determine whether type II fibers would respond similarly in men and women to a training program that comprised identical exercises, sets, repetitions, and relative loads. Although Häkkinen et al. (14, 15) have shown that muscle size and strength did not change over a 2-yr period in a group of highly competitive weight lifters, it is not known...
whether muscle mass and strength in highly competitive bodybuilders would show a similar resistance to improvement. Therefore the second purpose of this study was to determine whether highly competitive male bodybuilders (MB) and FB could further enhance muscle strength, fiber size, and muscle CSA during a heavy resistance training period that lasted 24 wk. By training the arm flexors in highly competitive bodybuilders of both genders who had already achieved substantial muscle hypertrophy and strength, we were able to largely eliminate low motivational factors that may potentially confound the interpretation of training studies that have examined previously sedentary subjects. We selected bodybuilders because their goal is largely to obtain a high degree of muscle mass in all muscles but especially in the arm flexors. Because bodybuilders train very differently from power lifters or weight lifters, we have examined only bodybuilders. This eliminated the confounding problem of other studies that have combined power lifters, weight lifters, and/or bodybuilders in a single subject group.

METHODS

Subjects. Subjects consisted of five MB, five FB, two untrained male controls, and two untrained female controls. Before participating, all subjects signed an informed consent form that was approved by the Human Review Board of University of Texas, Southwestern Medical Center at Dallas. Data obtained before training have been reported on some of these subjects in a previous study (7). All of these athletes were highly competitive because they had won their weight or height class at either National Physique Committee- or American Athletic Union-sanctioned bodybuilding championships in the states of Texas, Arkansas, or Louisiana. Three of the MB and two of the FB had placed second through fifth at national-level bodybuilding championships held by the National Physique Committee or the American Athletic Union. These were non-drug-tested events at the time of data collection. One MB had won a Natural Physique Competition national meet where drug testing against steroid use was enforced.

Dietary patterns for these athletes were assessed before and after the study by a questionnaire that recorded their food intake for 7 consecutive days. The athletes recorded the time of food intake, the type of food, and the weight of each food item. All athletes supplemented their diets with multivitamins, protein powders (from milk and soy products), and free-form amino acid capsules. In addition, two MB and one FB used a carbohydrate supplement before training. Dietary intake averaged 6,422 ± 877 and 4,241 ± 338 (SE) kcal for MB and FB, respectively, and this was consumed over 6–8 feedings per day. The nutrient composition was estimated from the dietary records of the athletes. Nutrient composition was similar among the subject groups, and it consisted of 67 ± 11% carbohydrate, 22 ± 9% protein, and 11 ± 4% fat. Nutrient composition of the diet was unchanged before and after 24 wk of the training study.

Because steroid use has been common among athletes at high levels of competition in most sports, all of the bodybuilders in this study were interviewed regarding their steroid usage. Three of the MB and two of the FB admitted to current steroid use. The remaining athletes (2 MB and 3 FB) had not taken anabolic steroids for a minimum of 4 yr preceding the current study. Blood samples were obtained from all athletes, and high-density and low-density lipoprotein levels were determined (data not shown). Although not all steroids will lower the ratio of low- to high-density lipoprotein, our data were consistent with the information of current steroid use provided to us by the athletes (i.e., steroid users had very low levels of high-density lipoprotein). Because it was not our intent to manipulate steroid usage but rather to assess the effects of training on the muscle characteristics of these athletes, we excluded subjects after their original interview if they indicated that they would alter their levels and/or types of steroids during the course of the experiment. High- and low-density lipoproteins were not significantly altered in assessments at 12 or 24 wk of this study. Therefore we assume that compliance with steroid usage or nonusage was maintained by all subjects.

All women athletes were premenopausal. All had menstrual cycles, although the two women who were using anabolic steroids reported irregular menstrual cycles.

Physical characteristics of the athletes were unaltered over the course of the study (Table 1). Competitive bodybuilders, like other athletes, train differently during the "off-season" than during the "competitive season." Typically, the off-season is a period when bodybuilders attempt to improve muscle mass and strength in all body parts and especially in those that might have shown some asymmetry during the previous competitions. Approximately 8–12 wk before a bodybuilding competition, bodybuilders will reduce their caloric intake and attempt to reduce subcutaneous body fat stores, while maintaining (but not adding to) the existing levels of muscle mass.

The bodybuilders in the current study were examined 2–4 wk after their most recent competition (range of 6–16 wk). During the 24 wk of this study, none of the bodybuilders competed in a bodybuilding competition, nor did they attempt to reduce caloric intake to reduce body fat stores. Thus they would have been considered in the off-season part of their competitive schedule.

These athletes trained with resistance exercises for 4 ± 1.1 h/day, 5–6 days/wk, and no difference was found between subject groups. We did not attempt to control training for muscle groups other than the arm flexors, so the bodybuilders trained their other body segments (thighs, chest, back) in the normal manner. A questionnaire indicated that the subjects typically used 15–20 sets of exercises for their thigh, chest, and back muscles, whereas only 12–15 sets of exercises were used for their shoulder, triceps, and triceps surae muscles. Likewise, the history of total length of training did not differ between subject groups (MB 5.8 ± 0.5 yr and FB 5.4 ± 0.7 yr).

Training program. The training program for the arm flexors was designed to reflect the type that is typically
TABLE 1. Subject characteristics

<table>
<thead>
<tr>
<th>Subj No.</th>
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<th>FFM, kg</th>
<th>FFM/Body Height, kg/cm</th>
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MB

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<th>FFM, kg</th>
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MC

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<th>FFM, kg</th>
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FB

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<th>FFM, kg</th>
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<td>46.6</td>
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<tr>
<td>Mean ± SE</td>
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<td>169.7±2.1</td>
<td>55.0±0.3</td>
<td>46.9±0.3</td>
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</table>

FFM, fat-free mass; MB, male bodybuilders; MC, untrained male controls; FB, female bodybuilders; FC, untrained female controls. * P < 0.05, MB vs. FB.

conducted by advanced bodybuilders of both sexes. This was determined after interviewing and observing 18 male and 15 female bodybuilders of state or national competition experience who performed the appropriate arm flexor exercises in their normal training routines. The training regimen is summarized in Table 2. It consisted of two parts, with each part followed once per week (the arm flexors received two training sessions per week). A 6-repetition maximum (RM) and 10 RM were determined for each of the four exercises. On the first training session, each exercise was performed for five sets of six repetitions in each set, with use of the resistance that equaled six RM. In the second exercise session, the resistance was reduced so that three sets of 10 repetitions were completed with the resistance that achieved 10 RM. The resistance was increased for an exercise when they could perform 8 repetitions in the first training session and 14 repetitions of each exercise in the second training session.

**Fat-free mass (FFM).** The total body volume of subjects was determined by water displacement in a body volume tank (Whitmore Enterprises, TX) according to procedures outlined previously (7, 8, 12, 16). Residual lung volume was determined by the method of Wilmore et al. (31). Body volume was calculated as follows: body volume = total body volume displacement from volume meter - residual lung volume - abdominal gas volume. Abdominal gas volume was assumed to be 0.11 liter (10). Mass was determined on land, and density was determined according to the following equation: density = mass / volume. Percent body fat was determined from the equation of Siri (23). FFM was calculated as total body mass - (total body mass × percent fat). Six subjects were brought in to determine the coefficient of variation from test to test, which was 3.2 ± 0.3% on these subjects.

**Percent fiber distribution.** Two needle biopsies were obtained from the same site from the long head of the biceps brachii before and after 24 wk of heavy resistance training. The depth of biopsy was controlled so that the same region of the muscle was sampled at both intervals. The tissue was frozen in isopentane cooled to the temperature of liquid nitrogen and was stored at -70°C before processing for histochemistry. Cryostat sections were cut at 10 μm, mounted on glass slides, and stained for myofibrillar adenosinetriphosphatase (mATPase) activity (3, 7, 9). Fibers were classified as type I or type II from the mATPase histochemical reactions after pH preincubations of 3.29 or 10.25, respectively. Photographic montages were assembled, all the fibers in the biopsy sample

### TABLE 2. Exercise training program for MB and FB

<table>
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<th>Exercise</th>
<th>Program 1</th>
<th>Program 2</th>
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<tr>
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<td>Reps</td>
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<td>Barbell curls</td>
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</tr>
<tr>
<td>Barbell Scott curls</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Bent-over dumbbell concentration curls</td>
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<td>6</td>
</tr>
<tr>
<td>Hammer curls</td>
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<td>6</td>
</tr>
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</table>

The training regimen was alternated between programs 1 and 2 each week. Program 1 used a 6 and 2 a 10 repetition maximum (RM) resistance. Two minutes of rest occurred between each set in program 1 and 60 s of rest occurred between sets in program 2. MB, male bodybuilders; FB, female bodybuilders.
were counted (667 ± 73), and percent fiber distribution was determined.

**Fiber CSA.** Fiber areas were determined by planimetry on a minimum of 200 type I and 200 type II fibers of each biopsy, because we have previously found that samples fewer than this may result in errors in fiber area data for bodybuilders (7). For this reason, fiber areas were determined for only the major fiber types, namely type I and type II fibers. Light micrographs were taken (×100) of cross sections of fibers after an alkaline mATPase reaction (pH 10.25) and were printed to a final magnification of about ×15,000. Fiber perimeters were manually traced on a summagraphics digitizing tablet. A minicomputer software computer program was used to store individual fiber areas and also to calculate type I and type II fiber area for each subject. Mean type I and type II fiber area values were determined for MB and FB groups by averaging fiber area from the respective fiber type for each subject in the sample group. In addition to the areas for type I and type II fibers, mean fiber area (F₄) was calculated as outlined previously (7).

**Volume density of nonmuscle tissue.** Nonmuscle tissue was identified on frozen tissue sections stained for Gomori’s trichrome (7, 9). The volume density of collagen and other nonmuscle tissue was determined from a 121-point grid lattice according to standard stereological techniques (29) as previously reported (2, 3, 7, 9).

**Muscle area.** CSA of the biceps brachii and total arm flexor mass (biceps brachii + brachialis muscles) was determined from computerized tomographic (CT) scans of the upper arm before the muscle biopsy (7). The hand was supinated, and the arm was in the extended position. Six scans were taken at 3-mm intervals from the mid-belly region of the upper arm containing the greatest area of the biceps. CT scans were taken with a soft tissue algorithm. This computer algorithm was part of the software package produced by the manufacturers of the CT scan unit that optimized the visualization of muscle and other soft tissue (Picker International, TX). Window and level settings were 160 and 64, respectively. The CSA of the biceps brachii was determined by planimetry from five traces of each scan. The scan that had the greatest CSA was selected to represent the biceps CSA. Both flexor and biceps CSA were corrected for the percentage of collagen and noncontractile tissue that was determined from biopsies of the biceps. Muscle CSA was determined before training and after 12 and 24 wk of training.

**Fiber number.** Biceps fiber number was estimated as follows: number of fibers = biceps CSA (corrected for noncontractile tissue) ÷ F₄.

Muscle obtained by the needle biopsy technique undergoes almost complete contracture postexcision (18); therefore fiber areas were measured with sarcomeres in a contracted state. Because muscle CSA was measured by CT scanning with the sarcomeres at resting length, the net result is that F₄ has been overestimated and therefore fiber number has been underestimated. We have therefore corrected the estimates of fiber number by 36% to account for sarcomere shortening, according to the correction of MacDougall and colleagues (18). We assume that if the degree of sarcomere shortening is the same in both subject groups and before and after training, valid intergroup comparisons can still be made on fiber numbers that are either corrected or uncorrected for sarcomere shortening.

**Isometric torque.** Voluntary isometric torque was determined before and after 12 and 24 wk of heavy resistance training. The Cybex II dynamometer (Rokonkoma, NY) was set at 0°/s to record isometric torque. Preliminary studies on four male and four female bodybuilders determined that an elbow angle of 90° (straight arm 180°) produced the greatest torque. There did seem to be some gender differences, because torque that was recorded at elbow angles of 70, 90, and 120° were similar in females, whereas in males, isometric torques were similar and the greatest at elbow angles of 90 and 120°, but these were always less than torques generated at an elbow angle of 70°. Intertest variance for isometric torque was assessed in six subjects at a 1-wk interval, and the coefficient of variation was 4.7 ± 0.9%.

**Peak isokinetic torque.** Peak torque (PT) was defined as the greatest torque developed during the contraction after the initial impact torque and was determined with an isokinetic dynamometer (Cybex II). Impact torque (13, 32) was not used for calculations of peak flexion or peak extension torques. Each subject received several submaximal practice contractions at each velocity to familiarize him with the test protocol. Four to five maximal voluntary efforts were performed at angular velocities of 30, 60, 180, 240, and 300°/s. Contractions at each velocity were separated by a minimum of 4 min to provide sufficient recovery. At the end of the study, subjects performed one to two maximal contractions at 30°/s and at 300°/s to check for signs of fatigue. These postsession measures were within intertrial variations. We assume that all of the subjects were contracting maximally at each velocity because the coefficient of variation on torque measures did not exceed 6.4 ± 1.1% during repeat measures of torque that were determined a minimum of 1 wk apart. Isokinetic PT measures were obtained before training, after 12 wk of training, and after 24 wk of training.

**Free-weight strength measures.** Ten and 6 RM measures were recorded before, at 12 wk, and after 24 wk of training. These data were used largely to assess the attempts of the subjects to improve the resistance for each exercise. Because the style of lifting (speed of movement, hand, elbow, and shoulder position) is not carefully controlled in free-weight assessments of strength, improvements in strength may not necessarily be the result of changes in the ability of the muscle to produce force. Nevertheless, it is recognized that training-specific changes are better assessed on the particular apparatus that was used for training. Thus, because the Cybex isokinetic device may not be a sensitive tool for determining changes due to free-weight exercises, assessments of 10 and 6 RM were obtained.

**PT to muscle CSA ratios.** Torque is the result of muscle force acting at a muscle moment arm length. An additional series of CT scans might have been able to determine the distance from the insertion of the bicipital ten-
RESULTS

Subjects. One of the five women athletes became pregnant during the final 4 wk of the study but continued her training. CT scans and isokinetic strength measures were not obtained on this subject at week 24 because of potential complications with the pregnancy; however, a needle biopsy was obtained at this time point. Statistical analyses were conducted on muscle CSA and strength for only the four women who completed the study in its entirety; however, because biopsies were obtained on all five women before and after training, statistical analyses for fiber area included all five FB.

Age, height, and years of training did not differ among the two subject groups. FFM was, however, significantly greater in MB. FFM did not change in either group over the duration of the study.

Elbow flexor and biceps CSA. Flexor and biceps CSA are given for each subject in Table 3. Because CT scans were not obtained from one FB at week 24, data in Table 3 are given both for the entire group (n = 5, data in brackets) and for the four FB who completed the entire study. Biceps and flexor CSA (biceps brachii + brachialis) were 24.8 ± 2.6 and 34.4 ± 2.8 cm², respectively, in MB. Biceps and flexor CSA were 14.1 ± 2.1 and 19.0 ± 2.9 cm² (FB n = 5, 19.6 ± 1.9 cm²), respectively, in FB. Thus MB had 76 and 81% greater CSA in biceps and flexor groups than in the FB group. The small increase in flexor muscle CSA of 3.1 ± 0.8% in MB and 4.2 ± 0.9% in FB (FB n = 5, 3.7 ± 0.5%) after 12 wk of training was not statistically significant. Similarly, the increase of 7.6 ± 1.5 and 7.8 ± 1.1% in MB and FB, respectively (FB n = 5, 5.8 ± 0.4%), after 24 wk of training (relative to pretraining) did not achieve statistical significance (training effect P = 0.09). Because there were no statistically significant differences in the absolute degree of improvement between the subject groups, data from all subjects were pooled. The pooled data demonstrated a significant improvement in flexor muscle CSA after 24 wk of training, but no changes were found after 12 wk of training. CSA in the biceps did not change in either subject group or when the data were pooled for either 12 or 24 wk of training. The ratio of flexor to biceps CSA was not significantly different between subject groups, and it was not altered by training (Table 3).

Flexor CSA/FFM. Because persons with a high FFM also have a large muscle CSA (7), flexor CSA/FFM was calculated to normalize for body FFM among subjects. This calculation demonstrated that muscle CSA was still significantly greater in MB than in other groups (Table 3). This relationship was, however, unaffected by the training program.

Isometric torque. Voluntary isometric torque was lower at an elbow angle of 70° than at either 90 or 120° in MB. This did not change over the course of the study. Differing the elbow angles did not significantly alter development of isometric torque in FB. Although there was test-to-test variability in the data, there were no significant changes in voluntary isometric torque over 24 wk of heavy resistance training in either subject group (Fig. 2).

Peak isokinetic torque. MB had significantly greater isokinetic torque at all velocities of contraction than FB. PT was greater at 120°/s than at contraction velocities of 150, 240, and 300°/s for MB subjects. PT at 60°/s exceeded the torque generated at all other velocities in both MB and FB at a given test period (Fig. 3).

Flexor PT/CSA. PT was strongly correlated to flexor CSA (pretraining R = 0.89, P < 0.001 and posttraining R = 0.90, P < 0.001). Thus subjects with large muscles were able to produce more torque than those with smaller muscles. In an attempt to normalize for torque, a measure of relative torque was calculated as flexor PT/flexor CSA. Isometric PT/CSA at an elbow angle of 90° averaged 2.9 ± 0.1 and 2.8 ± 0.1 in FB and MB groups, respectively, before and after 12 and 24 wk of resistance training. This ratio was also similar in MB and FB at all
TABLE 3. Flexor and biceps CSA

<table>
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<th>Subj No.</th>
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Mean ± SE: 31.6±3.8* 39.4±3.1* 27.9±4.1* 18.8±2.6* 23.2±2.5* 24.6±2.9* 1.3±0.1 1.5±0.1 1.4±0.1 0.37±0.03* 0.40±0.03* 0.46±0.04*

Mean ± SE: 21.3±0.8 20.9±0.9 21.0±1.0 14.4±1.4 14.1±1.4 14.2±1.4 1.5±0.1 1.5±0.1 1.5±0.1 0.41±0.07 0.40±0.07 0.40±0.07

Mean ± SE: 22.1±0.8 21.8±0.9 22.1±1.0 15.0±0.6 14.7±0.6 14.8±0.6 1.5±0.0 1.5±0.0 1.5±0.0 0.39±0.03 0.38±0.03 0.39±0.03

Mean ± SE: 19.5±1.5 19.3±1.5 19.8±1.5 14.5±1.7 14.8±1.4 1.3±0.1 1.4±0.1 0.38±0.05 0.39±0.04

Mean ± SE: 11.1±1.0 10.9±0.8 11.0±1.0 8.9±0.9 8.8±0.7 8.9±0.8 1.3±0.1 1.2±0.0 1.2±0.0 0.24±0.03 0.23±0.02 0.24±0.03

CSA, cross-sectional area; CT, computerized tomographic. For other abbreviations, see Table 1. *P < 0.05, MB vs. FB. † Data for 5 FB; no CT scans for 1 FB at 24 wk.

tested contraction velocities, but the ratio decreased parallel to the drop in torque (as a result of the force-velocity relationship).

Fiber type distribution. The percentage of type I and type II fibers did not differ among subject groups. Type II fibers averaged 62.1±2.6 and 58.0±2.9% in MB before and after training, respectively. The percentage of type II fibers in FB was 50.1±2.2 and 54.9±2.8% before and after training, respectively.

Nonmuscle tissue. The volume density of collagen and other noncontractile tissue was greater in females than in males and averaged 11.1±0.5 and 9.0±0.2%, respectively. Identical measures were obtained from the biopsy obtained before and after 24 wk of training. Because the percentage of nonmuscle tissue did not change during the duration of the study in MB and FB, correcting flexor or biceps CSA did not change the relative differences between subject groups.

FIG. 3. Voluntary isokinetic torque of elbow flexors before training and after 12 and 24 wk of heavy resistance training in 5 MB and 4 FB. Contraction velocities ranged between 60 and 300°/s. **P < 0.05, voluntary torque was less than torque generated at other elbow angles. Straight arm = elbow angle of 180°. Voluntary torque was greater in MB than FB at all elbow angles. Values are means ± SE.
Fiber area. $F_\alpha$ (corrected for fiber type distribution) averaged $10.51 \times 10^3 \mu m^2$ in MB and $5.33 \times 10^3 \mu m^2$ in FB (Table 4). This represented a significantly greater $F_\alpha$ in MB and was the result of increased areas in both type I and type II fibers.

Type I and type II fiber areas were 56 and 96% greater, respectively, in MB than the corresponding fiber areas of FB, pre- and posttraining. Type II-to-type I fiber area ratios were 1.5 and 1.1 in MB and FB, respectively ($P < 0.05$), before and after training.

Fiber area data plotted as a frequency distribution curve indicated that average type II fiber area reflected not only an organization of only larger fibers but also a wider distribution of type II fiber areas in MB (Fig. 4) relative to FB. One-way $\chi^2$ analysis of the type II fiber data indicated that MB and FB had a similar frequency of fibers $<0.5 \times 10^3 \mu m^2$ in area; however, MB had a significantly greater frequency of fibers between 0.5 and $2.0 \times 10^3 \mu m^2$ relative to FB (pretraining 4.1 vs. 3.8%, posttraining 2.1 vs. 3.0%, $P < 0.01$).

Average type I fiber area reflected a distribution of fibers larger in MB than in FB (Fig. 4). The frequency of type I fibers between 0.5 and $2.0 \times 10^3 \mu m^2$ was less in MB than in FB (pretraining 1.5 vs. 3.8%, postraining 2.1 vs. 4.3%; $P < 0.01$).

Fiber number. Estimated fiber number for MB was $227,829 \pm 36,637$ and $243,771 \pm 32,016$ pre- and posttraining, respectively. Fiber number for FB was estimated to be $239,208 \pm 19,637$ and $232,208 \pm 18,223$ pre- and postraining, respectively. The fluctuations in fiber number over the course of the 24-wk training period were not significant for either subject group. These small changes in estimated fiber number likely indicate the variability in the estimation procedure.
DISCUSSION

Muscle strength, muscle mass, and mean fiber size have been shown to be greater in highly competitive MB than in highly competitive FB (7, 8), and they are greater in resistance-trained males (6, 8, 14, 15, 18, 19) and resistance-trained females (7, 8, 25, 26) than in control subjects (22, 27). Nevertheless, the longitudinal effects of resistance training on muscle characteristics have not been studied extensively in females. To our knowledge, the current study is the first investigation of longitudinal effects of heavy resistance training on muscle fiber characteristics of highly competitive MB or FB.

Selective type II hypertrophy has been reported in some but not all muscles of males (4–7, 18, 22, 27). Selective type II hypertrophy has also been found after resistance training in the quadriceps muscles of women (25, 26). Nevertheless, our data indicate that FB did not obtain a selective type II hypertrophy by the 5th yr of training that preceded this study, nor was the relationship between type I and type II fibers altered by the training in this study. Type II-to-type I fiber area ratios were similar in FB and male and female controls, and these were significantly lower than that in MB before the training program in the current study. Because neither MB or FB altered their fiber characteristics with training, we were unable to establish whether preferential type II hypertrophy was possible in the biceps of women bodybuilders. Furthermore, we cannot rule out the possibility of a subject sampling error because there were only five FB examined in this study.

F₂ was greater in MB relative to other groups, but not all fibers were hypertrophied relative to FB. In this study we confirm our previous observations that MB have a greater frequency of fibers that are <2.0 × 10⁸ µm² relative to FB. This information is not readily apparent from F₂ data alone. Nevertheless, 24 wk of resistance training did not alter the frequency-area relationship in either athlete group, and it did not alter the frequency of small fibers. Although electron-microscopic examination of these small fibers has not been completed, light-microscopic examination of the tissue has failed to provide any evidence that suggests these are injured, atrophied, or denervated fibers. This is different from reports by Staron and colleagues (25), who observed apparently atrophic or denervated fibers in the quadriceps of women after a period of resistance training. These authors (25) suggested that the small and atrophic fibers found in their posttraining biopsy were from damage incurred during the pretraining biopsy procedure. If part of the small fiber population in our study were the result of fibers damaged by the previous biopsy, we would have expected a greater frequency of small fibers in all subject groups during the second biopsy. Although we did not find an increase in small fibers or any evidence of damage to the muscle fibers, we did find a large variation in fiber size both before and after training in our subjects. This emphasizes the importance of selecting enough fibers to obtain a representative sample of the data (7) and presenting fiber area as frequency histograms and not just as mean fiber size.

If part of the population of small fibers in our current study was the result of fiber proliferation, as is the case in an avian model of stretch-overload (3, 9, 17), then the lack of increase in these small fibers would indicate that fiber proliferation did not occur during the 24 wk of training. Furthermore, our estimates of total fiber number were not changed after training and therefore support this conclusion. Nevertheless, we recognize that our techniques may not have been sensitive enough to detect small changes in fiber number or new fiber formation. In support of this, Sjöström and colleagues (24) have recently suggested that while fiber proliferation probably occurs in human muscle, detection of new fibers from biopsy samples will be difficult because of the low frequency of this process. In addition, our techniques for estimating total fiber number from CT scans and needle biopsies might not be precise enough because the variability in estimates was large.

A small but significant increase in flexor (brachialis + biceps brachii) muscle CSA (~8%) was found after 24 wk of training. Such small improvements in muscle mass may be important to the overall muscle appearance of the bodybuilder, so these small changes should not be ignored. When CSA of biceps and brachialis muscles was determined independently, the relative increase in the brachialis was significant for both groups after 24 wk of training. It is therefore possible that the exercise protocol stressed the brachialis muscle to a greater extent than the training program that the bodybuilders had previously used. Because the brachialis inserts into the coracoid process of the ulna, it is equally efficient whether the wrist is pronated or supinated. In contrast, the biceps are most effective as an elbow flexor when the hand is supinated. It is therefore possible that the brachialis received more total work than the biceps brachii during the exercise program. An alternative explanation is that the biceps muscles may have received a greater amount of training before this study and therefore would have been closer to their peak potential for muscle mass than the brachialis.

It is worth noting that the small increases in muscle mass noted above did not contribute to an improvement in muscle strength as measured by the Cybex isokinetic dynamometer. However, isokinetic and isometric tests may not have been sensitive or specific enough to detect changes in muscle strength, because this type of strength testing differed from the free weight type of training that the subjects employed in the study. Although the bodybuilders increased the resistance of their 10 RM free-weight exercises by 10–15% over the 24 wk of the current study, their exercise biomechanics (e.g., elbow or shoulder position or swinging the weight slightly) were not rigidly controlled. A better assessment of strength could have been made if we had carefully controlled the cadence, arc, and movement pattern of the resistance and limb, hand position, and other biomechanical parameters during a free-weight one RM. However, because highly competitive bodybuilders do not train in such a rigid and consistent manner, we did not expect free-weight one RM strength to provide additional data pertaining to the athletes improvement in strength.
Nevertheless, because rigidly monitored one RM free-weight assessments of strength would closely parallel the free-weight exercise patterns in other athletes, such as weight lifters or power lifters, carefully controlled free-weight one RM assessments of strength can be considered as both accurate and valid measures of muscle strength for these and many other types of athletes (14, 15). Häkkinen and colleagues (14, 15) found an increase in dynamic strength and/or muscle CSA in highly competitive weight lifters when they used free-weight assessments to indicate an improvement in performance, rather than isokinetic or isometric tests. Because successful competitive weight lifting is judged on a consistent and specific lifting technique, it is likely that free-weight one RM assessments of strength are a good indicator for performance in those subjects. However, the primary goal for a bodybuilder of either sex is to achieve maximal muscle mass and minimal body fat, and in general one RM strength is not important. Therefore bodybuilders do not attempt to perform biomechanically strict training programs, as is the case in weight lifting. Rather, highly competitive bodybuilders will often alter the biomechanical movement between training sessions on the same exercises by changing hand, elbow, or arm position or by altering exercise cadence. It is therefore important to make a distinction between bodybuilders and weight lifters and, furthermore, it is not appropriate to combine bodybuilders and weight lifters or power lifters into a single group for analyses of longitudinal or cross-sectional training effects. Thus it is not clear that carefully controlled one RM strength assessments necessarily would have provided us with different results than isokinetic and/or isometric testing in the bodybuilders of this study. Nevertheless, it is possible that isokinetic and/or isometric testing underestimated training-induced changes in strength of the highly competitive bodybuilders. If this was the case, specific tension (torque/cm² of muscle) may have increased in MB and FB as a result of better recruitment of motor units (21), because there was no evidence for increases in fiber or muscle size.

The training program had little effect on fiber size or fiber number in either MH or FH. Thus it seems that after reaching a very high level of competition, these bodybuilders are only maintaining their existing muscle mass rather than adding to it. This observation is consistent with findings of highly competitive weight lifters, where muscle characteristics were relatively static when these athletes were examined over intervals of 1 and 2 yr (14, 15).

Although three males and two females used steroids during this study, there were large overlaps in the data of steroid vs. nonsteroid user in fiber number, fiber CSA, and muscle CSA, and the volume density of noncontractile tissue (i.e., steroid users did not consistently have the largest or smallest data points). However, the use of anabolic steroids did not further alter the muscle characteristics of these athletes over 24 wk of training.

The low number of subjects examined in this study resulted in part from an attempt to obtain bodybuilders that were state champions or better. We could have obtained a larger number of subjects if we had not chosen such a high caliber of athlete. We fully recognize the difficulties that are imposed on data interpretation from such few subjects in that very large changes would have had to occur before statistical significance was achieved. It is, however, important to recognize that we found very small changes in our subjects. In an attempt to determine the statistical power for fiber area and strength measures, we have estimated the number of subjects that would be necessary to obtain statistical significance with \( \alpha = 0.05 \) and \( \beta = 0.10 \). For these calculations we estimated variance in fiber area, muscle CSA, and muscle torque data from other studies using bodybuilders (1, 4, 8, 18, 19, 22, 28). Because the standard deviations in fiber area are greater in bodybuilders than nontrained subjects because of the existence of small as well as large fibers in bodybuilders (6-8) and because we found only small changes in fiber area pre- to posttraining, 30-50 subjects would have been necessary to obtain statistical significance in the current study. Stated differently, if 200 fibers had been examined in 20 subjects from each group, we would have needed a pre- to posttrained type I fiber change of 1.211.7 and 1.461.1 \( \mu \)m² in FB and MB, respectively, to obtain statistical significance. Similarly, if 200 type II fibers had been examined in 20 FB and 20 MB, we would have required pre- to postchange of 978.2 and 2369.4 \( \mu \)m² in FB and MB, respectively, to achieve statistical significance. Although less dramatic, 20 subjects in each group would have detected a change in biceps CSA of 2.9 cm² in MB and 1.5 cm² in FB. Twenty subjects in each group would have detected an isometric or isokinetic torque change of 22.5 N-m in MB and 18.9 N-m in FB groups. Because the actual changes in fiber areas, muscle CSA, and strength over 24 wk of training were far less than these estimated changes that would be needed if 20 subjects from each gender had been examined, it is likely that adding more subjects to our study would not have produced a different result. Nevertheless, we cannot discount the possibility that if the power of the statistical tests of significance had been higher, the outcome might have been different.

In summary, highly competitive MB and FB showed a lack of improvement in fiber size, fiber number, or muscle CSA over 24 wk of resistance training. This suggests that after reaching a highly competitive status, further improvements are minimal. Nevertheless, although small improvements in muscle structure and mass may be statistically insignificant, they may represent a physiologically important factor in determining success in highly competitive levels of bodybuilding competition for both genders.

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