BRIEF REVIEW

The Effects of Endurance, Strength, and Power Training on Muscle Fiber Type Shifting

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Abstract

Wilson, JM, Loenneke, JP, Jo, E, Wilson, GJ, Zourdos, MC, and Kim, J.-S. The effects of endurance, strength, and power training on muscle fiber type shifting. *J Strength Cond Res* 26(6): 1724–1729, 2012—Muscle fibers are generally fractionated into type I, IIA, and IIX fibers. Type I fibers specialize in long duration contractile activities and are found in abundance in elite endurance athletes. Conversely type IIA and IIX fibers facilitate short-duration anaerobic activities and are proportionally higher in elite strength and power athletes. A central area of interest concerns the capacity of training to increase or decrease fiber types to enhance high-performance activities. Although interconversions between type IIA and IIX are well recognized in the literature, there are conflicting studies regarding the capacity of type I and II fibers to interconvert. Therefore, the purpose of this article is to analyze the effects of various forms of exercise on type I and type II interconversions. Possible variables that may increase type II fibers and decrease type I fibers are discussed, and these include high velocity isokinetic contractions; ballistic movements such as bench press throws and sprints. Conversely, a shift from type II to type I fibers may occur under longer duration, higher volume endurance type events. Special care is taken to provide practical applications for both the scientist and the athlete.

Key Words fast twitch muscle, slow twitch muscle, fast oxidative fibers, slow oxidative fibers, specificity

Introduction

A myriad of experimental research has centered on the role that skeletal muscle fiber makeup plays in determining performance (1,9,16,17,47), and results of the research collected from our group have clearly demonstrated the ability of skeletal muscle to undergo cellular changes in response to resistance exercise (7,27–29,33,36). Muscle fibers are generally fractionated into slow twitch I (slow-oxidative), fast twitch IIA (fast-oxidative glycolytic), and fast twitch IIX (fast glycolytic) types. Several studies have analyzed muscle fiber types of elite athletes across various sports (1,9,49). In a classic study, Costill et al. (13) found that untrained individuals had a 50/50 ratio of fast (type IIA and IIX) to slow twitch (type I) fibers. However, in the athletic population, long and middle distance runners had 60–70% slow twitch fibers, whereas sprinters demonstrated an 80% fast twitch fiber makeup. Moreover, elite weight and power lifters have been found to have a significantly greater fast twitch fiber makeup (60%) than endurance athletes (40%) have (49). Other studies have indicated that athletes in sports requiring the greatest aerobic and endurance capacities have slow twitch fiber percentages as high as 90–95%, whereas athletes in sports requiring greater anaerobic capacities, strength, and power (e.g., weight lifting and sprinting) have fast twitch fibers ranging from 60 to 80% (1,9,17).

By examining the attributes of different fiber types, it becomes evident as to why there is such variation in their distribution among groups of athletes. To illustrate, type I fibers have been observed to have both greater mitochondria volume densities and capillary-fiber contact length when compared with those of type II fibers (45). In addition, mitochondria volume density was highly correlated ($r = 0.99$) with O_2 diffusion coefficients across 3 different muscle groups (retractor, sartorius, and soleus) suggesting greater aerobic capacity in type I fibers (45). More recent data from single fiber studies demonstrate that type IIX and IIA fibers have 10 and 6 times greater peak power, respectively, than type I fibers do (49). Moreover, type IIX and IIA fibers have demonstrated 4.4 and 3 times greater contractile

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velocity than type I fibers have demonstrated, respectively (32). Although no differences were found in specific force (force/cross sectional area [CSA]), absolute force was greater in type II fibers because of a 39 and 26% greater CSA in IIX and IIA than in type I fibers, respectively (32). Type II fibers have a greater capacity for exercise-induced hypertrophy (26,40) and hydrolyze adenosine triphosphate (ATP) 2–3 times faster than type I fibers do (46). Finally, isolated single fibers belonging to the same type demonstrate identical contractile properties regardless of their muscle group origin (46).

The contribution of slow twitch muscle fibers to endurance performance was investigated by Bergh et al. (9) who found a direct relationship between $\dot{V}O_2max$ and the percentage of slow twitch fibers ($r = 0.67$) in 53 weightlifters and endurance athletes. Moreover, a positive relationship has been demonstrated ($r = 0.52$–0.55) between slow twitch fiber composition in well-trained runners and performance in 1-, 2-, and 6-mile runs (16). In anaerobic activities, strong correlations are present between the percent of IIA fibers and 1 repetition maximum (1RM) snatch performance ($r = 0.94$), static vertical jump height ($r = 0.79$) and power ($r = 0.75$), and countermovement vertical jump power ($r = 0.83$) in national caliber Olympic weightlifters (17). Similarly, research studies have demonstrated moderate ($r = 0.61$) to high correlations ($r = 0.93$) between myosin heavy chain (MHC) II percentage in the quadriceps muscle and knee extension strength at medium and high velocities, respectively (1). In addition, relationships exist between type II fiber distribution in the triceps brachii muscle with both normal ($r = 0.7$) and seated shot put (range $r = 0.6$–0.79) and bench press performances ($r = 0.86$) (47).

Although the above data suggest a strong role of muscle fiber makeup and performance, the question begets itself: "Are athletes endowed with greater percentages of fast or slow twitch fibers, or can correlations between fiber types and performance be accounted for by training?" The purpose of the following article is to analyze the contribution of training to muscle fiber type expression. Concepts will be discussed from both practical and future research-oriented perspectives.

The Effect of Exercise on Muscle Fiber Types

Research from our laboratory and from others has clearly shown that training can shift type IIX fibers to IIA and vice versa (6,26,41). Therefore, the argument centers on whether training can change fast twitch fibers into slow twitch fibers and vice versa.

The first study to examine the effects of exercise on fiber type plasticity in human skeletal muscle was conducted by Gollnick et al. (18) using myosin ATPase staining. Six untrained participants exercised 1 $h \cdot d^{-1}$, 4 $d \cdot wk^{-1}$, for 5 months, at 85–90% of $\dot{V}O_2max$. The results found no significant difference in pretest to posttest measurements (32% slow twitch, to 36% slow twitch post). The authors suggested that the small sample size might have prevented them from reaching significance. It is interesting to note from this study that the 2 participants with the largest percentage of slow twitch fiber types increased their percentage of slow twitch fibers by 9% during the study (23–32%).

Following this pioneer experiment (18), several investigators (2,11,21,34) have obtained similar results when examining muscle fiber type plasticity with various populations and differing protocols. For example, neither 8 weeks of jump squats using either 30 or 80% of subjects' 1RM (34) nor 4 $d \cdot wk^{-1}$ of 3 sets of 3 second maximal sprints (21) resulted in an interconversion between fast and slow muscle fiber types in the quadriceps (21,34) or the soleus (21). Similarly, 6, 9 (11), or 19 weeks of resistance training (2) failed to elicit interfiber conversions. Collectively, these results oppose the contention that exercise induces fiber type shifting from slow to fast twitch and vice versa. However, additional studies suggest that by using certain training programs, exercise-induced muscle fiber type conversions may be possible.

One particular variable of interest concerns high velocity contractions. To illustrate this, Liu et al. (31) investigated the effects of training on MHC isoform expression in the long head of the tricep brachii, in 24 male participants with 3–5 months of weight training experience. The participants trained 3 $d \cdot wk^{-1}$, for 6 weeks, and were subjected to 2 experimental conditions. The first group (max) performed a 3RM on the bench press for 5 sets during each training session. A second combination group performed the same routine as the max group on Monday, 10 concentric-repetition bench press throws with a workload of 30% 1RM on Wednesday, and 10 stretch-shortening type push-ups on Friday, for 5 sets per exercise. The results showed that in the max group, there was a decrease in MHCIIX (33.4–19.5%), an increase in MHCIIa (44.9–66.7%), and no significant change in MHCI. However, in the combination group, there was no change in MHCIIX/d, but an increase in MHCIIa (47.7–62.7%), which was accounted for by a 50% decrease in MHCI (18.2–9.2%) indicating that high velocity movements may stimulate slow to fast twitch fiber type shifting. Similarly, Paddon-Jones et al. (35) found that 10 weeks of 4 sets of 6 repetitions of fast isokinetic resistance training was able to decrease the percentage of type I fibers (53–39%), with a simultaneous increase in the percentage of type IIX fibers (5.8–12.9%). The effects of high velocity contractions have also been extended to ambulatory activities. For example, Andersen et al. (4) found that 12 weeks of sprint training in trained male sprinters resulted in an increase in MHCIIa (34.7–52.3%) with a concomitant decrease in MHCI (52–41%). The percentage of type IIX fibers decreased (18–10.5%) with an increase in the percentage of type IIA fibers. These results suggested a bidirectional transformation of type I and IIX fibers to type IIA fibers with sprint training. Further support for rapid movements was found by Jansson et al. (25) whose results indicated that 4–6 weeks, 2–3 $d \cdot wk^{-1}$, of 30-second all-out sprints on the cycle ergometer was able to decrease the percentage of type I fibers (57–48%) with a concomitant increase in the proportion of type IIA fibers (32–38%) in 15 male physical education students.

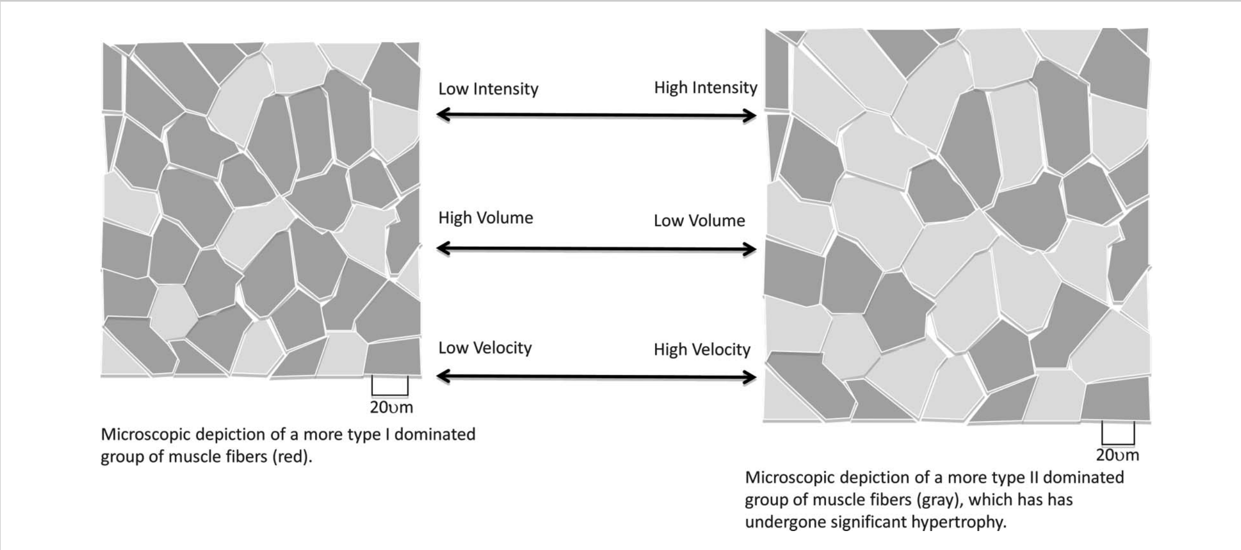

Figure 1. Training variables affecting conversion from type I to type II muscle fibers. This graphically depicts the effects of manipulating intensity, volume, and contractile velocity of all training types (endurance and resistance training) on muscle fiber type conversions.

Other studies have supported the findings that the percentage of type I fibers may be increased with various types of aerobic training protocols such as endurance cycle training (+12% type I) (24) and long distance running (+17% type I) (25), whereas studies indicate that sprint training (15) may facilitate the change of slow twitch fibers to fast twitch fibers. To illustrate this, Esbjornsson et al. (15) found that 6 weeks of high-intensity sprint training resulted in a 7 and 6% decrease in the proportions of type 1 and type IIX fibers, respectively, whereas the proportion of type IIA increased 12% with training.

Research also indicates that a lack of exercise may facilitate changes between slow and fast twitch fiber types. For example, Hortobagyi et al. (23) investigated the effects of 3 weeks of knee immobilization, followed by 12 weeks of resistance training 3 times per week, on vastus lateralis fiber characteristics and MHC mRNA in 48 recreationally active men and women. They found that immobilization reduced the percentage type I fibers (−9%), increased the percentage of type IIX fibers (+11%), and did not affect the percentage type IIA fibers. The ensuing exercise program increased the percentage of type I fibers (by 13%) and the proportion of type IIA fibers (by 7%), while decreasing the proportion of type IIX fibers (by 11%). These changes corresponded with similar increases and decreases in MHC mRNA.

Additional evidence for the possibility of changing fast to slow twitch fibers and vice versa comes from studies using decreased weight-bearing activity paradigms such as space flight and hind limb immobilization (see Baldwin and Haddad (5) for an in-depth review). For example, Staron et al. (44) found that 10–14 days of microgravity in rats resulted in a decrease in the percentage of MHCI (90–82.5%) and a corresponding increase in MHCIIX.

In summary, several previous studies indicated that exercise-induced muscle fiber shifting solely exists between IIX and IIA fast twitch fiber types. However, a limited, yet growing, body of evidence also suggests that particular exercise protocols may elicit a mutual shift between fast and slow twitch fibers. In any case, findings opposing alterations in fiber type do exist; thus, the contention that exercise elicits a shift in fiber type remains unsubstantiated, at least in part. Many researchers, including those in our group, believe that the interpretation of past and present research results should be completed with caution considering some fibers may contain 2 or more MHC isoforms (37,38). In addition, because of advancements in the histochemical staining technique used to evaluate myosin ATPase, there are now 7 recognized human muscle fiber types, which is much more complex than the original classifications of Type 1, IIa, and IIx (41). However, mechanistic evidence demonstrating possible conversions of fiber types may provide greater insight into the possible impact of exercise in this regard.

Mechanisms of Muscle Fiber Type Conversion

Skeletal muscle is remarkable in that it can readily adapt to meet the demands of a particular activity. This article has provided evidence that muscle fiber type transformations may be possible, but the exact mechanisms for this change are unknown. Studies of early development suggest that initial fiber type differentiation is likely determined by the myoblast cell lineage and is independent of any other external factor. To illustrate, muscles transplanted to an area outside their original origin take on some of the properties related to the muscles' original area of origin, not the new location or innervation (20,22). However, factors related to fiber type transformations differ in later development, particularly in athletes. Several mechanisms underlying these late development changes in fiber type have been proposed (e.g., neurotrophic factors, electrical activity, and hormones), and these may play some role in the overall change of the contractile phenotype (19). The following text will focus particular attention on motor neuron modifications.

Neurotrophic substances and electrical activity from the motor neuron may play a prominent role in the phenotype change. Buller et al. (10) provide evidence of this in their experiment in which they transplanted nerves from one fiber type to another. Upon receiving their opposite innervation, slow twitch became fast twitch and vice versa. They concluded that nerves to fast and slow twitch muscles send out different signals that can change the muscles properties in the opposite direction (fast → slow; slow → fast). These different signals released from the nerve were postulated to be either electrical activity or neurotrophic factors. It has been demonstrated, however, that the electrical activity alone can maintain strength at fairly normal levels in denervated muscle (48), suggesting that neurotrophic factors do not likely play a large role in changing muscle properties.

"Fast" nerves transmit impulses in short, high frequency bursts, whereas the opposite is true for slower nerves. It may be that consistently training with short intense bursts, over time, could result in adaptation to the motor neuron. It should be noted that although electrical activity can result in the transformation of one fiber type to another, evidence suggests that this transformation might be incomplete, implying that the muscle cells may retain at least some memory about its original cell lineage. This has been seen in studies investigating the transformation of the largely fast twitch extensor digitorum longus to slow twitch, in that it never becomes as slow as the predominate slow twitch soleus (8,14). This has also been seen in the transformations in the opposite direction (12,14). This incomplete transformation might also be the result of insufficient time because there is evidence that fiber types can change from one type to an intermediate type (type IIx → type IIa) and remained unchanged for a long period of time before further changing (50). Thus, the time course of many studies may only be sufficient to observe alterations within the fast twitch fibers and may not capture possible changes occurring with continued training.

Many limitations exist with such mechanistic interpretation as crossinnervation and electrically stimulating denervated muscles do not extrapolate to normal physiologic conditions. Additionally, fiber type distributions in human skeletal muscles are usually based on a sample of approximately 1,000 fibers weighing $\leq$100 mg (43). From this small biopsy, the fiber type of an entire muscle or muscle group is estimated. In light of these noted mechanistic limitations, under the normal conditions of the athlete, the degree to which they could alter the rate of muscle fiber firing would likely be limited by the athletes' muscle fiber adaptive range and limitations of their individual motor neurons and central nervous system (19). It is plausible that a complete fiber type transformation is possible, provided there is sufficient stimuli intensity and time frame for exercise adaptations to occur.

Conclusions

This review sought to analyze the role of training in muscle fiber type shifting. Several studies reviewed indicated that exercise-induced muscle fiber shifting only exists between fast twitch fiber types (26,41,42), whereas other findings discount the bidirectional shifting between slow and fast twitch fibers. However, regardless of evidential conflict, several findings imply that with careful manipulation of exercise variables, one may "potentially" experience fast to slow twitch fiber shift and vice versa (15,24,25,30,42). Although substantiation of such outcomes necessitates further research, the current findings indicate that altering fiber types and MHC percentages might be achievable via exercise (Figure 1). Although the discrepancies among findings impose some difficulty in developing evidence-based practical application, we can provide general exercise guidelines for the athlete and an insight into future research based on the existing evidence correlating fiber type shifting and specific exercise variables.

Practical Applications

Despite inconclusive findings substantiating training-induced fiber type shifting, "general" evidence-based guidelines can benefit endurance and strength and power athletes. For sports requiring optimal aerobic and endurance capacities (e.g., long distance running and crosscountry skiing), a greater expression of slow twitch fiber percentages would be advantageous for performance. If endurance athletes attempt to increase slow twitch fiber percentages, they should engage in training protocols (e.g., resistance and endurance training) characterized by high volume and low intensity and high volume, high-intensity intermittent training programs (e.g., interval sprint training). Conversely, for athletes in sports requiring greater anaerobic capacities, strength, and power (e.g., weight lifting and sprinting) expressing greater fast twitch fiber percentages would be advantageous to performance. If strength or power athletes attempt to increase fast twitch fiber percentages, they should employ high-intensity, low volume, and high velocity training programs. Strength and power athletes should also limit low-intensity training protocols or high volume, high-intensity intermittent training programs, which may facilitate a shift of fast twitch to slow twitch fiber phenotypes. Again, the aforementioned guidelines are presented to the extent to which the current body of evidence allows. Therefore, as of now, only general guidelines, as such, can be provided for the athlete and practitioner. Accordingly, future investigations addressing training-induced fiber shift is necessary to further specify any additional training guidelines.

For scientists, we propose several areas for future research. First, what accounts for these conflicting results on the effects of exercise on fiber types? The fact that not all studies support muscle fiber shifting between fast and slow fibers may suggest that we need to know more about the phenomena. For instance, is there variability in the capacity of muscle groups to change muscle fiber types? That is, are the biceps more malleable than the quadriceps? Furthermore, what is the optimal training prescription–exercise frequency, duration, intensity, and volume–for changing muscle fiber types? An impressive amount of work has gone toward answering this question, and we certainly have some idea that high-intensity power movements have a greater chance of increasing fast twitch fibers, whereas low intensity endurance activities have a greater chance of increasing slow twitch fibers.

Another question would be the effects of age on muscle fiber type shifting. For instance, could muscle fibers be more malleable during various stages of maturation? Such a finding would indicate that early specialization in a sport would be advantageous to developing muscle fibers types conducive to success; but taking muscle biopsies from youth may be difficult because of ethical concerns. Another question concerns work by Roth et al. (39) demonstrating associations between various gene polymorphisms and fat-free mass. Future research may analyze the association between gene polymorphisms and muscle fiber type shifting capacity after following various exercise protocols.

Even if it can be consistently shown that fast and slow muscle fiber types can transform to one another, we do not know whether there are limits to this. For instance, can those who are born with 40% slow twitch fibers change their percent of slow twitch fibers to the magnitudes seen in elite distance runners, such as 90% slow twitch? Perhaps, there is an asymptote in the capacity of exercise to modify muscle fiber types, and one could only change fiber types by 20%. The answer to this question is unknown.

Finally, one last observation is the relatively short duration of these studies. Considering that it typically takes approximately 10 years of active participation to become an expert in a specific sport, the results of exercise studies of 5–6 months in duration would hardly be conclusive on the effects of exercise on muscle fiber types. It may be that fast to slow twitch muscle fiber transitions either occur at a slower rate or increase exponentially after a certain duration of training. In this context, Anderson et al. (3) suggest that, "We do know that if fast type IIa fibers can be converted to type I, the time required for the conversion is quite long in comparison with the time for the shift from IIX to IIa (pp. 52)." Therefore, the authors of this study suggest that longitudinal and case studies are needed, optimally over entire elite athletic careers, to fully examine the effects of exercise training on muscle fiber types. Because of the difficultly in performing such experiments, it may be advantageous to create animal expert performance training models, in which we are able to analyze changes in fiber types, throughout the duration of training programs, from start to finish.

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