Strength and skeletal muscle adaptations in heavy-resistance-trained women after detraining and retraining

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STARON, ROBERT S., MARK J. LEONARDI, DANIEL L. KARAPONDO, ERIC S. MALICKY, JEFFERY E. FALKEL, FREDRICK C. HAGERMAN, AND ROBERT S. HIKIDA. *Strength and skeletal muscle adaptations in heavy-resistance-trained women after detraining and retraining.* J. Appl. Physiol. 70(2): 631–640, 1991. —Six women who had participated in a previous 20-wk strength training study for the lower limb detrained for 30–32 wk and subsequently retrained for 6 wk. Seven untrained women also participated in the 6-wk "retraining" phase. In addition, four women from each group volunteered to continue training an additional 7 wk. The initial 20-wk training program caused an increase in maximal dynamic strength, hypertrophy of all three major fiber types, and a decrease in the percentage of type IIb fibers. Detraining had relatively little effect on fiber cross-sectional area but resulted in an increased percentage of type IIb fibers with a concomitant decrease in IIa fibers. Maximal dynamic strength decreased but not to pretraining levels. Retraining for 6 wk resulted in significant increases in the cross-sectional areas of both fast fiber types (IIa and IIab + IIb) compared with detraining values and a decrease in the percentage of type IIb fibers. The 7-wk extension accentuated these trends such that cross-sectional areas continued to increase (nonsignificant) and no IIb fibers could be found. Similar results were found for the nonpreviously trained women. These data suggest that rapid muscular adaptations occur as a result of strength training in previously trained as well as nonpreviously trained women. Some adaptations (fiber area and maximal dynamic strength) may be retained for long periods during detraining and may contribute to a rapid return to "competitive" form.

strength training; hypertrophy; fiber types; fast fiber conversions

NUMEROUS INVESTIGATIONS have described neuromuscular adaptations occurring as a result of resistance training in men (12, 29). Although there has been a dramatic increase in the number of women participating in strength and conditioning programs over the last decade, few investigations are available that document the adaptive responses of women to strength training. Resistance training is employed not only by female athletes to enhance performance but also by nonathletes who have incorporated resistance training into personal fitness programs.

Until recently, it had been assumed that women gain strength primarily from neural adaptations with minimal hypertrophy (18, 32). It now appears that women, like men, have the capacity to increase muscle fiber size and strength if the training intensity and duration are sufficient (1, 4, 27). As with men (15), women are capable of increasing the cross-sectional area of all three major fiber types (I, IIa, and IIb) with strength training (27). However, the fast-twitch fibers appear to be affected to the greatest extent in both men (10, 31) and women (1, 27). In addition, our laboratory has recently demonstrated that significant fast fiber type conversions (type IIb to type IIa) take place as a result of heavy-resistance training (27). These data support the hypothesis that the fast type IIb fibers are seldom recruited in normal daily activities and if recruited often enough (during a strength or endurance activity) they will transform into type IIa fibers (26). Conversely, strength detraining should cause an increase in the population of type IIb fibers at the expense of the IIa fibers.

Strength training-detraining studies are scarce and, with the exception of two case studies (25, 31), have been limited to relatively short detraining periods of 8–12 wk (after various periods of training). Detraining apparently causes a significant reversal of strength-induced neural (increased motor unit synchronization and activation) and muscular (hypertrophy, increased content of creatine phosphate and glycogen) adaptations (6, 7, 10, 14, 17), although not necessarily to pretraining levels. Little is known of the effects of long-term detraining on muscle strength and fiber area, and no study has addressed its effect on fiber composition.

Even less is known of the effects of retraining on skeletal muscle and strength adaptations. To our knowledge, no study utilizing muscle biopsies has been conducted on strength trained-detrained-retrained individuals. If neuromuscular adaptations are partially retained during detraining, differences could exist in the way previously trained individuals respond to retraining compared with untrained sedentary controls. Retrained muscle of previously trained individuals may undergo alterations in fiber type composition and size at a much earlier time than untrained muscle. Indeed, empirical observations suggest that strength-trained athletes experience a rapid return of strength and size after periods of inactivity. This phenomenon has been termed "muscle memory" in many popular muscle magazines.

The purpose of the present study was threefold: *1*) to investigate the effects of long-term detraining (30–32 wk) in strength-trained women, *2*) to investigate the effects of retraining on strength and muscle adaptations,

and *3*) to compare the effects of a short-term weight-training program on trained-detrained vs. nonpreviously trained women. An initial retraining period of 6 wk was chosen because strength gains occurring within that period of time are thought to be primarily the result of neural adaptations, with little effect on the muscle (14, 18). Longer periods of strength training result in increased adaptations within the muscle (increased cross-sectional area) (14, 18). Therefore, to further investigate this, the short-term retraining period was extended for an additional 7 wk.

METHODS

Subjects. Fifteen college-age women [8 previously trained (PT) and 7 nonpreviously trained (NP)] volunteered to participate. After approval from the Ohio University Institutional Review Board, all subjects were informed of the procedures, risks, and benefits and provided written consent before participation. Two PT women did not complete the study. The six PT women (age 21.4 ± 1.4 yr, height 1.61 ± 0.04 m) who completed the study were a subset of 24 women who had participated in a 20-wk resistance-training program (2 wk of orientation/preconditioning and 18 wk of high-intensity weight training) (27). Two of these women gave biopsies at the end of *week 18* (16 wk of high-intensity training).

After the conclusion of that investigation, the women returned to their normal daily activities. None of the women were involved in any regular exercise-training program (resistance or endurance) before the beginning of the present study. Therefore the detraining period was either 30 (n = 4) or 32 (n = 2) wk long. After 6 wk of retraining, four of the women volunteered to continue for an additional 7 wk when they returned to campus 4 wk later. The seven NP women (age 20.8 ± 1.0 yr, height 1.63 ± 0.04 m) had minimal or no weight-lifting experience and were not involved in any organized form of physical activity.

Throughout the period of this investigation, all subjects maintained a detailed training diary containing date, body weight, weights lifted, repetitions, sets, degree of lifting difficulty, and general impressions of each workout. Each subject underwent an extensive musculoskeletal and physical screening. Any subject who had a history of orthopedic or musculoskeletal complication was excluded from participation. During training, the subjects were closely supervised at all times.

Training protocol. After 30–32 wk of detraining for the PT group, both the NP and PT groups underwent a 1-wk orientation-preconditioning phase to ensure proper lifting techniques and to reduce the chance of injury and muscle soreness. The high-intensity retraining was divided into two phases: *1*) a short-term 6-wk program and *2*) after 4 wk of rest, an extension period of 7 wk. Four women from each group volunteered to participate in this extended portion of the study.

The training regimen consisted of three basic exercises (full squat, leg press, and leg extension) to induce increases in strength of the knee extensor muscles. A vertical leg press was used during the initial 20-wk study, whereas a leg press sled was used during the retraining phase. Resistance was based on the subjects' one repetition maximum (1 RM), which is the maximum amount of weight an individual can lift successfully one time for a particular exercise; whereas, for example, 6 RM is the maximum amount of weight an individual can lift successfully for six repetitions. For 1 RM determinations, the subjects performed warm-up sets (10 repetitions/set at 40 and 60%, 3 repetitions at 75%, and 1 repetition at 90% of the target 1 RM value) followed by an attempt at the target 1 RM determined for each exercise (20). The weight was increased for each subsequent set until failure. Maximal lifts for each exercise were determined twice during the acclimatization period to reduce the effect of learning, after 6 wk of high-intensity training, after the 4-wk rest, and at the end of the extension period. These were compared with 1 RM values obtained before and after the 20-wk training study.

Workouts took place twice per week (Monday and Friday). The rationale for an exercise frequency of 2 days/wk included that *1*) one body part trained twice per week is a typical workout schedule for bodybuilders and power lifters and *2*) our previous investigation (27) used this frequency with significant improvements in muscle strength and size. Monday workouts consisted of two warm-up sets (10 repetitions/set using ~40 and 60% of the 1 RM value) followed by three sets to failure of 6–8 RM (~80–85% of the 1 RM value) for each exercise. Friday workouts consisted of two warm-up sets (12 repetitions/set using ~40 and 60% of the 1 RM value) and three sets to failure of 10–12 RM (~70–75% of the 1 RM value) for each exercise. Progressive resistance training was employed; therefore the weights were continually adjusted to maintain the range of either 6–8 RM on Mondays or 10–12 RM on Fridays. Every workout began and ended with 10–15 min of flexibility and stretching exercises combined with calisthenics.

Anthropometric assessment. Body weight, skinfold thickness, and thigh girth were determined during the orientation-preconditioning period, after 6 wk of high-intensity training, and at the beginning and end of the extension period. Body weight measurements were also recorded before each workout. Percent body fat was approximated by skinfold anthropometry taken at three sites: triceps, suprailiac, and anterior thigh (11). Data are presented as skinfold thickness in millimeters (Table 1). Thigh girth was measured at three specific sites: 5 cm above the superior aspect of the patella, at the gluteal fold, and midway between these two sites. For the PT women, these data were compared with data collected during the initial 20-wk high-intensity training program (27).

Muscle biopsies. Muscle biopsies were performed on the vastus lateralis muscle by use of the percutaneous needle biopsy technique (2). Biopsies were taken from the same location and depth before the beginning of the orientation phase and at the conclusion of 6 wk of high-intensity training. An additional biopsy was obtained at the end of the 7-wk extension from those women who continued training. Muscle biopsies had also been obtained before and after the previous 20-wk training program (27). Therefore some of the women gave as many as five separate biopsies. To ensure adequate sample sizes

TABLE 1. *Anthropometric data*

	Weight, kg	Skinfold, mm	LBM, kg	Girth, cm		
				Knee	Midthigh	Gluteal
			PT women			
Pre-20	53.6±5.4	62.8±7.8	40.6±3.7	38.2±2.6	47.2±2.1	54.0±1.9
Post-20	54.6±5.0	52.5±7.1*	43.2±4.0*	38.8±1.9	47.4±2.1	53.8±2.1
Pre-6	54.1±5.3	51.5±6.9*	43.0±3.7*	38.2±1.9	49.4±4.7	53.2±3.3
Post-6	54.7±5.7	50.5±8.9*	44.2±3.7*	39.0±2.2	50.1±1.2	57.1±1.9†
			NP women			
Pre-6	55.5±5.5	49.1±8.6	44.3±3.6	38.0±2.8	47.1±3.3	53.5±3.4
Post-6	55.9±5.5	43.1±9.8‡	46.5±3.1‡	38.9±2.8	49.7±3.5‡	56.4±3.8‡

Values are means ± SD; n = 6 PT and 7 NP women. Skinfold, skinfold thickness summed from 3 sites (triceps, suprailiac, and anterior thigh); LBM, lean body mass; Pre- and Post-20, before and after 20-wk training program, respectively; Pre- and Post-6, before and after 6-wk training program, respectively. * Significantly different from respective Pre-20 value. † Significantly greater than respective Pre-20, Post-20, and Pre-6 values. ‡ Significantly different from respective Pre-6 value.

and to reduce methodological error, repeated biopsies were extracted at each time point from most subjects by a double-chop method (27). As a result, large sample sizes were obtained (Tables 2 and 3).

The vastus lateralis muscle was used because of its accessibility, mosaic fiber type composition, and trainability. In addition, this muscle was used in the previous weight-training study (27). A small piece of each muscle sample was taken and processed for electron microscopy. These data will be published elsewhere. The remainder of each muscle biopsy was oriented, immediately frozen in isopentane cooled by liquid nitrogen to −159°C, and stored at −70°C for subsequent analyses. Care was taken to ensure that the interval between removal of the muscle sample and freezing was between 2 and 4 min (13). All biopsies were identically treated.

Histochemistry. Muscle biopsy samples were thawed to −20°C and serially sectioned (12 μm thick). Routine myofibrillar adenosinetriphosphatase (ATPase) histochemical analysis was performed after preincubation at pH values of 4.3, 4.6, and 10.4 (3). A total of six fiber types were delineated (types I, Ic, IIc, IIa, IIab, and IIb) based on their staining intensities (28) (Fig. 1). The type I fibers were stable in the acid ranges but labile at pH 10.4. Type IIa fibers displayed a reverse pattern. All fibers that were stable at pH 10.4 and 4.6 but labile at pH 4.3 were classified as either type IIb or type IIab, depending on their staining intensities (type IIab stain intermediate between fiber types IIa and IIb at pH 4.6). Fibers that were classified as types Ic and IIc remained stable, to varying degrees, throughout this entire pH range. The type Ic fibers were indistinguishable from the type I fibers after the acid preincubation, and the type IIc fibers were indistinguishable from type II fibers after alkaline preincubation (28). To evaluate the possible occurrence of subtle fiber type conversions, cross sections of pre- and postbiopsies from the same individual were placed on the same glass coverslip and assayed together for myofibrillar ATPase activity (Fig. 2). All biopsies were thoroughly examined for evidence of damage (degeneration/regeneration) by use of serial sections for myofibrillar ATPase activity and/or stained for hematoxylin and eosin.

A composite photomontage of each preparation (preincubation pH 4.6) was made by use of Polaroid micrographs (×56 magnification) and used in combination with the histochemical preparations to determine the fiber type percents and total fiber number in each biopsy. The cross-sectional areas of 100 fibers per major fiber type (I, IIa, and IIab + IIb) per biopsy were measured by use of direct tracings (×200 magnification) and a digitizing tablet. These data were compared with data collected during the 20-wk high-intensity training program (27). With the exception of two muscle samples, atrophic fibers comprised a minor portion of the posttraining biopsies and were excluded from measurement.

Statistical analyses. The statistical package for the biomedical sciences (BMDP) was utilized for all statistical analyses. Descriptive statistics were used to derive means ± SD for all variables. A repeated-measures one-way analysis of variance was used for the anthropometric and strength data. A repeated-measures two-way analysis of variance with two within factors (time and fiber type) was used to analyze muscle fiber composition and cross-sectional area. Because of insufficient numbers of the type IIab and IIb fibers in three individuals (1 PT and 2 NP women) after 6 wk of training, the mean cross-sectional areas for this fiber group were derived from n = 5.

TABLE 2. *Muscle fiber type percentages for PT women*

	Type I	Type Ic	Type IIc	Type IIa	Type IIab	Type IIb	n
Pre-20	44.5±6.1	0.6±0.9	0.3±0.7	33.2±8.3	5.3±2.6	16.1±8.2	2,680±1,206
Post-20	49.9±6.0	1.3±1.2	2.1±2.1	39.2±8.4	6.6±4.5	0.9±1.0*	1,995±504
Pre-6	45.6±8.0	1.2±2.1	0.9±0.8	22.7±7.9†	5.4±2.8	24.2±7.9†	2,096±898
Post-6	49.3±13.1	0.6±0.5	5.0±5.2	26.7±8.2†	5.5±4.7	12.9±10.5†‡	1,398±444

Values are means ± SD of 6 PT women in %; n, no. of muscle fibers. Pre-6 values were taken after 30–32 wk of detraining. See Table 1 footnote for abbreviations. * Significantly different from Pre-20. † Significantly different from Post-20. ‡ Significantly different from Pre-6.

TABLE 3. *Muscle fiber type percentages for NP women*

	Type I	Type Ic	Type IIc	Type IIa	Type IIab	Type IIb	*n*
				6-Wk program NP women			
Pre-6	37.5±13.4	2.5±4.8	0.9±2.4	26.4±5.8	7.8±3.7	24.9±8.2	1,879±977
Post-6	50.5±9.3*	0.9±0.7	3.0±4.7	32.7±6.4	6.2±5.2	6.7±7.2*	1,975±725
				6-Wk program + 7-wk extension NP women			
Pre-6	39.1±17.6	0.2±0.2	0.1±0.1	26.5±7.6	6.8±4.4	27.3±9.9	1,796±924
Post-6	54.2±9.7*	0.8±0.9	4.1±6.3	31.1±2.8*	5.5±6.6	4.3±6.5*	2,091±784
Post-ext	47.2±8.2	1.0±0.7	1.1±1.5	47.6±8.8*†	3.1±4.0	0.0±0.0*	1,602±824

Values are means ± SD of 7 NP women in 6-wk program and 4 NP women in 6-wk program + 7-wk extension in %; *n*, no. of muscle fibers. Post-ext, values obtained after 7-wk extension. See Table 1 footnote for abbreviations. * Significantly different from respective Pre-6 value. † Significantly different from respective Post-6 value.

Significant differences between the means were determined by Tukey's post hoc test. Differences were considered significant at $P < 0.05$.

RESULTS

The 20-wk strength-training program resulted in a significant decrease in skinfold thickness with a concomitant increase in lean body mass (Table 1). For the PT women, no significant changes were detected in skinfold thickness or lean body mass after detraining or retraining compared with posttraining, with each value remaining significantly different from the respective pretraining value (Table 1). Total body weight remained stable throughout the study. Skinfold thickness for the NP women decreased and lean body mass increased ($P < 0.05$) after the 6-wk training program with no change in total body weight (Table 1). The gluteal fold measurement significantly increased after 6 wk of retraining for the PT women compared with the initial pretraining value (before the 20-wk program, Table 1). For the NP women, both gluteal fold and midthigh values increased ($P < 0.05$) after 6 wk of training (Table 1).

Improvements in dynamic strength for the 24 women who completed the initial 20-wk training program have been previously reported (27). To appreciate the time course for strength changes in the six women who detrained and retrained for this investigation, data accumulated during the 20-wk program from these six women are included here (Fig. 3). The 20-wk training response was the same in pattern and amount for these 6 women as for all 24 women. The 20-wk training program caused significant increases in the 1 RM values of all three exercises (67% for the squat, 148% for the leg press, and 70% for the leg extension, Fig. 3), and these increases were paralleled by increases in the training weights.

After detraining for 30–32 wk, significant decreases were found for the leg press (32%) and extension (29%) but not for the squat (13%). All detraining values were still significantly greater than pretraining values (Fig. 3). Retraining for 6 wk resulted in 1 RM values similar to those obtained at the conclusion of the 20-wk training program. For the four women who continued training, the 4-wk break between the 6-wk training and the 7-wk extension caused slight (nonsignificant) decreases in the leg press (7%) and leg extension (19%) and a significant decrease in the squat (11%). Retraining for an additional 7 wk resulted in significant increases in the squat (40%) and leg extension (28%) and a nonsignificant increase in the leg press (33%) compared with the preextension values.

Similar trends were found for the NP women (Fig. 3). After 6 wk of training, maximal dynamic strength increased ($P < 0.05$) for all three exercises: squat (40%), leg press (39%), and leg extension (40%). After 4 wk of rest, 1 RM values decreased nonsignificantly for the squat (5%) and leg press (1%) and significantly for the leg extension (15%). Seven additional weeks of training caused increases ($P < 0.05$) in all three exercises (squat 43%, leg press 37%, and leg extension 44%) compared with values obtained before the 7-wk extension.

After 20 wk of strength training, a significant decrease was found in the percentage of type IIb fibers (Table 2) with a nonsignificant increase in type IIa fibers. Conversely, detraining caused a significant increase in type IIb fibers with a concomitant decrease ($P < 0.05$) in the percentage of type IIa fibers. After 6 wk of retraining, the type IIb population decreased ($P < 0.05$) and the type IIa population increased (nonsignificant; Table 2, Fig. 2). No significant changes were found for any of the other fiber types. After an additional 7 wk of retraining, no type IIb fibers and only a small percentage (0.09 ± 0.06%) of type IIab fibers could be found.

The overall changes found for the NP women were similar to those for the PT women (Table 3). Six weeks of training resulted in a significant decrease in the percentage of type IIb fibers with a nonsignificant increase in the percentage of type IIa fibers. After another 7 wk of strength training, the percentage of type IIa fibers continued to increase ($P < 0.05$), and no fibers classified as type IIb could be found (Table 3, Fig. 2). In addition, the percentage of type I fibers, which had significantly increased after 6 wk of training, nonsignificantly decreased after the extended training period (Table 3).

Significant hypertrophy of all three major fiber types (types I, IIa, and IIab + IIb) occurred after the 20-wk training program (Fig. 4). Type IIab + IIb fiber area increased the greatest amount (46.5%), followed by type IIa (38.9%) and type I (16.5%). Detraining caused a significant decrease in the type IIab + IIb fiber area (14.2%) and nonsignificant decreases in the areas of type IIa (9.8%) and type I (1.4%) fibers. The mean area of all three fiber types remained significantly greater than their respective pretraining values (Fig. 4). Retraining caused significant increases in the cross-sectional areas

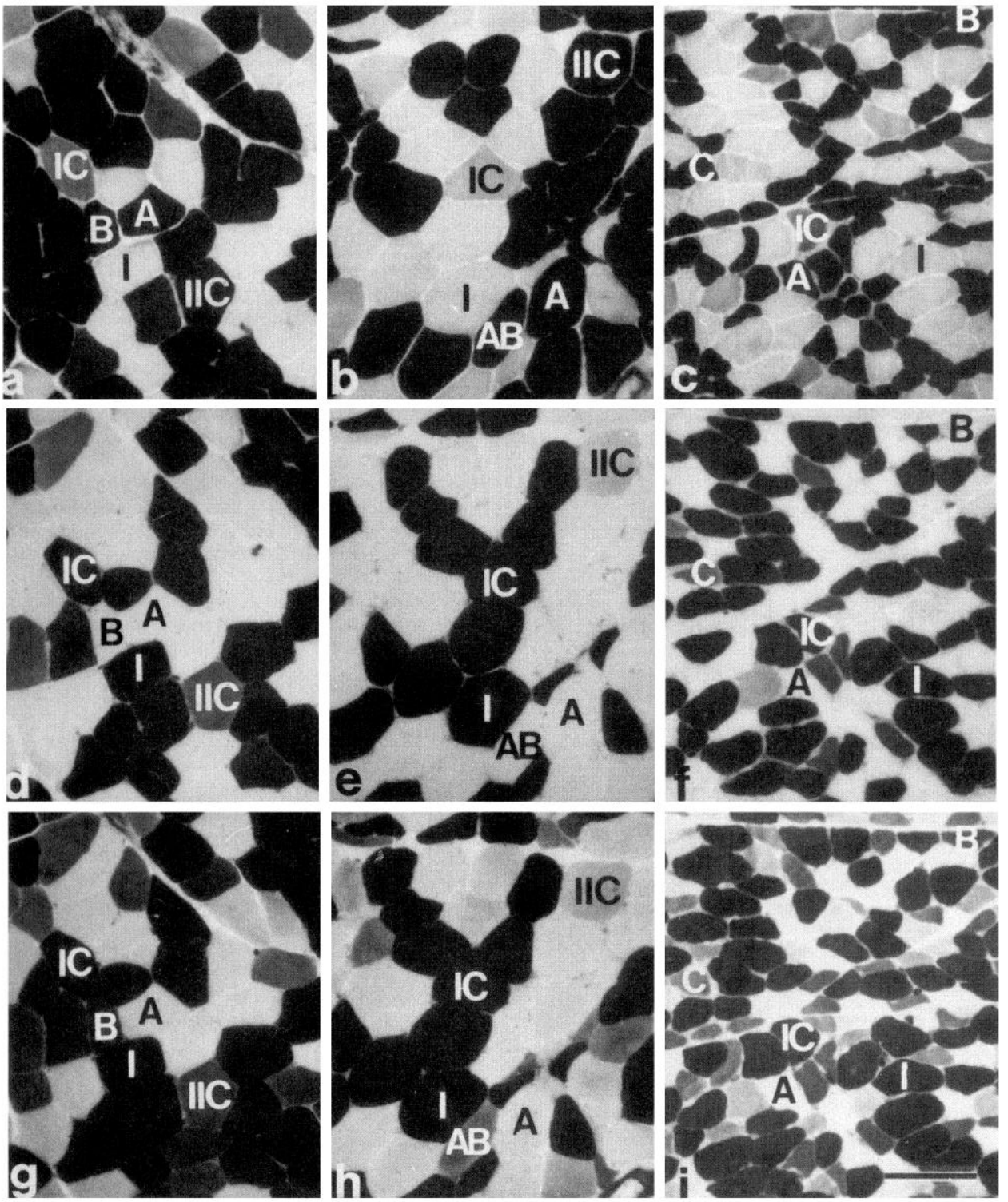


FIG. 1. Serial cross sections of muscle samples taken from 1 subject before (*a*, *d*, and *g*) and after 6 wk of training (*b*, *c*, *e*, *f*, *h*, and *i*). Sections were assayed for myofibrillar ATPase activity after preincubation at pH 10.4 (*a–c*), 4.3 (*d–f*), and 4.6 (*g–i*). *b*, *e*, and *h* were from 1 part and *c*, *f*, and *i* from another part of the same biopsy after 6 wk of training. Atrophic fibers are present in both regions. *c*, *f*, and *i* are from an area with large group atrophy (>1,000 fibers). I, type I; IC, type Ic; IIC, type IIc; A, type IIa; AB, type IIab; B, type IIb. Bar, 100 μm.

of types IIa (18%) and IIab + IIb (30%) compared with the respective detraining values, whereas the type I fiber area remained similar to the posttraining and detraining values with an increase of only 3.7%. For the PT women who continued training for an additional 7 wk, nonsignificant increases in fiber area were found for type I (5.3%) and type IIa (16.5%) with insufficient numbers of type IIab + IIb to determine a mean value.

Similarly, the mean cross-sectional areas of all three major fiber types significantly increased after 6 wk of strength training for the NP women: type I 15.6%, type IIa 17.3%, and type IIab + IIb 28.1% (Fig. 4). Seven addi-

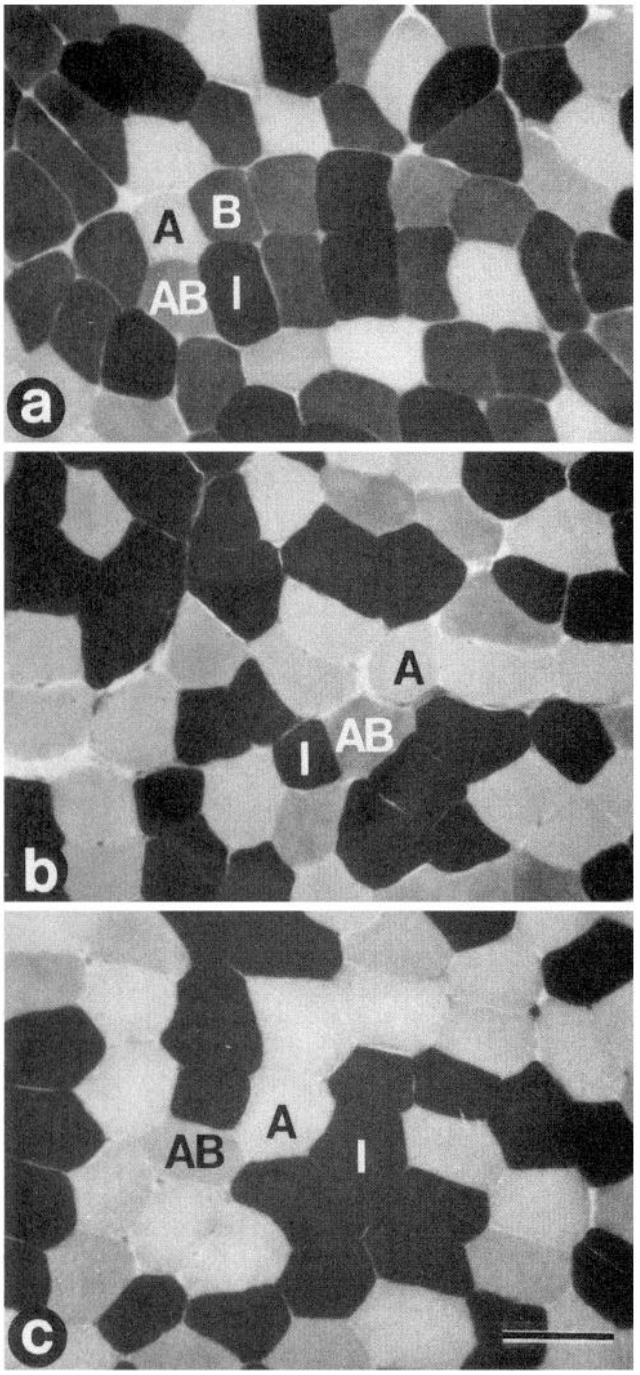


FIG. 2. Cross sections of muscle samples taken from 1 subject and assayed simultaneously for myofibrillar ATPase activity (preincubation pH 4.6) before (*a*) and after 6 wk of training (*b*) and after 7 wk of additional training (*c*). Note disappearance of fibers classified as type IIb. See legend of Fig. 1 for definitions. Bar, 100 μm.

tional weeks of training resulted in nonsignificant increases in the cross-sectional areas of type I (7.8%) and type IIa (29.9%) fibers, with insufficient numbers of type IIab + IIb fibers to determine a mean value.

The hierarchy of mean fiber areas was also affected by training. Before the 20-wk training program, the fiber areas of all three groups (types I, IIa, and IIab + IIb) were significantly different from each other. Type I fibers were the largest, followed by type IIa, and the smallest were type IIab + IIb. Posttraining and after 30–32 wk of detraining, the fiber areas for type I and type IIa were similar and significantly larger than type IIab + IIb. After retraining, the cross-sectional areas of all three fiber groups were similar. For the NP women, the cross-sectional areas of types I and IIa were significantly larger than that of type IIab + IIb before training. After 6 wk of strength training, the mean cross-sectional areas were similar for all three fiber groups.

Of the 13 biopsies obtained after 6 wk of training, 8 (3 PT and 5 NP women) contained varying amounts of degeneration-regeneration. Although most of the affected fibers comprised an extremely small portion of the biopsy (small group atrophy, Fig. 5), two biopsies from the NP women contained regions of >1,000 atrophic fibers (Fig. 1, *c*, *f*, and *i*). Most atrophic fibers were scattered within the biopsy, very irregular in shape, and not specific for any fiber type (Fig. 5). The fast fiber types appeared to be more affected than the slow type I fibers. The mean cross-sectional areas of 100 fibers per type measured in one area of large group atrophy were 1,905 ± 718 (SD) μm^2 for type I fibers, 1,060 ± 458 μm^2 for type IIa fibers, and 832 ± 300 μm^2 for type IIb fibers. Cross-sectional areas from a normal region of this same biopsy were 4,099 ± 964 μm^2 for type I fibers, 3,974 ± 1,104 μm^2 for type IIa fibers, and 2,968 ± 753 μm^2 for type IIb fibers. Pretraining biopsies and biopsies from the women who continued training an additional 7 wk were thoroughly searched and contained no abnormal fibers.

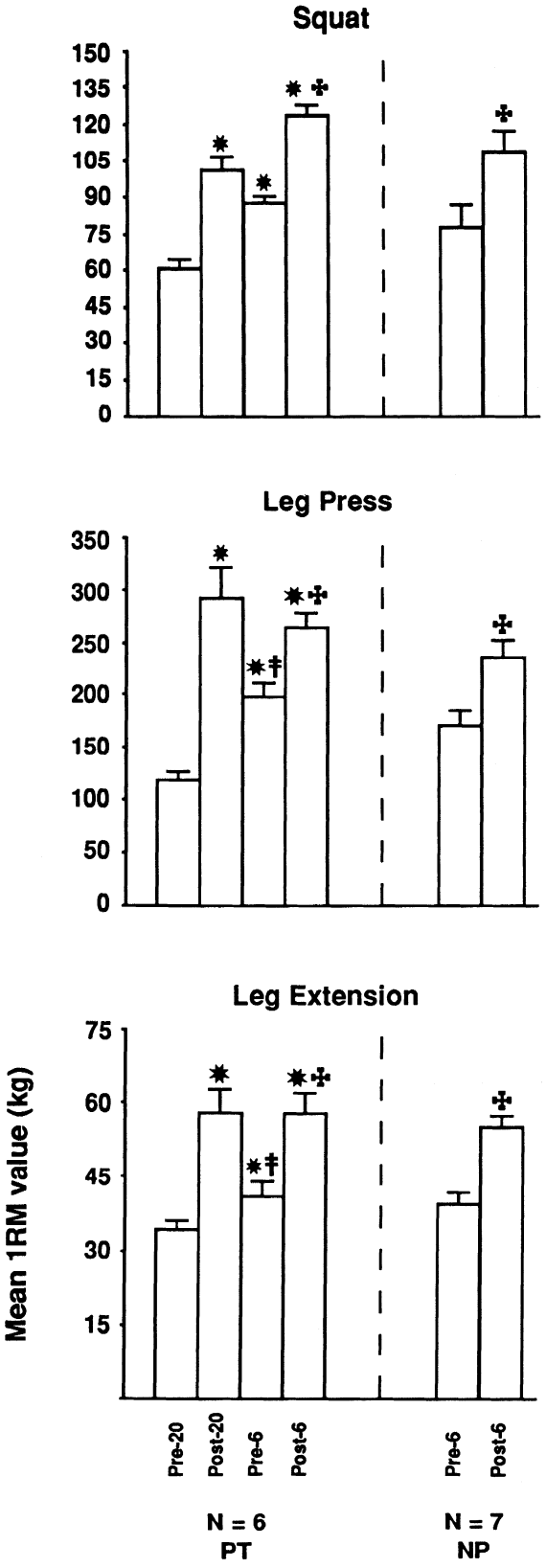
DISCUSSION

It is well documented that high-intensity resistance training will result in significant improvement in muscle strength as well as increased muscle mass. Although most prior studies have reported these findings utilizing male subjects, recent investigations suggest that women have a capacity similar to that of men for strength and size gains (4). In a recent study from our laboratory (27), we found significant hypertrophy of all major fiber types, improvement in dynamic muscle strength, and fast-twitch subtype conversions in female muscle after 20 wk of high-intensity resistance training. These data support the hypothesis that strength-trained muscle in women has the capability of considerable hypertrophy if sufficiently stressed.

Strength training followed by periods of reduced training or immobilization has been studied by only a few research groups. Detraining is a common occurrence in all aspects of athletics and sport. There are many reasons for an athlete to stop training for a period of time: the end of a competitive season, fatigue, injury rehabilitation, decreased motivation, and so on. Muscular strength and size, which increase as a result of resistance training, decrease during periods of detraining (up to 12 wk) but apparently not to pretraining levels. With the exception of two case studies (25, 31), most investigations have used relatively short detraining periods (5–12 wk).

Men who strength trained for 5–6 mo significantly increased their girth, maximal strength, fast- and slow-twitch fiber areas, and content of creatine phosphate and glycogen (15, 17). Immobilization for 5 wk caused significant decreases in all these parameters. Likewise, men

who strength trained for 10 (10), 16 (7), and 24 wk (6) experienced increases in maximal isometric strength, neural activation, and hypertrophy of the fast-twitch fibers. Detraining for periods of 8–12 wk resulted in decreases in these parameters. In lieu of our previous finding of fiber-type conversions during high-intensity resistance training (27), it was of interest to determine the effect of long-term detraining (30–32 wk) on muscle fiber type composition and strength.



It was not known what effect long-term detraining periods would have on muscle strength and size or to what extent neural and/or hypertrophic adaptations might be retained. The phenomenon of muscle memory implies that some aspect of training (e.g., increased neural activation and/or muscle hypertrophy) remains. Indeed, the present investigation indicates a significant retention of maximal strength capacity after a long period of inactivity. Although we do not know how much of this dynamic strength was the result of retained neural and/or muscular adaptations, the cross-sectional area of the previously trained women's muscle fibers in the present study did not decrease to pretraining values after 30–32 wk of detraining (Fig. 3). This, combined with the possible retention of neural adaptations (acquisition of a skill), may explain why maximal dynamic strength was still greater after long-term detraining compared with pretraining values (Fig. 3). However, it is interesting that the fiber type composition had returned to the pretraining distribution during this time (Table 2).

Very few studies have examined the effects of retraining after a period of inactivity (9, 19, 24), and all these investigations assessed the effects of retraining on cardiovascular and muscular endurance. To our knowledge, no study has specifically evaluated the effects of strength training-detraining followed by a period of retraining. These present data suggest a retention effect such that the previously trained women were able to increase their maximal strength in each exercise to trained levels in a relatively short time period. These data support empirical observations that suggest that strength-trained individuals who have detrained are able to return to competitive form relatively quickly. The term "muscle memory" (as applied to strength training) may then reflect the combination of a retention of neural and muscular adaptations in previously trained individuals.

Similar to our previous findings (27), significant fast fiber type conversions took place as a result of the high-intensity weight lifting. These transformations amounted to a conversion of type IIb fibers to type IIa and were consistent for all the women. This became a more obvious adaptation in the muscles of the women who had volunteered to continue training the additional 7 wk. After this extension period, no fibers classified as type IIb and very few as type IIab could be found (Figs. 1 and 2). Because the type IIa fibers (as a group) are more oxidative than the type IIb fibers in human muscle, a decrease in the percentage of type IIb and an increase in the percentage of type IIa fibers may suggest an increase

FIG. 3. Maximal dynamic strength measurements (1 RM values) for squat, leg press, and leg extension. Pre-20 and Post-20, before and after 20-wk training, respectively; Pre-6 and Post-6, before and after 6-wk training, respectively. Pre-6 values for PT women were taken after 30–32 wk of detraining. Regression analysis was used to determine missing data points for 1 RM values for 2 women at Post-20. A vertical leg press apparatus was used for Pre-20 and Post-20 measurements, and a leg press sled was used for Pre-6 and Post-6 measurements. *Significantly greater than Pre-20 values. †Significantly greater than Pre-6 values. ‡Significantly smaller than Post-20 values.

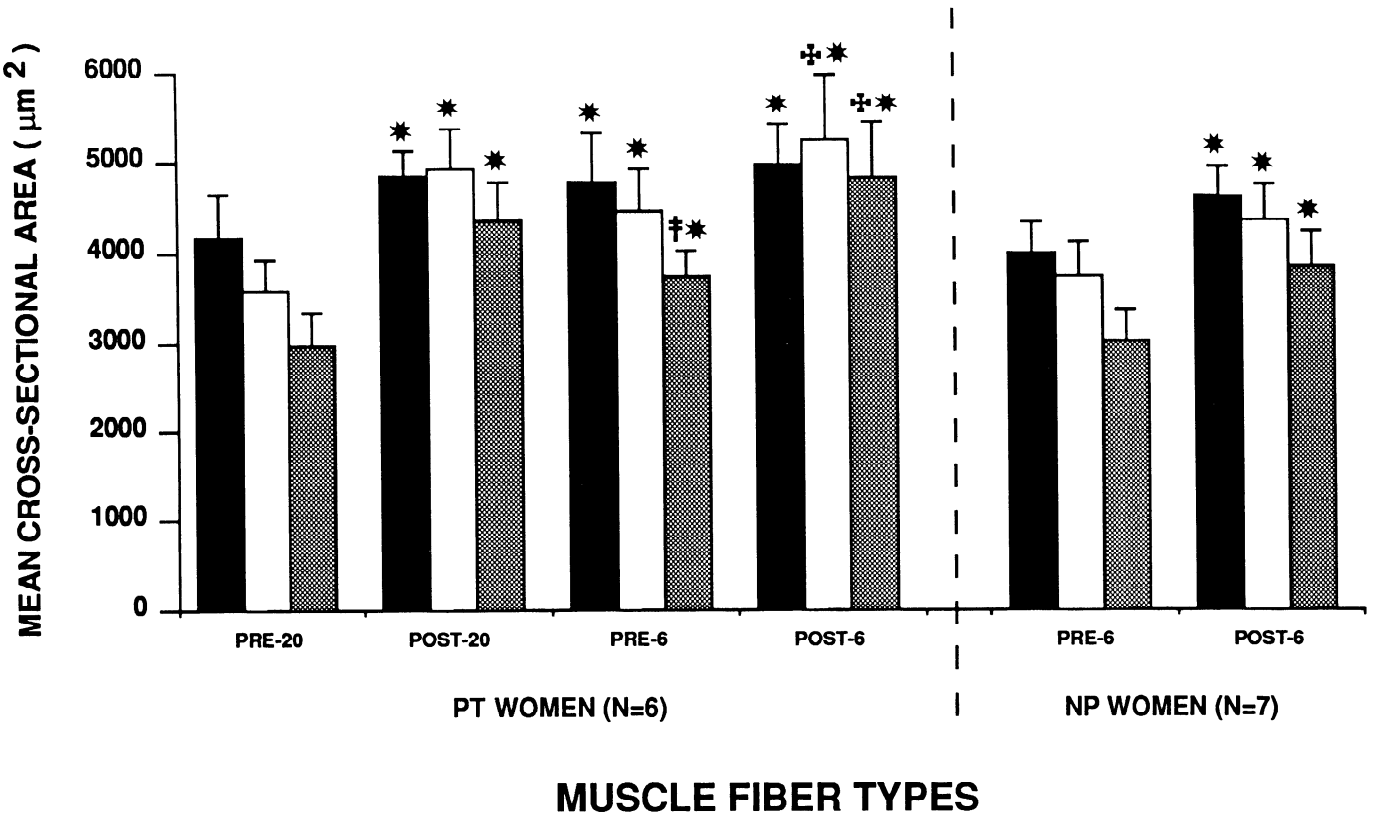


FIG. 4. Mean cross-sectional areas + SE for major fiber types. See legend of Fig. 3 for definitions. *Significantly greater than respective Pre-20 values for PT women and Pre-6 values for NP women. †Significantly greater than respective Pre-6 (detrain) values. ‡Significantly smaller than respective Post-20 value. [Three subjects (1 PT and 2 NP women) did not have sufficient type IIab + IIb fibers after 6 wk of training (Post-6), and mean areas were derived from $n = 5$.] ■, Type I; □, type IIa; ▨, type IIab + IIb.

in the oxidative capacity of the strength-trained muscle (J.-A. Simoneau and R. S. Staron, unpublished observations). In support of this, Frontera et al. (5) recently found a significant increase in capillaries per fiber and citrate synthase activity in the vastus lateralis muscle of strength-trained older men. Such an adaptation in strength-trained muscle may depend on the pretraining status of the subjects and/or the type of strength training program (30). Interestingly, these fast fiber type conversions appear to occur at a different rate than alterations in fiber cross-sectional area. The time courses of these are currently being investigated.

The inconsistent changes in the percentages of type I fibers observed in the present investigation cannot be easily explained. The percentage of type I fibers for the NP women increased after 6 wk of training but decreased after another 7 wk of training. Because no control group was used, other factors (small sample size, intraindividual variation, and others) may possibly have contributed to some of the observed fiber composition changes. Indeed, large intraindividual variations for the percentage of type I fibers were evident in some subjects (1 NP woman had 17% type I fibers during acclimatization, 52% after 6 wk of training, and 37% at the end of the extension period). Nevertheless, an increase in the percentage of slow (type I) fibers has recently been reported for strength-trained individuals (23).

A large percentage of the muscle biopsies obtained after the 6-wk training program contained evidence of damage (Figs. 1 and 5). Similar signs of degeneration-regeneration were reported after training in our previous weight-lifting study (27). The exact cause of this damage is not known. We have not observed this phenomenon in our other studies incorporating various types of training and muscle biopsies. Although all postbiopsies were in proximity to the prebiopsies, it is assumed that the injured region from the initial biopsy would have healed before the second biopsy. In support of this, no atrophic fibers were found in the detraining biopsies. However, little is known of the events that take place after a muscle biopsy. Lack of degeneration in the postbiopsies may simply be the result of sampling from nontraumatized areas. Indeed, a current investigation in our laboratory has documented muscle damage in successive biopsies from control as well as trained individuals (R. S. Staron, unpublished observations). However, it is possible that the high-intensity weight training may have caused additional fiber damage and/or delayed regeneration in the traumatized areas where the biopsies were extracted. Recent evidence suggests that weight training may cause skeletal muscle damage in humans (8, 21, 22), and atrophic fibers have been reported in bodybuilders and power lifters (16).

Because the atrophic fibers were excluded from cross-sectional area measurements, it may be argued that there was an overestimation of the hypertrophic response. With the exception of two posttraining biopsies, atrophic fibers comprised a very minor portion of the entire

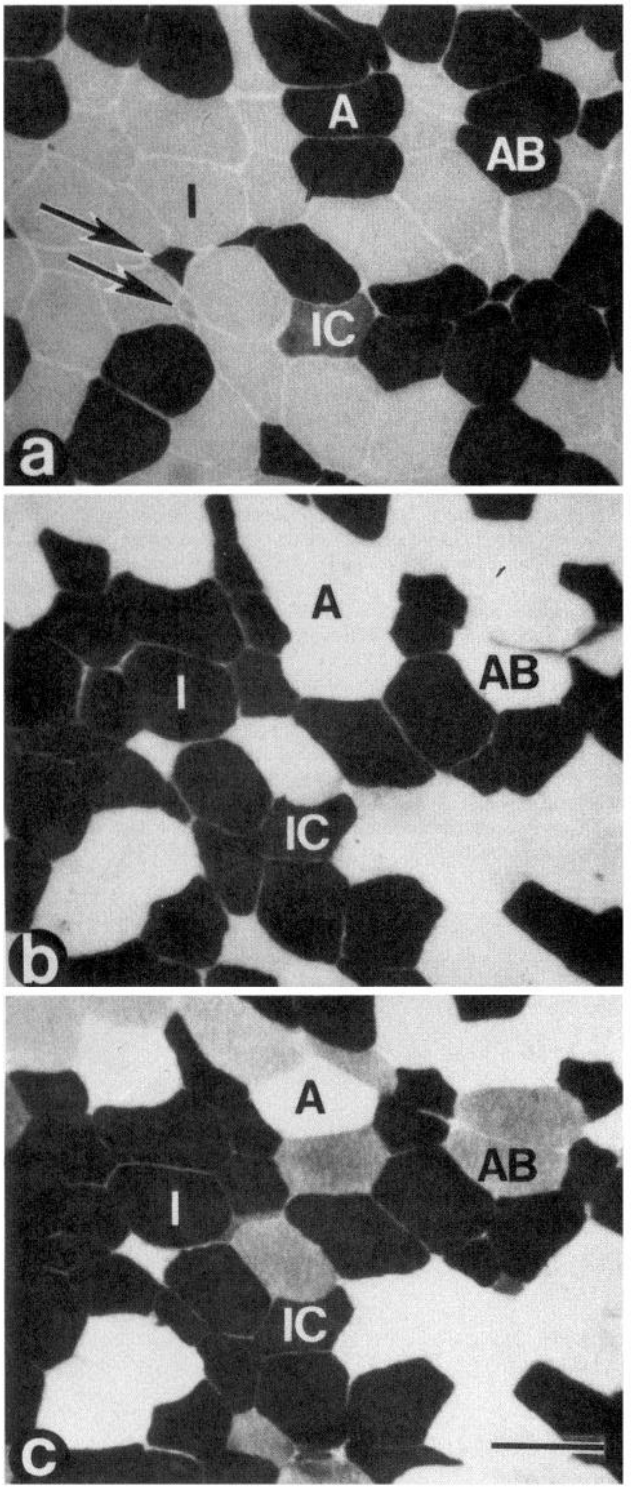


FIG. 5. Cross sections of muscle samples taken from 1 subject after 6 wk of training and assayed for myofibrillar ATPase activity after preincubation at pH 10.4 (*a*), 4.3 (*b*), and 4.6 (*c*). Note appearance and distribution of atrophic fibers (arrows). Such fibers were characteristic of those found scattered in 6 of the 13 posttraining biopsies. See legend of Fig. 1 for definitions. Bar, 100 μm.

biopsy (Fig. 5). In addition, biopsies from the 7-wk extension contained no evidence of damage. Conversely, it may be argued that, because of initial significant differences in the cross-sectional areas of type IIa and type IIab + IIb (type IIa being significantly larger) and subsequent fiber type conversions (type IIb to type IIa), there was an underestimation of the hypertrophic response.

In conclusion, women are capable of considerable improvements in strength and specific muscular adaptations after a high-intensity resistance-training program. These adaptations can occur after only 6 wk of training (as few as 12 training sessions) and include significant increases in maximal dynamic strength and fiber cross-sectional area as well as specific fast fiber type conversions (type IIb to type IIa). Detraining for 30–32 wk causes fast fiber type conversions in the reverse direction (type IIa to type IIb) with significant retention of maximal dynamic strength and fiber cross-sectional area compared with pretraining values. Retraining for short periods (6 wk) elicits a rapid return to the trained state with significant alterations in fiber composition.

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