LEARNING OBJECTIVES

After studying this lesson the reader will be able to do the following:

1. Describe the physiological adaptations within the muscle following strength exercises
2. Provide examples of the changes that occur with neural adaptations within muscle
3. List the major contributors to improving muscle strength
4. Explain the differences among strength, power, and endurance
5. Distinguish among how to train Type I, Type IIA, and Type IIB muscle fiber types
6. Identify the number of repetitions, sets, and amount of resistance necessary to increase muscle strength and hypertrophy
7. Describe the effects of aging on muscle
8. Describe the phases of periodization training
9. Describe the differences among eccentric, concentric, and isometric exercises
10. Provide examples of off-season, in-season, and maintenance programs for athletes

Strength training is an important part of any athlete’s rehabilitation or performance enhancement program, or both. Optimal resistance training programs require consideration of numerous variables. The muscle and muscle groups to be exercised, the type of exercise, frequency, intensity, and duration are all important variables that determine the success of any strength training program. What are the physiological and neural adaptations that occur within the muscle and how long does it take to make changes? Can muscle fiber types be converted with strength training? Should eccentric, concentric, or isometric exercises, or a combination of all three, be used? Periodization strength training programs can result in significant changes in muscle strength. What are the different phases of a periodization program, and how long should each phase last? How does the therapist incorporate neuromuscular exercises into a strength-training program? Answers to these questions are essential to professionals responsible for prescribing resistance exercise for improvement of sports performance or for returning the athlete to normal function following injury and treatment.

Strength is the ability of the muscle to exert a maximum force at a specified velocity. Power is defined as the force exerted multiplied by the velocity of movement. Muscular power is a function of both strength and speed of movement. For most large muscle groups, maximal mechanical power is achieved at 30% to 45% of one’s 1RM (one repetition at maximum effort). Endurance is the ability to sustain an activity for extended periods of time. Local muscle endurance is best described as the ability to resist muscular fatigue. The authors of this lesson believe that a good strength base is important to reestablishing function and improving performance. Often specific strengthening exercises have been labeled as nonfunctional because they are performed in the open kinetic chain (OKC). For the purposes of this lesson, a functional exercise is defined as an exercise specific to the muscle groups that are important to the activity the athlete wants to return to and that sufficient resistance, repetitions, and sets are used to stimulate the muscle to adapt by increasing strength. Several studies have demonstrated that when OKC exercises were used to strengthen the glenohumeral rotators, significant gains were made in the strength of the shoulder rotators and the velocity of the baseball in pitchers and the velocity of the tennis ball in a tennis serve. Therefore strength training the rotators of the glenohumeral joint by moving the shoulder into internal and external rotation in an open kinetic chain position is a functional exercise (Figure 1).

This lesson describes the neural and physiological adaptations in muscle as a result of strength training programs. Time frames for developing strength gains, in addition to the amount of resistance, sets, and repetitions necessary to make these changes, are discussed. The effects of aging on muscle and
exercise adaptations in the elderly are also discussed. Finally is a review of the differences among eccentric, concentric, and isometric exercises.

Understanding the cellular and molecular adaptations of skeletal muscle in response to strength training is important to provide the framework to improve performance in the athlete and the health and quality of life of the general population with or without chronic diseases.

PHYSIOLOGICAL ADAPTATIONS OF MUSCLE

Neural Adaptations

The first signs of muscle adaptation to strengthening exercises are neural adaptations. Several studies have demonstrated that early strength gains induced by resistance training are primarily due to modifications of the nervous system. Moritani and DeVires, in a landmark study, found that “neural factors” accounted for the significant improvements observed during the first 4 weeks of an 8-week resistance-training program. Staron et al demonstrated that only after 6 weeks of training was significant muscle fiber hypertrophy detected. Furthermore, Staron et al demonstrated that with heavy resistance training the conversion of Type IIB fibers to Type IIA fibers occurred at 2 weeks in females and 4 weeks in males.

Views on the relative contribution of neural versus muscle adaptation with strength training lasting longer than 2 to 3 months are conflicting. Deschênes et al indicate that with prolonged resistance training, the degree of muscle hypertrophy is limited and that significant hypertrophic responses can occur within a finite period of time, lasting no more than 12 months. A secondary neural adaptation explains the continued strength gains with prolonged resistance training. The secondary phase of neural adaptations takes place between the sixth and twelfth months. In contrast, Shoepo et al demonstrated substantial muscle hypertrophy as a result of several years of resistance training, when compared with a group of sedentary individuals.

The neural adaptations elicited by resistance training include decreased co-contraction of antagonists and expansion in the dimensions of the neuromuscular junction, indicating greater content of presynaptic neurotransmitter and postsynaptic receptors. Greater synchronicity of the discharge of motor units after strength training has also been reported.

Contractile Adaptations

The contractile protein in muscle includes the actin and myosin filaments. Beyond the first few weeks of resistance exercises, an increased contractile capacity that exists within the muscle accounts for strength gains.

The turnover rate of muscle protein is one of the slowest in the body. Within skeletal muscle, synthesis and growth of contractile proteins lag behind that of other proteins, such as mitochondria and sarcoplasmic reticulum. The synthesis and accretion of contractile proteins account for the hypertrophy that occurs with resistance training. This hypertrophy occurs mostly within the intracellular myofibrils (25% to 35%), in addition to hypertrophy within the whole muscle (5% to 8%).

Hypertrophy versus Hyperplasia

Resistance exercise is a potent stimulus to increase the size of muscle. For a muscle to become larger, it must either increase in cross-sectional area (hypertrophy) or increase the number of muscle fibers (hyperplasia). The number of muscle fibers is generally believed to be innate and does not change during life. In contrast, several researchers reported that muscle is capable of increasing its size as a result of an increase in fiber number.

The exact mechanism responsible for muscle hypertrophy is uncertain, but several theories have been expressed in the literature. Skeletal muscles are capable of remodeling under various conditions. The activation of myogenic stem cells within the muscle is one of the most important events that occurs during skeletal muscle remodeling.

The muscle (myogenic) stem cells remain dormant under the basement of the myofibers, and on stimulation they differentiate into satellite cells to form myofibers. The muscle or myogenic stem cells start to generate, by a series of cell divisions, daughter cells that become satellite cells. Evidence suggests that strength training induces a significant increase in satellite cell content in skeletal muscle. Because the myonuclei in mature muscle fibers cannot divide, it is suggested that the incorporation of satellite cell nuclei into muscle fibers results in the maintenance of a constant nuclear/cytoplasmic ratio.
Therefore new muscle fibers are formed following strength training. When resistance or endurance exercises promote satellite cell proliferation and differentiation can be detected in injured fibers and those with no discernible damage, muscle hypertrophy occurs in human skeletal muscle.18-21

Resistance training has been shown to elicit a significant acute hormonal response, which is more critical to tissue growth and remodeling than chronic changes in resting hormonal concentrations. Anabolic steroids, such as testosterone and the growth hormones, have been shown to elevate during 15 to 30 minutes of exercise using high-volume, moderate-to-high-intensity, short rest periods and stressing a large muscle mass, when compared with low-volume, high-intensity protocols using long rest intervals.22

Other anabolic hormones, such as insulin and insulin-like growth factor-1 (IGF-1), are critical to skeletal muscle growth. Blood glucose and amino acid levels regulate insulin. However, following resistance exercise, elevations in circulating IGF-1 have been reported, presumably in response to growth hormone—stimulated secretion.22

Force developed by the myofilaments (actin and myosin) may stimulate the uptake of amino acids and thus result in muscle tissue growth.23 Heavy forces encountered during resistance training lead to disruption in the Z lines. The dis-organization after disruption of the Z disks may cause the myofilaments to split and grow back full size.23 Furthermore, the disruption and rebuilding of the muscle result in an increase in the connective tissue surrounding the muscle fibers.

In summary, as a result of strength training exercises, physiological adaptations of muscle result in an increase in strength. These adaptations include hypertrophy (within the first 6 to 8 weeks), hyperplasia, hormonal changes, increase in the connective tissue surrounding the muscle fibers, disruption of the myofilaments, and neuromuscular changes (within the first 2 weeks of training). In addition, metabolic adaptations occurring within the muscle fiber increase the ability of the muscle to generate adenosine triphosphate (ATP) for anaerobic metabolism. Anaerobic metabolism requires that the muscles increase phosphocreatine, glycogen stores, the enzyme creatine phosphokinase that breaks down PC, and the rate-limiting enzyme phosphofructokinase of glycolysis.

**Muscle Fiber Type: Specific Adaptations**

The fact that a prolonged program of resistance training brings about fiber type conversion with the muscle is well documented. The most common finding is an increase in the percentage of Type IIA fibers with a decrease in the percentage of Type IIB fibers.6,26,27

Apparently, as soon as a Type IIB muscle fiber is stimulated it starts a process of transformation toward the Type IIA, by changing the quality of proteins and expressing different types and amounts of myosin adenosine triphosphatase (mATPase).

Following a resistance-training program, few Type IIB fibers remain, which is reversed during detraining. However, when resistance training starts again, the conversion from Type IIB to Type IIA is quicker. Although resistance training promotes hypertrophy in all three major muscle fiber types in humans—Type I, IIA, IIB—the amount of hypertrophy differs from each fiber type. On the basis of the examination of pretraining to posttraining muscle samples, it has been established that muscle hypertrophy is greatest in Type IIA fibers, followed by Type IIB, with Type I fibers demonstrating the least amount of hypertrophy.5,6,26,27,29 Sex differences are apparent in muscle cross-sectional examination before and after training; Type IIA fibers are the largest among men, whereas the Type I fiber is the greatest size among women.30

**Exercise Variables**

In order to achieve the physiological adaptations described earlier, several variables must be considered. The variables that need to be carefully planned for in the development of an exercise program include the choice of exercise, order of exercises, number of sets, number of repetitions, intensity of exercise, duration of rest between sets and exercises, and frequency of training.

The type of exercise should be specific to the specific muscle deficits revealed in the initial evaluation. Furthermore, the type of exercises should be specific to the muscle groups that are important to improving the performance of the athlete. For example, in the overhead-throwing athlete, the external rotators, infraspinatus and teres minor, provide a breaking action in the deceleration of the shoulder. Eccentric loading to the external rotators is a specific exercise to strengthen the external rotators, and eccentric activity of the external rotators is specific to the movement pattern and exercise performed by the athlete in competition. Furthermore, high-speed eccentric loading is damaging to the muscle. By increasing the eccentric strength of the external rotators, there is greater protection of the muscle from damage. This concept is discussed in greater detail later.

The order of the exercises performed by the athlete typically involves performance of large muscle group exercises before smaller muscle group exercises. Because the metabolic demand is greater for large muscle group exercises, exercises that recruit more than one muscle group, such as closed kinetic chain exercises, should be performed before isolation exercises.38

Once again, debate exists in the literature regarding the number of sets and frequency of strength training. For the athlete the number of sets within a workout is directly related to individual training goals. Multiple-set programs optimize the development of strength and local muscular endurance.31 Gains in strength occur more rapidly with multiple-set programs compared with single-set protocols.32 Single-set exercise programs may be effective for individuals who are untrained or those just beginning a resistance training program. One-set workouts are also useful for maintenance programs. Furthermore, strength changes over a short-term training period and nonperiodized multiple-set program may not be different among one, two, or three sets of 10 to 12 RM.33 However, when single-set protocol is compared with multiple-set periodized
programs, significant superior results are observed with the multiset periodized programs that last longer than 1 month.\textsuperscript{44} Gotshalk et al\textsuperscript{45} demonstrated that higher volumes of total work produced significantly greater increases in circulating anabolic hormones during the recovery phase following multiset heavy-resistance exercise protocols.

McLester et al\textsuperscript{36} demonstrated that training 1 day per week was an effective means of increasing strength, even in experienced recreational weight lifters. However, the previous study reported superior results with training 3 days per week when compared with 1 day per week when the total volume of the exercise was held constant.

Advanced training frequency varies considerably. Hoffman et al\textsuperscript{47} demonstrated that football players training 4 to 5 days per week achieved better results that those who trained either 3 or 6 days per week. Frequencies as high as 18 sessions per week have been reported in Olympic weight lifters.\textsuperscript{38}

The intensity of the exercise or the amount of resistance used for a specific exercise is the most important variable in resistance training. The most common method of determining the amount of resistance used in a strength-training program is the maximal load that can be lifted a given number of repetitions within one set. The greatest effects on strength measures or maximal power outputs are achieved when the strength training repetitions range between 6 and 12.\textsuperscript{28} In other words, the maximum weight that can be lifted six times and six times only is the amount of resistance to start with. Addition of sets and repetitions occur at subsequent workouts until 3 sets of 12 repetitions (reps) are reached. After reaching this reps and sets goal, the reps are reduced down to eight and weight is added, allowing only eight repetitions. Once 15 reps are achieved with a specific weight, the muscle will no longer continue to improve in strength. However, lighter loads allowing 15 to 20 reps are effective for increasing absolute local muscle endurance.\textsuperscript{39,40}

Maximizing power requires a good strength base. Given that both force and time components are relevant to maximizing power, training to increase muscle power requires two general loading strategies. First, heavy resistance training recruits high-threshold fast-twitch muscle fibers that are necessary for strength. The second strategy is to incorporate lighter loads. Depending on the exercise, this may encompass 50\% to 60\% of 1RM.\textsuperscript{41,52} Weight training for power has been referred to as “explosive strength training.” Paavolainen et al\textsuperscript{45} demonstrated that explosive strength training could improve 5-km running time by improving running economy and muscle power, although a large volume of endurance training was performed concomitantly. The maximum amount of resistance used in the explosive strength training exercises was 40\% of 1RM. When performing explosive weight-training exercises, the athlete moves as fast as possible throughout the range of motion, resulting in losing contact with the ground in an explosive squat or losing contact with the bar in a bench press. During a traditional bench press and squat weight-training exercises performed at an explosive velocity, one study has shown that 40\% to 60\% 1RM and 50\% to 70\% 1RM, respectively, may be most beneficial in the development of power.\textsuperscript{44}

The final variable that is important to muscle adaptation from strength training is the time intervals between sets. The rest interval depends on the intensity of the training. For example, it has been shown that acute force and power production may be compromised with short rest periods of 60 seconds or less.\textsuperscript{45,46} Longitudinal studies have shown greater strength increases resulting from long rest periods between sets, 2 to 3 minutes versus 30 to 40 seconds.\textsuperscript{46,47}

### Aging and Muscle Changes

Professional athletes have been performing longer and longer over the past decade. Demographics data clearly illustrate that, overall, the U.S. population is growing older. Aging causes a loss of functional capacity resulting from a decrease in muscle mass (sarcopenia).\textsuperscript{48} Approximately one third of the total muscle mass is lost between 30 and 80 years of age.\textsuperscript{50} This decrease in muscle loss is primarily as a result of selective loss and remodeling of motor units. By the seventh decade of life, some muscles may have only half the number of motor units and 75\% of the total number of fibers compared with muscles of young adults.\textsuperscript{50} Type II fibers appear to be the most affected, gradually decreasing in both size and number with advancing age. Loss of fiber begins at approximately 25 years of age and accelerates thereafter.\textsuperscript{51} However, it appears that training can both reverse aging atrophy and maintain fiber-type distributions in elderly individuals similar to those found in the young. Several studies have determined that strength improvements in the elderly are coupled with cellular and whole muscle hypertrophy.\textsuperscript{8,52,53} Also, muscle hypertrophy responses to resistance training have been found to be indistinguishable between young and elderly people.\textsuperscript{8,54} The recommendations for the strength training variables noted as follows are beneficial to use with the elderly or the young athlete or patient, or both.

- Strength training reps 6 to 12
- Multiple sets 2 to 3
- At least 2 days per week and a maximum of 3 days per week of strength training
- 90 seconds’ to 2 minutes’ rest between sets

![ACTIONS](image)

**Eccentric Strengthening**

Simply stated, an eccentric action occurs whenever opposing force acting on a muscle exceeds the force produced by that muscle.\textsuperscript{55} This causes the muscle to lengthen while it is being activated. Eccentric actions are characterized by an ability to achieve high muscle forces and an enhancement of the tissue
damage that is often associated with muscle soreness, and perhaps require unique control strategies. Eccentric actions are used frequently throughout everyday life, especially in athletic competition. A common human movement strategy is to combine concentric and eccentric actions into a sequence called the stretch-shorten cycle. This cycle typically involves a small-amplitude, moderate-to-high velocity eccentric contraction that is followed by a concentric contraction. Eccentric contractions are mechanically efficient and can attenuate impact forces and maximize performance.

When a muscle is trained eccentrically, a number of structural signs of muscle damage exist. Under electron microscope it has been shown that sarcomeres will become out of register and extended, and z-line streaming is evident, along with a regional disorganization of the myofilaments and t-tubule damage. Mechanically, there are signs of a shift in the muscle’s optimum length toward a longer muscle length, a decrease in active tension, an increase in passive tension, and muscle swelling and soreness. This muscle swelling and soreness leads to delayed-onset muscle soreness (DOMS), which is thought to be purely mechanical and not an inflammatory response.

After a bout of eccentric exercise, an adaptation occurs. This adaptation can be called the repeated bout effect. When one performs an eccentric bout of exercise, a repeated bout effect adaptation will protect the muscle against further damage from subsequent eccentric bouts. This can help to improve performance and prevent injury. Recently the adaptations have been broken down into three categories: cellular, mechanical, and neural. At the cellular level there is evidence of an increase in sarcomeres after bouts of eccentric exercise. In fact, one study found an 11% increase in sarcomere number after eccentric loading. At the mechanical level there is evidence of increases in dynamic and passive muscle stiffness. Whitehead et al state that the rise in passive muscle tension depends on the length range over which the muscle is worked. On the neural level there is still discussion whether adaptation is on the central or local level. Research shows that with a high enough velocity, there is cross education to the contralateral limb, which means there is definitely a central connection. On the basis of this information, adaptations seemingly occur across the three categories and a unified theory has yet to exist.

With eccentric strengthening and adaptations, there are increases in strength, cross-sectional areas, and neural activation. Along with muscle adaptation, there has been discussion of possible tendon adaptations, but no clear evidence exists yet. With biceps brachii eccentric loading, the muscle sense organs and the body’s ability to sense joint position have shown both an increase and decrease in the flexed position. This seems to depend on whether there is actually a muscle spindle injury (increase flexed position) or if there is just sarcomere disruption (decreased flexed position) and the former happening with high-intensity strengthening. An increased signal from a muscle spindle has been shown with heavy eccentric strength, while there have been no studies to show evidence of significant neural adaptation more so than concentric strengthening.

Eccentric contractions are one of three types of muscle contractions. When a muscle can overcome an opposing force and shorten while being activated, this is called a concentric contraction. When the force generated is equal to the opposing force and there is no movement, this is called an isometric contraction. Typically, eccentric contractions can generate two to three times more force than concentric contractions. This has led some authors to believe that by training someone eccentrically, one has a greater capability of overloading the muscle to a greater extent and enhancing muscle mass, strength, and power when compared with concentric strengthening. This generalization may seem fair but may be too simple.

Many studies show an increase, decrease, or no change in functional performance, concentric strength, and eccentric strength after eccentric training. The outcomes noted earlier can be attributed to different training protocols and methods of assessment. Current research has shown that eccentric training is more effective than concentric training for developing eccentric strength and that concentric strengthening is more effective for developing concentric strength. The specificity of training noted earlier is another application of the specific adaptations to imposed demands (SAID) principle.

The degree of that strength gain is relative to the volume/intensity and velocity of the eccentric exercise. In the majority of the studies the load used was appropriate to induce failure in the muscle. The actual volume does vary, but there is a study that supports the use of low-volume eccentric exercise. Another study found that when compared with high-intensity eccentric training, low-intensity eccentric training has the same amount of muscle damage but without the large drop in muscle performance. On the basis of these two studies, one may not need to use a high-intensity/volume model for eccentric strength gains. Other research has shown that to get the greatest hypertrophy and strength gains, one must work eccentrically 180 degrees per second over the range. This study was performed with isokinetic equipment, so the carryover to isotonic is unknown.

Differences also seem to occur in relation to eccentric strength across genders and lifespan. Lindle et al found that concentric peak torque decreased more with age than did eccentric peak torque for both men and women. In another study they found that women tended to better preserve muscle quality with age for eccentric peak torque. In addition, older women seemed to have an enhanced capacity, about a decade longer, to store elastic energy better than similarly aged men and younger men and women.

### Concentric Strengthening

As discussed earlier, there are neural, contractile, and muscle fiber–type adaptations with strength training. Most athletes use a combination of eccentric, concentric, and isometric contractions. Because of the need to control a load when returning it to the starting position, most strengthening studies have used a combination of eccentric and concentric actions. As previously noted, the stretch shortening cycle is initiated by an eccentric action followed by a concentric contraction, while an...
eccentric contraction can happen by itself. Because of this, any time people work isotonically, they are working eccentrically even if they are concentrating on the shortening contraction. In the real world it is almost impossible to work only concentrically. This makes it so difficult to discuss the adaptations of concentric-only contractions. What follows is an attempt to discuss concentric strengthening, although the changes associated with concentric strength training are poorly understood.81

A concentric contraction occurs when the force produced by the muscle exceeds the external force or load.26 This contraction causes the muscle to shorten and is the latter action of the stretch-shorten cycle. This cycle, as pointed out earlier, happens in most day-to-day activities and occurs without specialized training.56 Enoka56 considered that by performing a concentric contraction only without an eccentric action, muscle performance would be decreased.56

Concentric-only strengthening does not produce as much exercise-induced muscle injury as eccentric strengthening.82 In fact, more muscle damage is produced when a muscle is loaded eccentrically than if it is loaded eccentrically and concentrically, regardless of whether this is done alternately or separated.83 Whereas eccentric strengthening carryover seems to be specific to intensity, mode, and velocity of training, concentric strengthening may be more general with its carryover. One study found that velocity-specific, concentric-only strengthening resulted in increased peak torques above and below the training velocity.84 Another study found that concentric training was less mode- and speed-specific than corresponding eccentric training.85

Isometric Strengthening

Isometric strengthening occurs when the force generated by muscle and the external force is the same and there is no shortening of the muscle. Isometric strengthening has been shown to be joint angle specific, and there is not much carryover to other joint angles. Only about a 20-degree carryover exists either way from where the muscle was trained, although one study did show that there is greater carryover throughout the entire range when the muscle is trained isometrically in the lengthened position.86 The question of what type of adaptations the muscle will undergo with isometric strengthening also exists. One study has reported that this depends on the type of rate of contraction. Progressive contractions produced modification of the nervous system at the peripheral level, whereas ballistic contractions affected the muscle’s contractile properties.87 Another study found increased isometric strength might be due to factors associated with hypertrophy, independent of neural adaptations.88

CLINICAL APPLICATION

With all this information, how does one apply it to a clinical situation? First, clinicians need to integrate eccentric strengthening into their practice. It needs to be more than just lowering the weight after a concentric contraction. On the basis of current research, it is known that in order to train an athlete for eccentric movements, they must perform eccentric movements. In the definition of a stretch-shorten cycle, an eccentric contraction is a low-amplitude and moderate- to high-velocity contraction. Therefore eccentric movements must be faster than concentric contractions. Eccentric isotonic training must produce forces two to three times greater than their concentric counterparts to have the proper intensity. This does not necessarily mean that isometric loads should be doubled or tripled. Force that is generated during an exercise is dependent on the amount of resistance used; the greater the resistance, the slower the speed. (Force equals mass times acceleration). Because an eccentric action should happen at a greater speed, one may have to only increase the load by 20% to 30% if one is moving the limb twice as fast as the concentric contraction. A rest period longer than 48 hours must be allowed. Athletes must be trained in a specific eccentric manner to get maximum gains from their rehabilitation and performance training. How to do that in a controlled clinical setting isotonically is the first question.

What injuries or muscle groups would benefit the most from eccentric strengthening? A number of studies discuss the use of eccentric strengthening in treating patients with Achilles tendinosis, patellar tendinopathy, iliotibial band syndrome in runners, and chronic isolated posterior cruciate ligament injured knees.56-93 MacLean et al92 demonstrated that in posterior cruciate ligament-deficit knees a significantly decreased eccentric-to-concentric ratio was noted compared with the contralateral hamstring. A study by Mafi et al89 found that more patients with chronic Achilles tendinosis had a better overall satisfaction and decreased pain with eccentric strengthening training than concentric strengthening training. Another study by Young et al93 showed that eccentric training with a decline squat protocol was superior to a traditional eccentric protocol with decreased pain and improved sporting function in elite volleyball players over 12 months who had suffered patellar tendinopathy. Ohberg et al88 showed that with eccentric training in patients with Achilles tendinosis, there was an actual decrease in Achilles tendon width along with decreased pain. These studies indicate that eccentric strengthening should be a definite part of any tendinopathy treatment.

Other applications may include using eccentric actions and loading on muscle groups that primarily work concentrically but that have been immobilized. An example is a patient who has undergone anterior cruciate ligament repair. If the knee has been braced and the quadriceps group has been in a shortened position, muscular atrophy will occur along with a decrease in the number of sarcomeres. This remodeling can occur within the first 5 days of immobilization.57 If the quadriceps group is eccentrically loaded properly in the open chain, sarcomere lengthening exists along with an increase in the actual number of sarcomeres. This adaptation will help to speed up the return of a good quadriceps eccentric action and possibly the concentric contraction as well. With the eccentric loading of the tibia in the open chain position, the tibia will glide posteriorly, which will eliminate any anterior shear force on the anterior cruciate ligament. With a concentric open-chain quadriceps contraction, the force generated will be an anterior shear.
When working with athletes, one must consider what the specific function of a muscle is in relation to the athletes' sport. A track sprinter may be going through rehabilitation from a hamstring group strain. If the athlete's hamstring is properly loaded eccentrically, this may help to prevent further injury secondary to the repeated bout effect. The same is true with a baseball pitcher, who, by eccentrically training the rotator cuff muscles, may be able to adapt to higher eccentric forces and therefore decrease the chances of suffering from a deceleration injury. But in order to gain these benefits from eccentric training, the athlete would most likely need to be trained specifically by training the same muscle groups with the same intensity as needed by the sport. One study showed a decrease in the occurrence of hamstring strain injuries in elite soccer players after undergoing eccentric overload training.95

Examples of when not to use an eccentric loading action would be during the initial rehabilitation after a tendon repair or the initial stages of muscle healing. Because the force generated by an eccentric action can be two to three times greater than a concentric contraction, failure may be generated at the repair sight or the sight of tissue injury. For example, if a patient has just gone through a supraspinatus tendon repair and is status post 2 weeks, obviously eccentric loading should be avoided. However, if the same patient is working on active assistive range of motion with wall walks and at the top of the exercise starts to lower his or her arm, he or she will eccentrically load that tendon and may rupture the tendon repair. Because concentric loading generates less force, it may be more beneficial when working with a repaired tissue to initially use concentric-only strengthening when the tissue has healed enough to withstand an external load.

Isometric contractions seem to be most beneficial when used to increase the endurance of those muscles that function as spinal stabilizers.96 This will help to maintain low but continuous activation of the paraspinal and abdominal wall muscles that function as stabilizers.97 According to recent research, isometric contractions lend themselves to more of a neural than contractile adaptation.97

CONCLUSION

In order to make progressive, efficient, and major strength gains in the athlete, one must apply numerous concepts. The athlete must be worked specifically toward his or her goals whether they are strength, hypertrophy, power, or endurance in the context of the sport. At the same time the athlete must vary his or her strengthening program with periodization if training will occur for extended periods. The basic concept of periodization is changing the intensity, velocity, and volume as needed. There also needs to be consideration of the type of muscle action (eccentric, concentric, and isometric) and the amount of focus that action will require to help the athlete in his or her sport. The authors of this lesson, when rehabilitating or training an athlete, or both, recommend the exercise variables listed as follows:

- Strength training repetitions of 8 to 12 repetitions for strength and hypertrophy, 4 to 6 repetitions for power, and 12 to 15 repetitions for endurance.
- Multiple sets for all types of strengthening.
- At least 2 days of strength training per week.
- 1- to 2-minute rest periods for smaller muscle groups and 2- to 3-minute rest periods for larger muscle groups.
- Start with multiple joint exercise and finish with single joint exercises.
- Intensity will start with 8 repetition (rep) max for strength and 10 rep max for hypertrophy, 6 rep max for power at either high or moderate velocity, and 15 rep max for muscular endurance.
- Velocity can be slow, moderate, or fast depending on specific goals.
- Eccentric strengthening needs to be focused on with deceleration muscles, and eccentric and concentric together need to focused on for the acceleration muscles.
- Any time an athlete's strength training goes beyond 4 weeks, his or her program needs to periodize.

The choice of exercises should be based on an evaluation of muscle strength and the muscles that are important to the type of activity in which the athlete competes. As previously noted, the greater the intensity of the activity, the greater the intensity of the training should be. Appendix B reviews three cases that exemplify strength training concepts and periodization principles.

REFERENCES

8. Hakkinen K, Alen M, Kallinen M: Neuromuscular adaptation during prolonged strength training, detraining,


