CHAPTER

5

Impaired Muscle Performance

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Muscular performance is an essential component of a person's life. Every human activity from breathing to walking to the bathroom to running a marathon requires muscle activity. Physiologic, anatomic, psychological, and biomechanical factors affect muscle performance. Pathology and disease affecting the cardiovascular, endocrine, integumentary, musculoskeletal, neuromuscular, or pulmonary systems can also affect muscle performance; strength training can improve the function of these systems. Muscle performance impairments can be considered as impairments in muscle *strength, power,* or *endurance*. These impairments must be related to an activity limitation or participation restriction, or promote prevention, health, wellness, and fitness, in order to justify therapeutic exercise intervention. For example, an individual lacking the muscular ability to carry a bag of groceries into the house requires intervention to achieve this instrumental activity of daily living. A worker lacking the muscle endurance to maintain efficient posture and safe movement patterns throughout the workday requires intervention to prevent work disability. A person with osteoarthritis of the knee and poor quadriceps muscle performance requires quadriceps muscle training to prevent further knee joint deterioration.

Although not all scientific and clinical information on strength, power, and endurance production can be covered in this text, this chapter provides a strong foundation for this element of therapeutic exercise intervention. Fundamental terms and concepts are defined, the essential morphology and physiology of skeletal muscle relative to muscle performance are reviewed, and clinical applications are presented.

DEFINITIONS

Definitions of key terms vary from one researcher, text, or profession to another. The following definitions are presented to clarify how these terms will be used throughout this text.

Strength

Impaired muscle performance is commonly treated by clinicians and is usually described as a strength deficit. However, strength is only one of the three components of muscle performance (i.e., strength, power, and endurance).

Strength is defined as the maximum force that a muscle can develop during a single contraction, and is the result of complex interactions of neurologic, muscular, biomechanical, and cognitive systems. Strength can be assessed in terms of force, torque, work, and power. If appropriate decisions are to be made regarding these impairments, operational definitions are necessary.

Force is an agent that produces or tends to produce a change in the state of rest or motion of an object.[1] For example, a ball sitting stationary on a playing field remains in that position unless it is acted upon by a force. Force, described in metric units of newtons (N) or British units of lb, is displayed algebraically in the following equation:

$$\text{Force} = \text{mass} \times \text{acceleration}$$

Kinetics is the study of forces applied to the body. Some of the factors influencing muscular force production include the neural input, mechanical arrangement of the muscle, cross-sectional area, fiber-type composition, age, and gender.[1]

Torque is the ability of a force to produce rotation. All human motion involves rotation of body segments about their joint axes. These actions are produced by the interaction of forces from external loads and muscle activity. Torque represents the rotational effect of a force with respect to an axis:

$$\text{Torque} = \text{force} \times \text{moment arm}$$

The *moment arm* is the perpendicular distance from the line of action of the force to the axis of rotation. The metric unit of torque is newton-meter (Nm); the foot-pound (ft lb) is used in the older British system of units.

Clinically, the word *strength* is often used synonymously with torque. Large amounts of torque are produced by the musculoskeletal system during everyday functional activities such as walking, lifting, and getting out of bed. Torque can be altered in biomechanics through three strategies:

1. Changing the force magnitude
2. Changing the moment arm length
3. Changing the angle between the direction of force and momentum

In the human musculoskeletal system, changing the force magnitude (i.e., tension-producing capability of muscle) can be altered by training. The moment arm can be decreased by positioning a load closer to the body, and the angle between the force and moment arm may be changed by altering joint alignment through postural education (see **Building Block 5-1**).

BUILDING BLOCK 5-1

A patient with thoracic spine and neck pain works at a research laboratory where the work stations are positioned such that it requires the patient to either (a) bend over a table top or (b) work with her arms extended well in front of his or her at shoulder height. Please apply the three principles of altering torque just discussed to minimize thoracic and cervical spine pain for this patient.

Power and Work

Power is the rate of performing work. *Work* is the magnitude of a force acting on an object multiplied by the distance through which the force acts. The unit used to describe work is the joule (J), which is equivalent to 1 Nm (the foot-pound unit is used in the British system). Work is algebraically expressed in this equation:

$$\text{Work} = \text{force} \times \text{distance}$$

The unit of power in the metric system is watt, which is equal to 1 J per second (foot-pound per second in the British system). Power can be determined for a single body movement, a series of movements, or for a large number of repetitive movements, as in the case of aerobic exercise. Power is algebraically expressed as:

$$\text{Power} = \text{work/time}$$

For the simple movement of lifting or lowering a weight, the muscle must overcome the weight of the limb and the weight (force), acting some distance from the axis of rotation (torque) through a range of motion (ROM) (work) during a specific time frame (power). This example summarizes the practical aspects of force, torque, work, and power in resistance training.

Endurance

Endurance is the ability of muscle to sustain forces repeatedly or to generate forces over a certain period of time. It is often measured as the ratio of the peak force that can be generated by a muscle at a given point in time, relative to the peak force that was possible during a single maximum contraction. Muscle endurance is the ability of a muscle group to perform repeated contractions against a load. This load can be applied externally or as a result of posture, such as when someone is working over a desk, counter, or work station all day (**Fig. 5-1**). Muscle endurance can be examined by isometric contractions, repeated dynamic contractions, or repeated contractions on an isokinetic dynamometer.

Muscle Actions

Poorly defined muscle actions can be a source of confusion and inaccuracy. Resistive exercise uses various types of muscle contraction to improve impaired muscle performance. Muscle actions can be divided into two general categories: static and dynamic. A static muscle action, traditionally referred to as *isometric*, is a contraction in which force is developed without any motion about an axis, so no work is performed. The amount of force generated by the muscle matches the external resistance applied.

All other muscle actions involve movement and are called *dynamic* or *isotonic*. An **isotonic exercise** suggests a uniform

A B

FIGURE 5-1 Individual standing at a computer workstation using **(A)** poor posture or **(B)** good posture.

force throughout a dynamic muscle action. No dynamic muscle action uses constant force because of changes in mechanical advantage and muscle length. *Isotonic* is therefore an inappropriate term to describe human exercise performance, and the term *dynamic* is preferred.

Dynamic muscle action is further described as concentric or eccentric action. The term *concentric* describes a shortening muscle contraction, and the term *eccentric* describes a lengthening muscle contraction. A concentric contraction happens when the internal force generated by the muscle exceeds the external load, whereas an eccentric contraction occurs when the external load exceeds the muscle force and the muscle lengthens while still developing tension.[2] Eccentric contractions differ from concentric and isometric contractions in several important ways. Per contractile unit, compared to concentric contractions, eccentric contractions:

- Can generate more tension and at a lower metabolic cost (i.e., less use of ATP-derived energy)[3]
- Are an important component of a functional movement pattern (e.g., required to decelerate limbs during movement)
- Are the most energy-efficient form
- Can develop the greatest tension of the various types of muscle actions

The term *isokinetic* refers to a concentric or eccentric muscle contraction in which a constant velocity is maintained throughout the muscle action. A person can exert a continuous force by using an isokinetic device, which provides a resistive surface that restricts movement to a preset, constant velocity. Some acceleration and deceleration occurs as the individual accelerates the limb from a resting position to the preset velocity and decelerates the limb to change directions. By constraining the speed of the isokinetic device, the limb moves at a constant velocity. Because the device cannot be accelerated beyond the preset speed, any unbalanced force exerted against it is resisted by an equal and opposite force. This muscular force may be measured, displayed, recorded, or used as concurrent visual feedback. Although the isokinetic device may be moving at a constant velocity, it does not guarantee that the user's muscle activation is at a constant velocity. Despite this inaccuracy, the terms *isokinetic* and *isotonic* to describe muscle action are likely to be employed for pragmatic reasons.

During functional movement patterns, combinations of static and dynamic contractions occur. Trunk muscles contract isometrically to stabilize the spine and pelvis during movements of the extremities such as reaching or walking. Lower extremity muscles are subjected to impact forces requiring combinations of concentric and eccentric contractions, sometimes within the same muscle acting at two different joints. Muscles commonly perform eccentric contractions against gravity, as in slowly lowering the arm from an overhead position.

Muscles often act eccentrically and then contract concentrically. The combination of eccentric and concentric actions forms a natural type of muscle action called a *stretch-shortening cycle* (SSC).[4,5] The SSC results in a final action (i.e., concentric phase) that is more powerful than a concentric action alone. This phenomenon is called *elastic potentiation*.[5] The SSC is discussed in more detail later in this chapter.

PHYSICAL FACTORS AFFECTING MUSCLE PERFORMANCE

The total force a muscle can produce is influenced by numerous factors. Knowledge of muscle morphology, physiology, and biomechanics is critical for successful therapeutic exercise prescription. The following section discusses the primary factors influencing force production and, hence, muscle performance. A brief review of the structure of muscle and the physiology of muscle contraction can be found on thePoint.lww.com/BrodyHall4e.

Fiber Type

Sedentary men and women and young children possess 45% to 55% slow-twitch fibers.[6] Persons who achieve high levels of sport proficiency have the fiber predominance and distributions characteristic of their sport. For example, those who train for endurance sports have a higher distribution of slow-twitch fibers in the significant muscles, and sprint athletes have a predominance of fast-twitch fibers. Other studies show that men and women who perform in middle-distance events have an approximately equal percentage of the two types of muscle fibers.[7] Any resistive rehabilitation program should be based on the probable distribution of fiber type of the individual.

Clear-cut distinctions between fiber-type composition and athletic performance are true for elite athletes. A person's fiber composition is not the sole determinant of performance. Performance capacity is the end result of many physiologic, biochemical, and neurologic components, not simply the result of a single factor such as muscle fiber type.[6]

Fiber Diameter

Although the different fiber types show clear differences in contraction speed, the force developed in a maximal static action is independent of the fiber type but is related to the fiber's cross-sectional diameter. Because type I (slow-twitch) fibers tend to have smaller diameters than type II (fast-twitch) fibers, a high percentage of type I fibers is believed to be associated with a smaller muscle diameter and therefore lower force development capabilities.[8]

Muscle Size

When adult muscles are trained at intensities that exceed 60% to 70% of their maximum force-generating capacity, the muscle increases in cross-sectional area and force production capability. The increase in muscle size may result from increases in fiber size (i.e., hypertrophy), fiber number (i.e., hyperplasia), interstitial connective tissue, or some combination of these factors.[9,10]

Although the major mechanism for increased muscle size in adults is hypertrophy, ongoing controversy surrounds evidence of hyperplasia. Mammalian skeletal muscle does possess a population of reserve or satellite cells that, when activated, can replace damaged fibers with new fibers.[11,12] The mechanisms for fiber hyperplasia probably are the result of satellite cell proliferation and longitudinal fiber splitting.[9]

Despite few investigations of the effect of strength training on interstitial connective tissue, it appears that, because interstitial connective tissue occupies a relatively small proportion of the total muscle volume, its potential to contribute substantial changes in muscle size is limited.[13]

Force–Velocity Relationship

Muscle can adjust its active force to precisely match the applied load. This property is based on the fact that active force continuously adjusts to the speed at which the contractile system moves. When the load is small, the active force can be made correspondingly small by increasing the speed of shortening appropriately. When the load is high, the muscle increases its active force to the same level by slowing the speed of shortening (**Fig. 5-2**).[14]

Slowing the speed of contraction allows a patient time to develop more tension during concentric contractions. This principle is evident during resistive exercise in water, where the water's viscosity slows limb movement, allowing more time for tension development. However, during eccentric contractions, increased speed of lengthening produces more tension. This appears to provide a safety mechanism for limbs excessively loaded. Increasing the speed of a concentric contraction significantly lowers the amount of concentric torque developed. In contrast, increasing the speed of an eccentric contraction increases the amount of torque developed until a plateau speed is reached.

Length–Tension Relationship

A muscle's capacity to produce force depends on the length at which the muscle is held with maximum force delivered near the muscle's normal resting length (**Fig. 5-3**). The relationship between strength and length is called the length–tension property of muscle. The number of sarcomeres in series determines the distance through which the muscle can shorten and the length at which the muscle produces maximum force. Sarcomere number is not fixed, and in adult muscle, this number can increase or decrease (**Fig. 5-4**).[15] Regulation of sarcomere number is an adaptation to changes in the functional length of a muscle.

Length-associated changes can be induced by postural malalignment or immobilization.[16,17] In muscles chronically maintained in a shortened range because of faulty posture or immobilization, sarcomeres are lost, and the remaining sarcomeres adapt to a length that restores homeostasis; the new length enables maximum tension development at the new immobilized, shortened position.[18] For example, people who spend most of the day sitting can develop adaptive shortening of their hip flexor muscles. These muscles need to be stretched to avoid chronic shortening. In muscles immobilized or posturally held in a lengthened position, sarcomeres are added, and maximum tension is developed at the new increased length. This may be true of people at workstations where the scapular retractor muscles are lengthened due to thoracic kyphosis and a chronically protracted scapula. When a cast is removed or posture restored, the sarcomere number returns to normal. The stimulus for sarcomere length changes may be the amount of tension along the myofibril or the myotendon junction, with high tension leading to an addition of sarcomeres and low tension to a subtraction of sarcomeres.[19]

The clinical implication of the length–tension relationship is that the evaluation of muscle "strength" must be reconsidered. Muscles that tend to be shortened (e.g., hip flexors) may test as strong as normal-length muscles, because the manual muscle test position is a shortened position.[20] Conversely, the lengthened

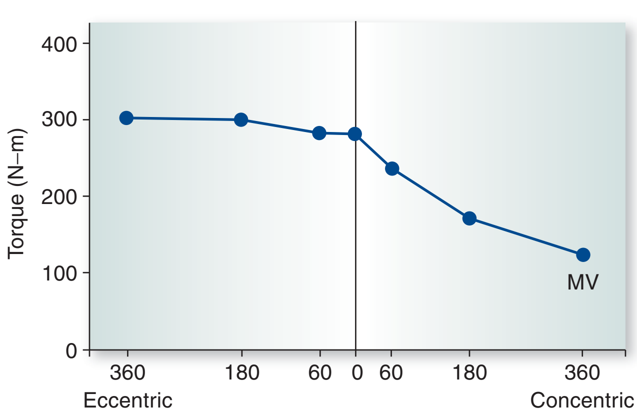


FIGURE 5-2 Relationship between the force and velocity of eccentric muscle contractions. (Adapted from Herzog W, Ait-Haddou R. Mechanical muscle models and their application for force and power production. In: Komi PV, ed. Strength and Power in Sport. 2nd Ed. Malden, MA: Blackwell Scientific Publications, 2003:176.)

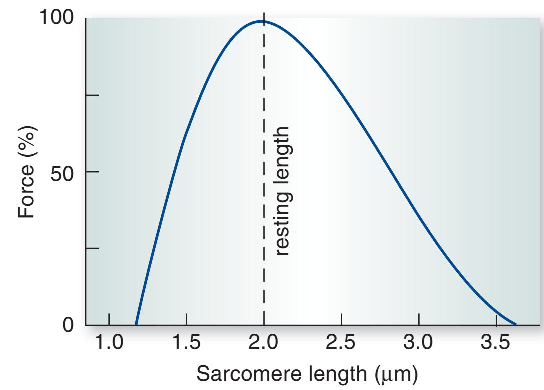


FIGURE 5-3 The length–tension curve depicts the relationship between muscle length and force development.

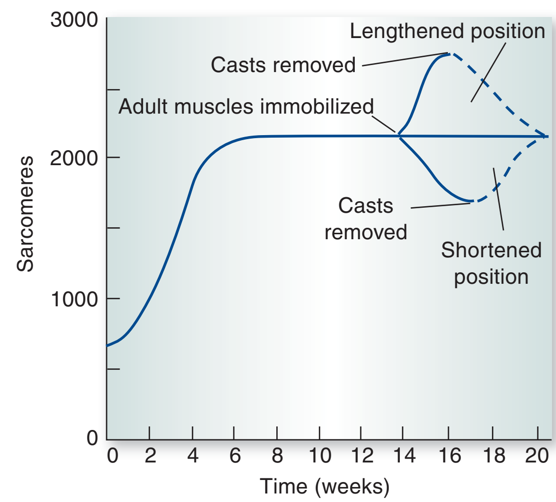


FIGURE 5-4 Changes in the number of sarcomeres in various conditions.

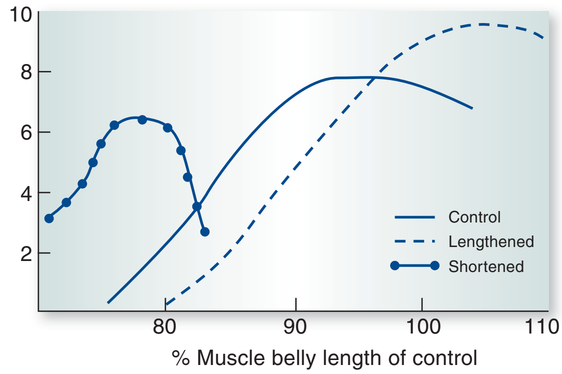


FIGURE 5-5 Changes in the length–tension relationship caused by length changes associated with immobilization. (Modified from Gossman, Sahrmann SA, Rose SJ. Review of length-associated changes in muscle. Experimental evidence and clinical implications. Phys Ther 1982;62:1799.)

muscle (e.g., the lower trapezius in the patient with protracted scapula) tests weak, because the manual muscle test occurs at a relatively shortened range, which is an insufficient position. According to animal studies,[21,22] the short muscles should develop the least peak tension, followed by the normal-length muscle and the lengthened muscle, which develops the greatest peak tension (**Fig. 5-5**). This finding directly reflects the number of sarcomeres in series. The lengthened muscle may be interpreted as weak although it is capable of producing substantial tension at the appropriate point in the range. This phenomena is called *positional strength*. Clinically, this is why a muscle should be tested at multiple points in the range. It is imperative that the physical therapist determine whether the muscle is positionally weak or weak throughout the range, as these findings will affect the selection of interventions (see **Building Block 5-2**).

BUILDING BLOCK 5-2

Think of some other muscle groups that might not test "normal" when testing at mid-range position due to positional weakness (shortening or lengthening of the muscle).

The emphasis of therapeutic exercise intervention should be on restoring normal length and tension development capability at the appropriate point in the range, rather than just strengthening the muscle. The positionally weak muscle should be strengthened in the shortened range, and the weak muscle should be strengthened dynamically throughout the range.

Muscle Architecture

The arrangement of the contractile components affects the contractile properties of the muscle dramatically. The more sarcomeres lie in series, the longer the muscle will be, the more sarcomeres lie in parallel, the larger the cross-sectional area of the muscle will be. These two basic architectural patterns affect the contractile properties of the muscles in the following ways:

- The force the muscle can produce is directly proportional to the cross-sectional area.
- The velocity and working excursion of the muscle are proportional to the length of the muscle.

Generally, muscles with shorter fibers and a larger cross-sectional area are designed to produce force, whereas muscles with long fibers are designed to produce excursion and velocity.[22] For example, the quadriceps muscle contains shorter myofibrils and appears to be specialized for force production, whereas the sartorius muscle has longer fibers and a smaller cross-sectional area and is better suited for high excursion (see **Building Block 5-3**).

BUILDING BLOCK 5-3

How might the rehabilitation of someone with a quadriceps muscle strain differ from someone with a hamstring muscle strain based upon the muscle architecture?

CLINICAL CONSIDERATIONS

Many factors impact the effectiveness of resistive exercise program. Issues such as medication use, physical health, age, and program design can impact a person's ability to participate in and successfully respond to a training stimulus.

Dosage

Exercise is described in terms of **dosage**. The components of the exercise dose include the exercise frequency, intensity, duration, volume, and rest interval. The exercise **frequency** is how often the exercise is performed, usually described as the number of days per week. The *intensity* is the amount of force necessary to achieve the activity, usually described as mass (in kilograms) or weight (in lb). The intensity is often described as a percentage of a **repetition maximum (RM),** or the maximum amount of weight that can be lifted for a certain number of repetitions. For example, a 10 RM is the maximum amount of weight that can be lifted 10 times and a 1 RM is the maximum amount of weight that can be lifted once.

The *duration* is the number of repetitions or time the exercise is performed. Often, a certain number of repetitions are performed in a **set,** and several sets of an exercise might be performed in a single session. The exercise *volume* is the total amount of exercise performed in a single session. Volume has been defined in different ways for different purposes. In weight training, volume is often defined as the product of the number of sets and repetitions and the weight. For example, the volume for 3 sets of 10 repetitions at 15 lb would be $3 \times 10 \times 15$ lb $= 450$ lb. It has also been defined as the total number of repetitions performed in a training session.[23]

The *rest interval* is the amount of time between each set and/or between each exercise. The rest interval can be passive or active, where *passive rest* is simply resting before the next exercise bout, whereas *active rest* is rest where the person performs a light activity such as walking or stretching between resistive exercise bouts. In order for resistive training to improve muscle performance, the muscle must be overloaded. *Overload* means exercising or applying resistance above the loads currently or normally encountered.

The exercise dosage can be altered in a variety of ways. Some examples include:

- Increasing the intensity or amount of weight
- Changing the relationship to gravity

- Increasing the lever arm length
- Increasing sets and repetitions
- Decreasing the rest interval
- Increasing the frequency

The dosage parameters of intensity, duration, and frequency are related and together are considered the training *volume*; all must be considered when designing a resistive exercise program. Choose appropriate dosage parameters based on the needs of the patient (**Display 5-1**). Be aware of patients with fair or lower muscle grades who cannot perform resistive exercise against gravity with proper recruitment and movement patterns. In this situation, the patient may be forced to train a faulty movement pattern (see **Building Block 5-4**). Determine whether the goal is to develop muscular strength, power, endurance, or some combination of these muscle performance parameters. Subsequently, progress the resistive exercise to a functional activity to transition intervention at the impairment level to the activity limitation level (**Fig. 5-6**).

BUILDING BLOCK 5-4

A patient complains that he or she is unable to lift her arm overhead without pain. The patient is evaluated and is found to have a physiologic impairment of a muscle strength grade of fair for the lower trapezius and serratus anterior. How do these muscles function in arm elevation to an overhead position? Given her strength grade, what approach or approaches might be appropriate for initiating the rehabilitation program? Provide several options in different positions.

DISPLAY 5-1

Dosage Options for Individuals with Muscles of Various Strength Grades

Muscles Fair or Below Progressing to Muscles Above Fair:

1. Work in a gravity-lessened position or against gravity with other modification
2. Use active assistive, active, or resisted muscle contractions as available
3. Modify the working ROM, using resistance when possible, and assistance at other time
4. Progress from a shorter lever arm to a longer lever arm

Muscles Above Fair Strength Grade:

1. Vary the type of contraction (e.g., isometric, concentric, eccentric, isokinetic, plyometric)
2. Increase the amount of weight or resistance
3. Increase the number of sets or repetitions
4. Increase the frequency of training sessions (be cautious of overtraining)
5. Modify the speed of movement (slower speed increases amount of force or torque generated during concentric exercise)
6. Increase the distance (e.g., running, jumping, throwing)
7. Decrease the rest interval between sets

Dosage parameters can be manipulated for maximum gains in strength, power, and endurance through a system of training called *periodization*. Periodization systematically varies the training dosage to prevent "plateaus" in training gains, to maintain interest, and to provide a well-balanced program. Varying the training program is essential to making long-term gains in training. Periodization breaks the training program down into cycles of a specific length and goals (i.e., hypertrophy, basic strength, power, and endurance). The cycles can vary from "minicycles" of 1 week to mesocycles of several months. Often a training program comprises a variety of cycles of variable

A B

FIGURE 5-6 Progression of exercise: **(A)** Lifting free weights overhead to **(B)** placing a box up on a shelf.

lengths. Further discussion of periodization is presented later in this chapter in relation to training the advanced or elite athlete.

Intensity

Extensive strength training research has been performed on individuals without injury. Dosage parameters to increase strength began with DeLorme's classic paper in 1945.[24] He proposed a 10-RM, 10-set regimen. Later, DeLorme and Watkins[25] modified this regimen to a 10-RM, three-set regimen with loads increasing progressively for each set from one half to three fourths to a full 10-RM set. DeLorme called this regimen *progressive resistance exercise* (PRE), a term still used today (**Table 5-1**). DeLorme's three-set progressive resistance program has served as a control condition by which the effectiveness of other methods has been judged.

In 1951, an alternative to the DeLorme regimen was proposed by Zinovieff[26] at Oxford. He suggested adjusting the intensity of the load to allow for progressive fatigue. This was achieved by selecting an initial load that was just enough to permit each set to be completed. This regimen was called the Oxford technique. McMorris and Elkins[27] compared the DeLorme and Oxford techniques and found the Oxford technique to be slightly better, but the differences were not statistically significant.

The daily adjustable progressive resistive exercise (DAPRE) technique has been proposed as a more adaptable progressive exercise program than the Oxford or DeLorme approaches (see Table 5-1).[28] This program eliminates arbitrary decisions about the frequency and amount of weight increase. The DAPRE program can be used with free weights or with weight machines. A 6 RM is used to establish the initial working weight. Thereafter, weight increases are based on the performance during the previous training session.

These guidelines have been based on studies of uninjured subjects. When treating a patient with specific impairments, the resistive exercise dosage varies.[29] Exercise should be performed to substitution or form fatigue, the point at which substitution or alterations in form occur.

Duration/Volume

Duration or volume of resistive training can be considered the number of sets, repetitions, or time of a specific exercise session. Most exercises are performed for a given number of repetitions and sets that can be considered the exercise duration or volume. In rehabilitation, resistive exercises might also be prescribed for a certain time interval such as 15, 30, or 60 seconds depending on the goal of the exercise.

In weight training for fitness, *volume* is often defined as the total number of repetitions performed during a training session multiplied by the resistance used. Intensity and volume are inversely related. The greater the intensity, the fewer are

TABLE 5-1

Common Strength Training Dosages and DAPRE Program and Adjustments

TECHNIQUE	BASE REPETITION MAXIMUM (RM)	SETS	NUMBER OF REPETITIONS
DeLorme	10	1. 50% of 10 RM	10
		2. 75% of 10 RM	10
		3. 100% of 10 RM	10
Oxford	10	1. 100% of 10 RM	10
		2. 75% of 10 RM	10
		3. 50% of 10 RM	10
DAPRE	6	1. 50% of 6 RM	10
		2. 75% of 6 RM	6
		3. 100% of 6 RM	As many as possible
		4. Adjusted weight based on number of reps performed in set 3[a]	As many as possible; this number of reps is used to determine the working weight for the next day[a]

NUMBER OF REPETITIONS	ADJUSTED WORKING	ADJUSTED WORKING
Performed in set 3[a]	Weight for set 4[a]	Weight for next day[a]
0–2	Decrease 5–10 lb	Decrease 5–10 lb
3–4	Decrease 0–5 lb	Same weight
5–6	Keep weight the same	Increase 5–10 lb
7–10	Increase 5–10 lb	Increase 5–15 lb
11	Increase 10–15 lb	Increase 10–20 lb

[a]Adjustments for the DAPRE program.

the repetitions performed. When training at a low RM (near 1 RM or maximum amount of weight that can be lifted), very few repetitions are performed, and strength gains are the chief goal. When training at 10 RM or higher, many repetitions are performed, and the goals are endurance and other aspects of muscle performance.

Very little stimulus is necessary to make strength gains in the beginner. In untrained individuals, one set of 10 RM, two to four times per week, may be adequate. In advanced or elite athletes, multiple set routines, three times per week, will be necessary to achieve strength and power gains. For this group, performing one set of an exercise is less effective for increasing strength than performing two or three sets, and there is evidence that three sets are more effective than two sets.[30] However, multiple sets pose higher risk for injury; therefore, careful technique must be employed to avoid injury.

For most individuals, a moderate training volume is sufficient to achieve strength gains and these gains can be made via any resistive training mode.[31,32] A review of meta-analyses concluded that:

- In untrained subjects, a dosage of 60% of 1 RM, 3 days per week with a mean training volume of four sets per muscle group produced optimal strength gains.[33]
- For recreationally trained nonathletes, an intensity of 80% of 1 RM, 2 days per week with a mean training volume of four sets per muscle group was best.
- For athletes, a training of 85% of 1 RM, 2 days per week with a mean training volume of eight sets per muscle group was necessary for optimal strength gains.

The rest interval between sets is another important variable to consider. Much research has been performed to determine the optimal rest interval to achieve different resistive training goals. Some controversy exists regarding single versus multiple sets and the length of the rest interval between sets.[34,35] Strength results might change when training at different rest intervals. Rest intervals will vary from <1 minute to 3 to 5 minutes depending on the intensity of the lift and the purpose of the training. The higher intensity required for strength training will necessitate longer rest intervals.

- For loads near 1 RM, a rest interval of 3 to 5 minutes allows for more recovery and the ability to train at a higher intensity for more repetitions.[34]
- For power training, a minimum of 3 minutes rest between activities, such as plyometric jumps, will retain the necessary intensity.
- When training for muscle endurance, a circuit program with approximately 30 seconds between sets is sufficient.
- Muscles can be overloaded by decreasing the rest interval between sets.

Frequency

Training frequency depends on the rehabilitation goals. Isometric exercise is performed several times per day, and heavy dynamic exercise may be performed every other day. Frequency of an exercise is related to the exercise goal, intensity, duration, and other exercises in the patient's rehabilitation program. Individuals training for power lifting or body building lift daily or twice daily, whereas individuals in rehabilitation programs may perform resistive exercise 3 days per week, cardiovascular exercise on alternate days and certain exercises daily. Be sure to allow adequate time for recovery between training sessions. Shortening the recovery period between training sessions can produce persistent fatigue.[36]

Studies provide a variety of frequency recommendations, and these need to be balanced with intensity, duration, initial training status, and the goals of the training. PRE training one time weekly with 1 RM for one set increases strength significantly after the first week of training and each week up to at least the sixth week.[30] Significant increases have occurred for beginners training 1 to 5 days per week.

Sequence

The sequence of training muscles can affect the development of strength. In general, multijoint exercises are advocated for strength and power gains. However, specific isolated muscle training is often necessary when rehabilitating individuals with impaired muscle performance. In this case, the single-joint exercises should be performed first, before the patient gets fatigued. Follow these exercises with multijoint functional movement patterns. When designing the sequence of rehabilitation exercises, consider whether the exercises are **stacked** (several exercises in a row that train the same muscle group) or **unstacked** (exercises are organized to alternate between different muscle groups, allowing rest intervals). In the early rehabilitation phases, unstacking exercises to allow for an active rest interval for the muscle group being trained may prevent overwork of that muscle. As rehabilitation progresses, the exercises can be rearranged to include a sequence of two or more exercises in a row working the same muscle group. For training novice, intermediate, and advanced individuals who do not have an injury who want to increase strength, the American College of Sports Medicine (ACSM) provides the following recommendations[37]:

- Exercise large muscle groups before small and perform multijoint before single-joint activities.
- When training all major muscle groups in one training session, alternate upper body and lower body activities.
- When training upper body and lower body muscles on different days, alternate agonist and antagonist exercises.
- When training individual muscle groups, perform higher-intensity exercises before lower intensity exercises.

Program Design

Program design simply means looking at the overall training session. This includes the sequence of the exercises discussed in the previous section as well as overarching issues like interval training and circuit training. *Interval training* is a type of training that is predominantly used to build anaerobic metabolic systems; although depending on the work:relief ratio, it can be used to train aerobic systems as well. Interval training prescription includes the exercise intensity and duration as well as the duration and activity for the relief interval.[2,23]

- The relief interval can be either passive (rest-relief) or active (work-relief).
- Examples of work-relief interval activities include active movement without resistance, stretching, or another light activity.

- The relationship of work:relief can vary from 1:1 or 1:1.5 when training the aerobic system and to 1:12 to 1:20 when training the phosphagen system (the system used for all-out exercise in the first 10 seconds).
- The combination of high intensity and short duration places greater loads on the phosphagen system and requires a longer relief interval.
- A longer work interval (3 minutes or more) works the aerobic system, minimizing the necessity of a long relief interval.

Interval training methods can be applied to resistance training by using weight equipment (free weights, variable resistance machines, elastic resistance) to obtain a certain number of repetitions within a given time frame. The relief interval can again be a passive rest interval or an active work interval. Interval training will be discussed in greater depth in Chapter 6 relative to the cardiopulmonary system.

Circuit training usually includes 8 to 15 exercise stations that are completed in a sequence or circuit. The stations can be general training for the major muscle groups, serving as a general fitness routine or can be specific. For example, a swim team might perform circuit training 3 days per week with exercises focused on preventing injuries specific to swimmers. Exercises can be one mode (i.e., variable resistance machines) or they can be a combination of stations such as variable resistance machines, free weights, elastic resistance, and functional skills such as jumping. Participants complete two or three circuits at a given intensity depending on goals with a prespecified relief interval of 15 to 30 seconds between stations. When designing the circuit, keep in mind the sequence considerations discussed previously.

Training Specificity

Training specificity suggests that "you get what you train for." The SAID (**S**pecific **A**daptations to **I**mposed **D**emands) principle extends the idea first put forth in Wolff's law. Wolff's law states that bone will adapt to the loads placed upon it. The soft-tissue corollary is called Davis' law and states that soft tissues will remodel according to the loads placed upon them.[38] This specificity is particularly significant in terms of training range, mode, contraction type, posture and velocity[39–41] (**Evidence and Research 5-1**).

EVIDENCE and RESEARCH 5-1

The effects of posture on the specificity of training were assessed using squat and bench press lifts as the training tool. A variety of tests followed an 8-week training session that included skills such as vertical jump, 40-m sprint, isokinetic tests, and a 6-second bout on a power bicycle. The authors found results to support the concept of posture specificity, because the exercise postures similar to the training postures enabled the greatest improvements.[42]

The greatest training effects are evident when the same exercise type is used for testing and training, although this principle varies by muscle contraction types (**Evidence and Research 5-2**). A muscle trained isometrically will show the greatest strength improvement when tested isometrically and a muscle trained dynamically will test stronger when evaluated dynamically. However, a study of concentric and eccentric quadriceps training found that specificity was related to eccentric training but not concentric training.[44] Concentric training showed increases only in concentric and isometric strength.[43] Studies have shown bilateral transfer; training one limb resulted in strength gains in the contralateral limb.[39,45,46] Further studies of bilateral versus unilateral training have shown improved bilateral scores when training bilaterally and improved unilateral scores when training unilaterally. These findings were consistent for upper extremity and lower extremity training.[47]

EVIDENCE and RESEARCH 5-2

A group of 12 men was trained in a traditional isotonic strength program for knee flexor and extensor muscles.[43] They were tested isokinetically before and after the 12-week program. Their isotonic strength increased nearly 227%, whereas their isokinetic strength at 60 degrees per second increased only 10%.

ROM specificity also exists; strength improvements are greatest at the joint angles exercised.[40] A study of eccentric training showed isometric strength gains that were joint-angle specific; a similar study of concentric training showed improvements throughout the range.[46] The importance of training specificity is highlighted by the many variables affecting strength development. If the muscular system were the only system involved, then strength development would be predictable and linear. However, functional strength development is a complex relationship between the muscle tissue and the neural system dedicated to that tissue. This includes local and central nervous system mechanisms.

This specificity of exercise is evident to anyone who has trained for one activity (i.e., running) and subsequently discovered little transfer to another activity (i.e., tennis). Even resistive training, while providing a good strength base, does not transfer to other activities, even activities using the same muscle group. Therefore, it is important that resistive training serve as the training base upon which functional training is imposed.

Neurologic Adaptation

Muscle performance is determined by the type and size of the involved muscles and by the ability of the nervous system to appropriately activate muscles. When an unfamiliar exercise is introduced into the resistive exercise program, the early increase in strength partially results from adaptive changes in the nervous system control. Inappropriate instruction or failure to monitor the exercise and ensure appropriate nervous system control can render it ineffective or detrimental to the expected outcome. In order to achieve efficient and effective muscle performance, the following must occur:

- The agonists (muscles responsible for producing the large force in the intended direction) must be fully activated.
- The synergists (muscles that assist in coordinating the movement) must be appropriately activated to ensure precision.
- The antagonists (muscles producing force in the opposite direction of the agonists) must be appropriately activated or relaxed.

DeLorme and Watkins[25] hypothesize that the initial increase in strength after PRE occurs at a rate greater than can be accounted for by muscle morphologic changes. The initial rapid increases in strength probably result from motor learning. When a new exercise is introduced, neural adaptation predominates in the first several weeks of training as the individual masters the coordination necessary to perform the exercise efficiently. Eventually, hypertrophic factors gradually dominate over neural factors in the gain in muscle performance.[43] Although neurologic adaptations were once thought to dominate in the first few weeks of training, Staron et al.[48] found that morphologic changes begin to occur in the second week of training.

Other adaptations, such as the ability to fire motor units at very high rates to develop power, may require a longer period of training to attain and be lost more rapidly during detraining.[49] In the long term, further improvement in performance critically depends on the way the muscles are activated by the nervous system during training.[50]

Muscle Fatigue

Muscle fatigue may be defined as a reversible decrease in contractile strength that occurs after long-lasting or repeated muscular activity.[51] Human fatigue is a complex phenomenon that includes failure at more than one site along the chain of events that leads to muscle fiber stimulation. Fatigue involves a central component, which puts an upper limit to the number of command signals that are sent to the muscles, and a peripheral component. Peripheral changes in cross-bridge function associated with fatigue include a slight decrease in number of interacting cross-bridges, reduced force output of the individual cross-bridge, and reduced speed of cycling of the bridges during muscle shortening (**Table 5-2**).

When the patient is performing resistive training, be alert for signs of fatigue. Fatigue can lead to substitution or injury. The dosage for resistive exercise is often limited to *form fatigue,* the point at which the individual must discontinue the exercise or sacrifice technique. Quality of motion is necessary to ensure that the muscles of interest are being recruited. Synergists can readily dominate a movement pattern when muscle fatigue causes form fatigue. Changes in activation and optimum length for torque activation have been found following fatiguing exercise.[52,53] The patient should be instructed to stop the exercise once form is compromised (i.e., form fatigue). Continuing to exercise with poor technique compromises the outcome and may be detrimental. It is not good enough to perform the exercise; it must be performed correctly and with the appropriate recruitment pattern (**Fig. 5-7 A** and **B**). *A person cannot strengthen a muscle that is not being recruited*.

Muscle Soreness

During resistive training, especially in an untrained state, minor lesions of the muscle structure and inflammation can result in muscle soreness.[54] Most people who initiate a resistive exercise program will feel some stiffness and soreness in the exercised muscles following activity. Soreness may be caused by myofibrillar damage, membrane damage, or inflammatory processes. The serum or plasma level of creatine kinase, an enzyme found almost exclusively in muscle tissue, may be elevated, indicating muscle damage.[55–57] This muscle damage extends beyond just the local muscle environment, but it leads to systemic inflammation as well as increased arterial stiffening, negatively impacting central macrovascular function.[58,59]

TABLE 5-2

Chain of Events Leading to a Muscle Contraction

	CHAIN OF EVENTS LEADING TO A MUSCLE CONTRACTION (ANATOMIC SITES OF FATIGUE)	MECHANISMS INVOLVED IN PROCESSING INFORMATION THROUGH THE CHAIN OF EVENTS (PHYSIOLOGIC PROCESSES RESPONSIBLE FOR FATIGUE)	
Central fatigue	Limbic, premotor, and association cortices ↓	Insufficient motivation or incentive	Processes involved in delivery of sufficient electrical excitation from CNS to muscle
	Sensorimotor cortex ↓	Insufficient cortical motoneuron activation	
	Spinal cord ↓	Depressed alpha motoneuron excitability	
Peripheral fatigue	Peripheral motor neurons ↓	Failure in neural transmission	
	Neuromuscular junction ↓	Failure in neuromuscular transmission	
	Sarcolema ↓	Depressed muscle membrane excitability	
	Transverse tubules ↓	Failure of muscle action potential propagation	
	Sacroplasmic reticulum ↓	Insufficient release and/or reuptake of Ca^{3+}	Metabolic and enzymatic processes involved in providing sufficient energy for contraction
	Formation of actin–myosin cross-bridges	Failure in excitation–contraction coupling, insufficient energy supplies, inadequate energy supply replenishment, metabolic accumulation	
	Muscle contraction		

From Currier DP, Nelson RM. Dynamics of Human Biologic Tissues. Philadelphia, PA: FA Davis, 1992:165.

A B

FIGURE 5-7 Ensuring proper exercise mechanics: **(A)** Inappropriate shoulder elevation during arm raising and **(B)** appropriate scapular stabilization during arm raising.

A specific type of muscle soreness referred to as **delayed-onset muscle soreness** (DOMS) is common following eccentric exercises, especially when the exercises are performed at a high velocity.[60] DOMS usually peaks about 2 days after exertion and can last for up to 7 days. During this time, muscle function deteriorates, and muscle strength may be reduced for a week or more after intensive eccentric exercise. Additionally, there is a shift of the optimal angle of peak torque production to longer lengths.[52,53] However, an adaptive process reduces the soreness after repeated eccentric training sessions.[52] Soreness following eccentric training can also be attenuated by preconditioning the muscle groups, performing isometric muscle contractions in a lengthened position.[61,62]

The unaccustomed eccentric exercise and associated high muscle forces damage aboth the muscle contractile and noncontractile structures, and abnormal metabolite accumulation in the muscle cell produces additional damage. Because eccentric contractions utilize a smaller number of motor units than concentric contractions, the excess stress on these motor units appears to be the source of tissue damage and associated inflammation.[63,58] The inflammation initiates the healing process, resulting in an adaptive process, protecting the muscle from similar damage in subsequent exercise bouts.[52]

Even during the soreness period, moderate activity is advised, because the adaptation response occurs before full recovery and restoration of muscle function. A single session of eccentric exercise provides a protective effect against DOMS in subsequent exercise bouts for up to 6 weeks.[52] Therefore when initiating a resistive training program that includes eccentrics, it is best to begin with a light exercise session to protect against significant DOMS.[62]

Patients should be cautioned that eccentric training may lead to muscle soreness 24 to 48 hours after exercise, but that moderate exercise should continue during the recovery period. However, some research has shown attenuation of position sense and joint reaction angle following a bout of eccentric exercise (**Evidence and Research 5-3**). Therefore, use caution when treating populations who are training or working in at-risk environments (i.e., steel workers, roofers).[67,68,69]

EVIDENCE and RESEARCH 5-3

Position sense and reaction angle were tested in the upper extremity by fatiguing the elbow flexors and in the lower extremity by fatiguing knee flexors via repeated eccentric muscle contractions. Although the exercise induced greater muscle damage and loss of position sense in the elbow flexors than in the knee flexors, the elbow flexors remained faster and more accurate than the knee flexors at all measured time points post exercise.[64] Errors were biased toward a more lengthened position.[64,65] A repeated bout of exercise resulted in less muscle damage and improved position sense of the knee flexors.[66]

Life Span Considerations

Newborn Through Preadolescence

Only about 20% of a newborn child's body mass is muscle tissue. The infant is weak, and muscular strengthening in the first months takes place by spontaneous movements. These movements should not be limited by tight clothes or constant bundling of the newborn. However, the infant and toddler should not be burdened with systematic resistive training; normal developmental progression provides an appropriate stimulus for the development of an optimal amount of muscular strength.

In the preadolescent phase (up to age 11 in girls and 13 in boys; approximately Tanner stages 1 and 2), muscle mass increases parallel to body mass. Children are able to make strength gains above and beyond growth and maturation. Benefits of exercise and specifically resistive training in this age group include[70]:

- Improved muscle performance
- Increased motor performance
- Improved body composition
- Increased bone strength
- An enhanced sense of well-being
- A positive attitude toward fitness

During preadolescence, there are no differences between girls and boys with respect to the ability for strength training. Boys have a small genetic advantage, which is completely compensated by the developmental advantage of girls.[71] There is no biologic basis for a sex-dependent difference in strength performance. Most improvements in performance are the result of neurologic changes, such as increased motor unit activation, coordination, and motor learning.[70]

Moderate strength training is acceptable. Resistive training at this age should focus on the neurologic aspects of training (**Fig. 5-8**). See **Table 5-3** for recommendations for programs at the pre-adolescent level.[72,73]

Muscle performance training should always be supervised by knowledgeable staff to avoid risk of injury. Although it has been suggested that resistance training in pre-adolescent children leads to increased musculoskeletal injuries, this appears to be anecdotal. Controlled studies have not found an increase in muscle, bone or joint injuries in resistance training in this population when the program is run by experienced professionals.[74,75]

FIGURE 5-8 Child performing a squat exercise.

Adolescence

Adolescence refers to the time period between childhood and adulthood encompassing young girls aged 12 to 18 years and boys aged 14 to 18 years (Tanner stages 3 and 4).[72] The ability to improve strength increases rapidly during adolescence, particularly in boys. The increase in male sexual hormones is significant because of their anabolic (i.e., protein-incorporating) component. During maturation, the proportion of muscle in boys increases from 27% to 40% of body mass.[71] With the onset of adolescence, the strength of girls compared with boys diverges markedly. On average, the strength of girls is 90% that of boys at 11 to 12 years, 85% at 13 to 14 years, and 75% at 15 to 16 years.[71] Although this gender difference has a biologic basis, biology does not completely account for the differences seen, suggesting continued societal influences.

General strength training is recommended during this phase (**Table 5-4**). Optimal strength and muscular balance are critical for the quickly growing skeleton. Like preadolescence, evidence does not support increased musculoskeletal injuries in adolescents involved in appropriately supervised resistance training programs.[70,74] Low back or other musculoskeletal injuries in resistance training often occur in unsupervised settings where appropriate instruction may be absent.

Guidelines for resistance training in adolescents are similar to that of preadolescents with the most important factors being proper instruction, supervision, and safe progression. Additionally, participants must have the ability to listen and directions to ensure safety. As youth progress through a resistive training program, they progress with activities from isolated muscle exercises to complex multijoint activities that require more coordination. They progress with varies speeds, including higher-speed activities to develop power, and include activities that challenge balance as well (**Table 5-5**). For specific guidelines, see Behm et al.[70] and Faigenbaum et al.[72]

Early Adulthood

Strength potential is at its highest in the 18- to 30-year period.[75] The competent biologic structures show a state of good adaptability, and the joints tolerate high loads. Most individuals are actively involved in physical activity without the responsibility of working long hours. During this period, emphasis should be placed on a balanced fitness program comprised of cardiopulmonary fitness, muscle performance, and flexibility.

Middle Age

The decrement of strength during this phase of life must be differentiated according to training activities, gender, and body area. Training for as little as 2 hours or more each week is sufficient to positively influence strength. A small amount of training increases the difference between active and inactive persons as age increases. As obligations increase in middle age, exercise may become secondary to other responsibilities. Continuing a resistive exercise program can help maintain

TABLE 5-3

General Youth Resistance Training Guidelines

- Provide qualified instruction and supervision
- Ensure the exercise environment is safe and free of hazards
- Start each training session with a 5–10-min dynamic warm-up period
- Begin with relatively light loads and always focus on the correct exercise technique
- Perform 1–3 sets of 6–15 repetitions on a variety of upper- and lower-body strength exercises
- Include specific exercises that strengthen the abdominal and lower-back region
- Focus on symmetrical muscular development and appropriate muscle balance around joints
- Perform 1–3 sets of 3–6 repetitions on a variety of upper- and lower-body power exercises
- Sensibly progress the training program depending on needs, goals, and abilities
- Increase the resistance gradually (5%–10%) as strength improves
- Cool down with less-intense calisthenics and static stretching
- Listen to individual needs and concerns throughout each session
- Begin resistance training 2–3 times/week on nonconsecutive days
- Use individualized workout logs to monitor progress
- Keep the program fresh and challenging by systematically varying the training program
- Optimize performance and recovery with healthy nutrition, proper hydration, and adequate sleep
- Support and encouragement from instructors and parents will help maintain interest

From Faigenbaum AD, Kraemer WJ, Blimkie CJ, et al. Youth resistance training: updated position statement paper from the national strength and conditioning association. J Strength Cond Res 2009;23(5 Suppl):S60-S79.

TABLE 5-4

Recommendations for Strength Training in Youth

	NOVICE	INTERMEDIATE	ADVANCED
Muscle action	ECC and CON	ECC and CON	ECC and CON
Exercise choice	SJ and MJ	SJ and MJ	SJ and MJ
Intensity	50%–70% 1 RM	60%–80% 1 RM	70%–85% 1 RM
Volume	1–2 sets × 10–15 reps	2–3 sets × 8–12 reps	≥3 sets × 6–10 reps
Rest intervals (min)	1	1–2	2–3
Velocity	Moderate	Moderate	Moderate
Frequency (d/wk)	2–3	2–3	3–7

ECC, eccentric; CON, concentric; SJ, single joint; MJ, multijoint; 1 RM, 1 repetition maximum; rep, repetition.
From Faigenbaum AD, Kraemer WJ, Blimkie CJ, et al. Youth resistance training: updated position statement paper from the national strength and conditioning association. J Strength Cond Res 2009;23(5 Suppl):S60-S79.

TABLE 5-5

Recommendations for Power Training in Youth

	NOVICE	INTERMEDIATE	ADVANCED
Muscle action	ECC and CON	ECC and CON	ECC and CON
Exercise choice	MJ	MJ	MJ
Intensity	30%–60% 1RM VEL	30%–60% 1 RM VEL	30%–60% 1 RM VEL
		60%–70% 1 RM STR	70% to ≥80% 1 RM STR
Volume	1–2 sets × 3–6 reps	2–3 sets × 3–6 reps	≥3 sets × 1–6 reps
Rest intervals (min)	1	1–2	2–3
Velocity	Moderate/fast	Fast	Fast
Frequency (d/wk)	2	2–3	2–3

ECC, eccentric; CON, concentric; MJ, multijoint; 1 RM, 1 repetition maximum; VEL, Velocity; STR, strength; rep, repetition.
From Faigenbaum AD, Kraemer WJ, Blimkie CJ, et al. Youth resistance training: updated position statement paper from the national strength and conditioning association. J Strength Cond Res 2009;23(5 Suppl):S60–S79.

strength and function, bone density, and appropriate body composition.

Advanced Age

The body can adapt to strengthening exercise throughout the life span. It is possible to reverse existing muscular weakness in old age.[76] Strength increases can result from relatively low stimuli in detrained elderly individuals. Like younger individuals, these strength increases result from both muscular hypertrophy and neural factors.[77,78] Cross-sectional area of trained muscles in older individuals show increases after several weeks of resistive training[79] (**Evidence and Research 5-4**). In general, fatigability increases with advancing age, and older muscles require a longer period of recovery after strenuous exertion. There is also a significant increase in the collagen content of muscle with advancing age. This is associated with thickening of the connective tissue and increased muscle stiffness.

EVIDENCE and RESEARCH 5-4

Fourteen elderly subjects were randomly assigned to a resistive training (RT) or control group. The RT trained BIW for 4 sets of 10 repetitions of a leg press at 70% to 80% of 1 RM. The leg press 1 RM increased by 42% after 10 weeks of training, whereas significant increases in vastus lateralis muscle cross-sectional area were seen only after 9 weeks.[22] Walker et al.[80] compared the changes in neuromuscular performance and muscle hypertrophy between young and older men who performed 10 weeks of a high-volume, medium load resistance training program two times per week. Although both groups improved their muscle performance, only the young men showed significantly increased lean mass, and only the older men showed increased muscle activation. This program did not result in increases in muscle power measured by concentric rapid force production.[81]

The decrease in muscle performance with advancing age affects men and women differently. The absolute decline in strength is less steep in women than in men. Parts of the body are also affected differently. The arms are more affected than the trunk and legs, probably because of less use of the upper extremities in strength-related activities. Active elderly women surpass inactive men with respect to trunk muscle strength.

Adequate muscle strength helps to prevent or moderate the symptoms of degenerative changes of the joints. Resistive exercise by the elderly should be directed toward the muscles susceptible to atrophic changes, especially the deep neck flexors, scapular stabilizers, abdominal and gluteal muscles, and quadriceps. Unjustifiably, little attention is paid to strength of the ventilatory muscles (i.e., diaphragm) and pelvic floor muscles. Training should include both multijoint and single-joint exercises.

Additionally, the elderly should consider training for power, not just strength. Leg power has been shown to significantly influence the physical performance of mobility-limited elderly people.[82,83,84] In some cases, power training has been found to be more effective at improving physical function than traditional strength training.[81,83,85,86] Ankle dorsiflexor and plantarflexor peak power is predictive of chair rise and stair climb performance.[87] Elderly with low power have a two to three times greater risk of significant mobility limitations compared with elderly with low strength.[88] Most strength programs are performed at a slow velocity, whereas power training typically occurs at a higher velocity.

High-velocity resistance training has been shown to increase muscle power more effectively than low-velocity training in older women.[89] High-velocity power training at both high resistance (70% of 1 RM) and low resistance (40% of 1 RM) yielded improvements in muscle power and performance in mobility-limited elderly[90,91] (**Evidence and Research 5-5**). High-velocity power training has also improved braking speed in the elderly, an important factor in fall prevention.[92] As such, high-velocity training may be a preferred resistance training strategy in the elderly.[93] Power training in this group should include light to moderate loads performed for 6 to 10 repetitions with high velocity. See Chapters 17 through 26 for resistive exercises for the spine, shoulder, arm, hip, knee, and pelvic floor (**Fig. 5-9**).

EVIDENCE and RESEARCH 5-5

Researchers studied the effects of power training at different velocities on functional activities such as habitual gait velocity (HGV), stair climb (SC), and chair rise (CR) and compared these to strength training in older men and women. .Power training at 70% and 40% 1 RM showed greater associations with HCV and SC than did strength training at 1 RM. Additionally, power training at 40% 1 RM accounted for more of the variability in HCV than did power training at 70% 1 RM, supporting the use of higher-velocity training in older men and women with mobility limitations.[91]

With advancing age, the social needs and individual motivation for strength demands lessen; the atrophy reflects the effects of disuse, not mere age-related changes. The voluntary and deliberate use of the motor system in daily life activities and intentional resistive training are able to counteract the

FIGURE 5-9 Power training in the elderly using a leg press machine.

loss of muscle mass with increasing age. The vigorous use of muscles, particularly among old persons, improves their health and sense of well-being.

Cognitive Aspects of Performance

The cognitive or mental aspects of strength and performance are most easily seen in elite athletes. Sport psychologists and athletes support using mental imagery techniques such as visualization and positive self-talk. Positive cognitive strategies can enhance strength and performance, and negative strategies may have a negative or negligible impact (**Evidence and Research 5-6**).

EVIDENCE and RESEARCH 5-6

A study of different mental preparation techniques (i.e., arousal, attention, imagery, self-efficacy, and control-read conditions) showed that these techniques and other self-efficacy techniques produced greater posttest strength performance than a group of controls who did not use any mental preparation techniques.[94] Jump height was improved following stating or reading specific action verbs, after specific kinesthetic imagery activities, and after performing mathematical operations, suggesting a link between cognition and performance.[95]

Different kinds of imagery and their impacts on power and endurance activities (i.e., seated shot of endurance activities put and push-ups to exhaustion) have been studied. Results show that these imagery techniques have a positive impact and that using metaphors is particularly effective in improving power and endurance measures.[96] A study of the impact of imagery, preparatory arousal, and counting backward on hand grip strength found imagery to enhance grip strength in both older and younger subjects.[97] Gould et al.[98] found that imagery and preparatory arousal improved strength performance. Verbal encouragement and head-to-head competition enhance performance of endurance activities, whereas mental fatigue has a negative impact.[99]

Effects of Alcohol

The deleterious effects of alcohol abuse on muscle have been well documented.[100] The myopathic changes seen in patients abusing alcohol have at times been attributed to malnutrition or disuse. Experiments have demonstrated that, even with nutritional support and prophylactic exercise, normal subjects can develop alcoholic myopathy if they ingest large amounts of ethanol.[101]

Alcoholic myopathy has two clinical phases:

1. An acutely painful presentation that follows “binges”
2. A chronic phase that consists of morphologic and functional alterations in muscle[102]

Acute alcoholic myopathy has morphologic features, such as fiber necrosis, intracellular edema, hemorrhage, and inflammatory changes. Binges by chronic alcoholics can result in an acute myopathy characterized by muscle cramps, muscle weakness, tenderness, myoglobinuria, reduced muscle phosphorylase activity, and decreased lactate response to ischemic exercise. Exercise is contraindicated for persons with acute myopathy and those with myoglobinuria, because it may stress an already compromised system.

Changes seen with chronic alcoholic abuse include type II fiber atrophy, suggesting that alcoholic patients may exhibit an inability to generate tension rapidly and to produce power.[103] For many patients, abstinence leads to full recovery of muscle function, but for others, the injury may be more severe and resistant to treatment, and this must be considered as a comorbidity when projecting the prognosis.

Effects of Medications

The widespread use of oral corticosteroid agents as anti-inflammatory and immunosuppressant agents has led to cases of steroid atrophy.[104,105] Corticosteroids are a potent catabolic stimuli, and the atrophy caused by prolonged corticosteroid use occurs as protein degradation exceeds protein synthesis. In patients with chronic lung disease, the adverse effects appear to be dose related with increased muscle weakness, back pain, and bruising associated with higher-corticosteroid dosages.[106] The primary biopsy finding in patients treated with prednisone-like steroids (e.g., prednisone, prednisolone, methylprednisolone) is type II fiber atrophy, specifically in type IIB fibers[105,107]; it is believed to occur more often in women than men.[108] Goldberg and Goodman[109] believe that the constant use of the type I fibers during normal voluntary movement provides these fibers with a protective mechanism. Exercises recruiting type II muscle fibers may protect them from steroid-induced atrophy. Normal function can be expected to return within 1 year or, more often, within several months after steroid use has stopped.[108]

Myositis and more severe cases of rhabdomyolysis (requiring hospitalization) have been associated with statins, one of the most commonly prescribed cholesterol-reducing medications, statin[110–113] Although the benefits of cholesterol lowering are clear, side effects such as muscle fatigue, weakness, and pain can be debilitating for patients.[114] Muscle cell apoptosis has been suggested as a potential mechanism for statin-induced myopathy.[114] Myopathy may be caused by the drug itself, by interactions with other drugs, or by capitalizing on individual genetic, immunologic, or metabolic factors.[115] A few of the risk factors include polypharmacy, age >80 years, female sex, diabetes, immunocompromised, high-activity levels, or vitamin D deficiency.[116,117]

Patients with statin-induced myopathy will complain of muscle aching, pain, cramping, stiffness, and fatigue, often symmetrical, but not always. Creatine kinase levels may or may not be elevated.[117] Significant individual variability and lack of a gold standard test have made diagnosing this condition challenging. Physical therapists are uniquely positioned to use muscle performance measures to evaluate patients for statin-induced myopathy.[118] Additionally, close monitoring of patient activity levels can detect and prevent worsening conditions such as rhabdomyolysis.[119–121] Use caution when prescribing therapeutic exercise in patients who are on statin medications, particularly those patients with additional risk factors for statin-induced myopathy. Weight-bearing exercise and eccentric muscle contractions will place patients at additional risk of myopathy.[122] Additionally, statin use can blunt the usual response to aerobic and strength training.[123]

CAUSES OF DECREASE MUSCLE PERFORMANCE

Muscle performance can be impaired for a variety of reasons. Some of these include central or peripheral neurologic pathology; injury to the muscle from a strain or contusion; injury or inflammation to the tendon or its attachment to bone (see Chapter 11); certain medications (see previous section); and disuse or deconditioning for any reason. The goal of examination/evaluation of muscle performance is to determine the *cause* of the impairment in order to develop the most efficient and comprehensive intervention plan. The following section discusses the potential factors that can cause impaired muscle performance, examination/evaluation results of each potential cause, and general intervention concepts for each specific cause.

Neurologic Pathology

Neurologic pathology can affect the contractile capacity of muscle as a result of pathology in the central or peripheral nervous system. The peripheral nervous system can be affected at the nerve root or peripheral nerve level.

Individuals with nerve root pathology may present with muscle performance impairments in the nerve root distribution. For example, nerve root compression at the L4–L5 spinal level can produce quadriceps femoris weakness, whereas nerve root compression at the C5–C6 spinal level can result in deltoid and biceps weakness. Therapeutic exercise intervention depends on the prognosis for the nerve root involvement. If the changes are relatively recent and resolution of the nerve root compression is expected through conservative or surgical management, preventive and protective measures are taken. The goal of therapeutic exercise intervention is not only to promote optimal muscle performance of the muscles innervated by the affected spinal segment (pending prognosis) but also to promote spine stability and optimal movement patterns to alleviate any mechanical cause of nerve root pathology incurred by the spinal segment(s) (see Chapters 17 and 23).

Peripherally, use resistive exercise to maintain or improve current strength levels, while training deep lumbar or deep cervical flexor muscles to provide proximal stability. Centrally, use resistive exercise to train inner core muscles (i.e., longus coli, transversus abdominis, lumbar multifidus, pelvic floor; see Chapters 18, 19, and 24 for detailed muscle performance training) to effectively stabilize the spine and relieve mechanical nerve root irritants. After the mechanical or chemical cause of nerve root injury is remediated, use specific, localized resistive exercise of the involved musculature to restore precise recruitment patterns.

Neurologic weakness may also result from a peripheral nerve injury (i.e., median nerve at the carpal tunnel, the ulnar nerve at the cubital tunnel, or the common peroneal nerve at the fibular head). The pattern of sensory loss and weakness depends on which nerve and where along the nerve's course the insult occurs. Therapeutic exercise should be focused on remediating the mechanical cause of the peripheral nerve injury. For example, a depressed shoulder girdle may contribute to traction on the long thoracic nerve, causing motor changes in the serratus anterior. Exercise and posture education to elevate the shoulder girdle may alleviate the traction on the long thoracic nerve and ultimately restore normal innervation to the serratus anterior. Exercise should try to maintain muscle balance and efficient movement patterns without developing a dominant muscle group. Splinting, bracing, taping, or other supportive measures may be necessary to maintain balance, especially in the short term.

Other neurologic conditions include neuromuscular disease such as multiple sclerosis, postpolio syndrome, Guillain–Barré syndrome, and muscular paralysis or paresis resulting from spinal cord injury or stroke. Resistive exercise programs must consider the prognosis and tailor the exercises appropriately. In situations such as Guillain–Barré syndrome, certain cases of spinal cord injury and stroke and progressive stages of multiple sclerosis, some recovery is expected. Exercise programs focus on improving muscle performance in intact musculature and gently strengthening weakened muscles as recovery and remission advances. Avoid fatiguing weakened muscles during strengthening exercises. Dosage parameters generally include several short exercise sessions of a few repetitions interspersed throughout the day.

During quiescent periods of diseases such as multiple sclerosis, a general conditioning program of balanced strengthening and mobility exercises is appropriate. When recovery is not expected, resistive exercise programs emphasize functional strength of remaining musculature. This includes strength for functional activities such as self-care, transfers, and mobility. Take care to avoid overworking these muscles. Unlike persons with full innervation who use their muscles efficiently, the individual with paralysis uses the few innervated muscles they have for nearly all their activities. The potential for overuse injuries is very high.

Muscle Strain

Muscle strain occurs along a continuum from acute macrotraumatic injury to chronic microtraumatic overuse injuries and can be caused by traumatic strain, eccentric loading, chronic overuse, muscle dominance overuse, or continuous overstretching (see Chapter 11). Resistive exercise in the treatment of muscle strain injuries depends on where along this continuum the injury occurs. Resistive exercise that neither overloads nor underloads the tissue is optimal. Determining this resistance dosage is the challenge.

Acute traumatic injuries occur when a muscle is rapidly overloaded or overstretched, and the tension generated exceeds the tensile capability of the musculotendinous unit.[124] The hamstring muscle is a common site of muscle strain injury. A combination of insufficient strength, reduced extensibility, inadequate warm-up, and fatigue has been implicated in hamstring injuries[125] (see **Patient-Related Instruction 5-1**). Strength, extensibility, and fatigue resistance protect a muscle from strain injury.

Eccentric loading is a common mechanism of muscle strain injury, but a muscle prepared for eccentric loading is less likely to sustain an injury. Eccentric loading should be an integral part of any resistance training program (see **Selected Intervention 5-1**, for an example of eccentric loading). A program to prevent muscle strain injuries should include dynamic resistive exercises with a strong eccentric component, flexibility exercises, appropriate warm-up before activity, and attention to fatigue levels. The rehabilitation program after injury should also focus on these factors.

Muscles may also be strained from chronic overuse. For example, extensor digitorum longus (EDL) strain is common in workers performing continuous repetitive elbow, wrist, and hand activities as a result of using the EDL for wrist extension and elbow flexion. Training the individual to use the biceps for elbow flexion whenever possible (i.e., keep the hand supinated vs. pronated during elbow flexion) can alleviate the overuse strain to the EDL. A thorough evaluation can determine the cause of the overuse problem. Ergonomic assessment and appropriate work site modification are also necessary to prevent a recurrence of the strain if ergonomics is at the root of undesirable posture or movement patterns. If left untreated, this impairment can quickly lead to participation restrictions.

Strain resulting from muscle dominance overuse is managed by reducing the loads imposed on the strained muscle. When the tensor fasciae latae dominates over the iliopsoas during hip flexion and over the gluteus medius during abduction, the tensor fasciae latae is at risk for an overuse strain. Improving the strength and recruitment patterns of the iliopsoas and gluteus medius can reduce the load on the tensor fasciae latae and allow it to recover. Postural habits (e.g., standing in medial rotation) and movement patterns (e.g., hip flexion or abduction with medial rotation) must also be modified to improve recruitment of the underused synergists.

A potential risk factor of muscle strain is gradual, continuous overstretching, which occurs when a muscle is continuously placed in a relatively lengthened, tension-producing position. For example, the lower trapezius in a person with protracted scapulae is subjected to continuous tension and has adapted to a lengthened state. It may not take much force to produce a strain injury in a muscle that is already overstretched. This type of strain puts the muscle at risk for two forms of muscle weakness; (1) from length–tension changes and (2) from overstretch strain.

Patient education is a key component of the rehabilitation program in the case of muscle strain associated with continuous overstretch. In the lower trapezius example, educate the patient about optimal postural habits to reduce tension on the lower trapezius. Improving postural habits and reducing tension on the lower trapezius with bracing or taping (see Chapter 25) will allow the muscle to heal more rapidly. In addition, it will promote adaptive shortening and therefore ultimately achieve a more optimal length–tension relationship and reduce the risk for future reinjury.

Patient-Related Instruction 5-1

Preventing Muscle Strain

Although some muscle strains are not preventable, precautions can reduce your risk of injury.

1. Warm up before a vigorous activity; 5 to 7 minutes of a large muscle group activity such as walking, jogging, or cycling should suffice. This should be enough activity to break a sweat.
2. Stretch stiff and short muscles after your general warm-up. Stretching can be static or dynamic depending on your activity. Stretch each muscle for 15 to 30 seconds for 4 repetitions at the conclusion of your exercise session.
3. Balance your sports or other leisure activities with strengthening exercises. Your clinician can help you focus on muscles susceptible to injury.
4. Avoid fatigue during the activity. Fatigue can increase your risk of injury.
5. Strengthen underused muscles to prevent overuse to susceptible muscles. Your clinician can help you determine which muscles these are and what specific exercises you need to perform to maintain muscle balance.

SELECTED INTERVENTION 5-1

Lateral Kicks

See Case Study No. 1

Although this patient requires comprehensive intervention as described in other chapters, only one exercise related to resistive training is described. This exercise would be used in the late phase of this patient's rehabilitation.

ACTIVITY: Resisted hip abduction and ankle eversion.

PURPOSE: To increase the muscle performance of the ankle evertor and hip abductor muscles.

STAGE OF MOTOR CONTROL: Controlled mobility.

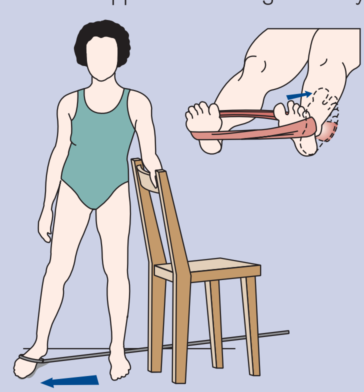
MODE: Resistive band.

POSTURE: Standing with one foot on the resistive band and the band around the other foot. A support should be readily available for balance as needed.

MOVEMENT: Standing on the uninjured leg, abduct the hip in the frontal plane, and evert (pronate) the ankle. Raise the leg to the side slowly and controlled (concentric phase) and lower to the starting position more quickly (eccentric phase), but controlled. Maintain good spinal posture throughout the exercise. Do not hike pelvis; move only at the hip joint. Maintain frontal plane movement; moving toward flexion results in the motion performed by the flexor abductor group. Repeat.

DOSAGE: Two to three sets per day to form fatigue. If patient does not fatigue by 20 repetitions, increase the resistance of the band.

EXPLANATION OF PURPOSE OF EXERCISE: This exercise increases muscle performance in the hip abductors and ankle evertors in a synergistic fashion. Abductors are strengthened in both concentric and eccentric modes. It may be progressed to a higher speed to increase the eccentric loading. Remove the support to challenge stability.



Disuse and Deconditioning

Muscle performance may be impaired because of disuse or deconditioning for a variety of reasons. Illness, surgery, specific physical conditions (e.g., pregnancy with twins), or injury may necessitate a period of decreased activity. Subtle muscle imbalances can lead to overuse of one muscle and to disuse and deconditioning of another.

Illness and injury are common causes of deconditioning. For example, illness such as pneumonia or an injury such as a herniated disk can result in a period of decreased activity and subsequent deconditioning. In these situations, total-body deconditioning occurs, and general conditioning is necessary, whereas specific exercises may be necessary to improve muscle performance and prevent secondary impairments. For example, an elderly individual may have relatively asymptomatic osteoarthritis until a bout with pneumonia produces general deconditioning. Subsequently, knee osteoarthritis becomes symptomatic because of impaired muscle performance in the lower extremity muscles involved in gait and other functional activities. Specific resistive exercises to address the impairment of muscle weakness are necessary to restore proper biomechanics and prevent activity limitations and participation restrictions.

Reduced activity levels can impair muscle performance in a similar manner. Multiparous pregnancies, exacerbation of a musculoskeletal injury, an episode of colitis, or social factors such as major life changes (e.g., job, school, divorce, family illness) can reduce activity levels and result in impaired muscle performance. For example, regular exercise may keep a woman's patellofemoral malalignment from becoming symptomatic. When her activity level decreases in the late stages of pregnancy, the combination of decreased activity, weight gain, and hormonal changes produces symptoms at the patellofemoral joint. Selective resistive exercises combined with patient education can prevent this exacerbation. Resistive exercises in the case of overall decreased activity must consider the muscles most likely to be affected, the patient's desired activity level and preference, and any underlying or residual medical conditions.

An overlooked source of deconditioning or disuse is a subtle muscle imbalance. When activating muscles for a functional movement, the body chooses the most efficient muscular and motor unit activation pattern. Certain motor units in a muscle may be preferentially recruited when a muscle is engaged in a particular task.[126] For example, motor units in the lateral portion of the long head of the biceps are preferentially activated when this muscle is engaged in elbow flexion, whereas motor units in the medial portion are preferentially activated in forearm supination.

The recruitment thresholds of motor units in a muscle are also influenced by the type of muscle actions associated with a movement. In elbow flexion, biceps motor units have a lower threshold in slow concentric and eccentric actions than isometric actions; the reverse is true for the brachialis.[127] The recruitment thresholds of motor units of a muscle active in a movement may also be affected by changes in joint angle.[128] Some muscles or portions of a muscle may be overused, whereas other muscles or portions are disused, and the resistive rehabilitation program must acknowledge this imbalance. In the previous example, instruction in general resisted elbow flexion may exacerbate the imbalance whereas specific training of the weaker recruitment pattern can restore muscle balance.

Length-Associated Changes

The principle of the length–tension curve affects muscle performance when a muscle is adaptively lengthened from prolonged posture and repetitive movement patterns with the muscle in that lengthened state. Positional weakness can result. Postural examination findings of a depressed shoulder suggest length weakness in the rhomboids and trapezius muscles, whereas findings of an adducted and medially rotated hip suggest length weakness in the gluteus medius muscle. Muscles will test weak in the short range when compared with synergists (i.e., posterior gluteus and tensor fasciae latae), paired muscle of the other extremity (i.e., right and left posterior gluteus medius), or other half of the axial skeleton (i.e., right and left external oblique muscles). Intervention should focus on strengthening the muscle in the shortened range, optimizing posture to reduce lengthening tension on the muscle, and altering movement patterns to recruit the muscle in the shortened range.

PHYSIOLOGIC ADAPTATIONS TO TRAINING

Strength and Power

The benefits of resistive exercise extend beyond the obvious improvements in muscle performance to include positive effects on the cardiovascular system, connective tissue, and bone. Moreover, these effects translate into function. Individuals perform their daily activities with more ease because they are functioning at a lower percentage of their maximum capacity. Functional activities such as gait velocity, stair climbing, and ease of transfers are all improved with resistive training.[90,129] Improved functioning also enhances the patient's sense of well-being and independence. Additionally, strength training has shown crossover effects, where training one limb translates into muscle performance improvements in the contralateral limb.[39,130]

Muscle

The most obvious benefits of resistive training are for the muscular system. Regular resistive exercise is associated with several positive adaptations, most of which are dosage dependent (**Table 5-6**). The cross-sectional area of the muscle increases as a result of an increase in the myofibril volume of individual muscle fibers, fiber splitting, and potentially an increase in the number of muscle fibers. These changes have been seen in a variety of age groups, and when using different resistance training modes and dosages.[131–135] Changes in the muscle depend on fiber type and the stimulus.[136,137] Hypertrophy of fast-twitch fibers occurs when all or most of the fibers are being recruited and is considered an adaptation for increased power output. Slow-twitch fibers hypertrophy in response to frequent recruitment. In repetitive, low-intensity activity, fast-twitch fibers are rarely recruited, and these fibers may atrophy while the slow-twitch fibers hypertrophy. Staron et al.[138] examined the differences in the proportion of muscle fiber types between distance runners, weight lifters, and sedentary controls. The weight lifters had a greater proportion of type IIA fibers than the controls or distance runners.[138] This exemplifies the need for specificity of resistive training when designing a training program.

On the cellular level, capillary density is unchanged or decreases, and the mitochondrial density decreases.[132,133] Although protein volume and cross-sectional area increase, some of the cellular or systemic factors may remain unchanged, resulting in a perceived decrease, although the decrease is only relative.

TABLE 5-6

Physiologic Adaptations to Resistance Training

VARIABLE	RESULT AFTER RESISTANCE TRAINING
Performance	
Muscle strength	Increases
Muscle endurance	Increases for high-power output
Aerobic capacity	No change or increases slightly
Maximal rate of force production	Increases
Vertical jump	Increases
Anaerobic power	Increases
Sprint speed	Improves
Muscle Fibers	
Fiber size	Increases
Capillary density	No change or decreases
Mitochondrial density	Decreases
Enzyme Activity	
Creatine phosphokinase	Increases
Myokinase	Increases
Phosphofructokinase	Increases
Lactate dehydrogenase	No change or variable
Metabolic Energy Stores	
Stored ATP	Increases
Stored creatine phosphate	Increases
Stored glycogen	Increases
Stored triglycerides	May increase
Connective Tissue	
Ligament strength	May increase
Tendon strength	May increase
Collagen content	May increase
Bone density	Increase
Body Composition	
Percentage of body fat	Decreases
Fat-free mass	Increases

Adapted from Falkel JE, Cipriani DJ. Physiological principles of resistance training and rehabilitation. In: Zachazewski JE, Magee DJ, Quillen WS, eds. Athletic Injuries and Rehabilitation. Philadelphia, PA: WB Saunders, 1996.

Energy sources that fuel muscle contraction increase after resistive training. In general, levels of creatine phosphate, ATP, myokinase, and phosphofructokinase increase in response to a resistive exercise program.[139–142] Lactate dehydrogenase is variably changed.[140]

Neural adaptations occur with resistive training. Studies have shown increases in the muscle's ability to produce torque and increased neural activation, as measured by electromyography (EMG).[49] Increased EMG values associated with greater power and maximal contraction were attributed to a combination of increased motor unit recruitment and increased firing rate of each unit.[143]

Connective Tissue

Although disuse and inactivity cause atrophy and weakening of connective tissues such as tendon and ligament, physical training can increase the maximum tensile strength and the amount of energy absorbed before failure.[144] Physical activity returns damaged tendons and ligaments to normal tensile strength values faster than complete rest.[145] Physical training, particularly resistive exercise, may alter tendon and ligament structures to make them larger, stronger, and more resistant to injury. Additionally, resistive training can increase the loading capabilities of the tendon-bone and ligament-bone interfaces.[146]

Bone

Weightlessness[147] and immobilization[148] can cause profound loss of bone density and mass. Weight-bearing activities that recruit antigravity muscles can maintain or enhance bone density and mass.[149] Individuals in sports requiring repeated high-force movements such as weight lifting and throwing events have higher-bone densities than distance runners, soccer players, or swimmers.[150] Those who play tennis regularly have higher-bone density in their dominant forearms, and professional pitchers have greater bone density in the dominant humerus.[151] A 5-month study of weight training compared with jogging found that weight training produced significantly better increases in lumbar bone density than the aerobic exercise.[152]

Resistive training to improve bone density is important for people of all ages, and particularly for women who are prone to osteoporosis[153] (**Evidence and Research 5-7**). In adolescents, resistive training and weight-bearing exercise consistently show improvements in bone density compared with sedentary peers.[157–159] Impact activities that include jumping and landing are particularly effective in building bone mass and strength, especially when combined with proper nutrition in the pre- and peri-pubertal periods.[160] Research into bone mass and exercise dosage found that daily loading regimens broken down into four sessions with recovery time in between improved bone mass significantly over a loading schedule that performed the training in a single, uninterrupted session.[161] Thus smaller exercise sessions separated by recovery periods may be a better prescription when increased bone mass is the goal.

EVIDENCE and RESEARCH 5-7

A study of adolescent female athletes found runners to have higher total body and site-specific bone mineral density than swimmers or cyclists, and that knee extension strength was an independent predictor of bone mineral density in this population.[154] Adolescent female swimmers did not show increases in bone mineral density compared with a control group, highlighting the importance of weight-bearing or impact activities for adolescent females.[155] Female athletes participating in high impact or odd impact (i.e., soccer, racket sports) demonstrated thicker cortices and denser bones than controls or swimmers.[156]

Cardiovascular System

Resistive training benefits the cardiovascular system. The idea that strength training causes hypertension is erroneous. Most reports show that highly strength-trained athletes have average or lower than average systolic and diastolic blood pressures.[162] When performed properly and heeding the proper precautions, strength training can have a positive effect on the cardiovascular system.

Increased intrathoracic or intra-abdominal pressures may affect cardiac output and blood pressure during resistive exercise. In the classic model, increased intrathoracic pressures are thought to decrease venous return, decrease cardiac output, and cause an increase in blood pressure. Performing resistive exercises with a Valsalva maneuver, which elevates intrathoracic pressure, leads to a greater blood pressure response than performance of the exercise without a Valsalva maneuver.[163] Instructing the patient to breathe properly during exercise may reduce the increase in blood pressure sometimes seen during exercise.

Increased intramuscular pressure during resistive exercise may result in increased total peripheral resistance and increased blood pressure. Mechanically induced increases in peripheral resistance probably are the cause of higher blood pressures during isometric and concentric exercise compared with pressures during eccentric exercise.[164] Isometric or concentric exercise combined with a Valsalva maneuver can produce the greatest increase in blood pressure. This combination should be avoided, especially by individuals at risk for elevated blood pressure (see Section "Precautions and Contraindications").

Resistive exercise does result in a pressor response that affects the cardiovascular system by causing hypertension through exciting the vasoconstrictor center, which leads to increased peripheral resistance. If precautions are taken to ensure proper breathing and avoid isometric contractions in persons at risk for a pressor response, resistive exercise's benefits outweigh the risks. Long-term performance of resistive exercise can result in positive adaptations of the cardiovascular system at rest and during work. Cardiovascular adaptations to resistive training are summarized in **Display 5-2**.

Endurance

As expected, the muscle's response to endurance training is different from its response to strength or power training. Muscular endurance depends on oxidative capacity, and training increases the muscle's metabolic capacity. During prolonged activities, depletion of intramuscular glycogen reserves may contribute to impaired muscular endurance.

Muscles trained for endurance demonstrate cells with increased mitochondrial size, number, and enzymatic activity,[166] allowing the muscle to better use the oxygen delivered. In addition, endurance-trained muscle demonstrates increased local fuel storage; they increase fatty acid use and decrease the use of glycogen as a fuel, allowing more exercise before fatigue. Lastly, endurance muscle training improves the oxygen delivery system by increasing the local capillary network, producing more capillaries per muscle fiber.[166] Increased perfusion slows the accumulation of lactate in the working muscles.

DISPLAY 5-2

Benefits of Strength Training on the Cardiovascular System[165]

- Decreased resting heart rate
- Decreased or unchanged systolic blood pressure
- Decreased or unchanged diastolic blood pressure
- Increased or unchanged cardiac output
- Increased or unchanged stroke volume
- Increased or unchanged maximal oxygen consumption
- Decreased or unchanged total cholesterol

EXAMINATION AND EVALUATION OF MUSCLE PERFORMANCE

Decreases in muscle performance may occur for a number of reasons. The physical therapist must perform a thorough examination to determine the cause of impaired muscle performance and the link between impaired muscle performance and activity limitations or participation restrictions. After that relationship is established, therapist must then match the intervention to the cause of impaired muscle performance. The muscle test is only one small part of the examination process and must be used with additional information (e.g., ROM, joint mobility, balance, sensory, and reflex integrity) to determine the specific cause of impaired muscle performance.

The tests and measures recommended by the *Guide to Physical Therapist Practice*[167] ensure comprehensive assessment of the patient's impairments, activity limitations, and participation restrictions. Various muscle performance tests include manual muscle tests, dynamometry, electrophysiologic testing, and an analysis of functional muscle strength, power, or endurance. Of these, manual muscle testing is the most fundamental of all strength tests. Consider length–tension relationships, muscle imbalance, and positional weakness when choosing manual muscle test positions. Minimize the chance of erroneous results by paying close attention to substitution patterns and by testing in a variety of positions. When used reliably, hand-held dynamometers can provide muscle performance information that is more reliable than that of tests using the traditional criteria of 0 through 5.

Isokinetic dynamometers are commonly used to assess muscle performance. Computerized systems provide tremendous data reduction capabilities. Tests can be performed at a variety of speeds and comparisons made with antagonists, the contralateral limb, normative standards, or previous test results. These tools provide reliable data that can be used to assess progress, as a motivator, or as criteria for progression to more advanced rehabilitation phases. A variety of muscle actions can be assessed using this equipment.

Dynamic strength can also be determined using the RM method. For example, a 10 RM is the maximum amount of weight that can be lifted 10 times, and a 1 RM is the maximum amount of weight that can be lifted once. The amount of weight that can be lifted for a given number of repetitions can be determined and compared with that for the antagonist, the opposite limb, or to a previous test result.

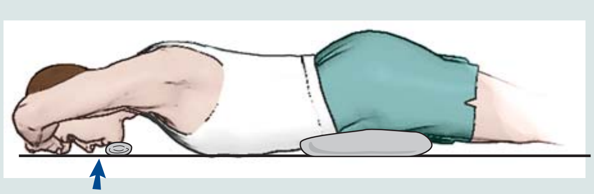
The magnitude of measured increases in force or torque depends on how similar the test is to the training exercise.[168] For example, if athletes train their legs by doing the squat exercise, the increase in strength measured as maximal squatting is much greater than the strength increase measured in isometric leg press or open kinetic chain knee extension tests. This specificity of movement pattern in strength training probably reflects the role of learning and coordination.[169] Improved coordination takes the form of the most efficient activation of all of the involved muscles and the most efficient activation of motor units within each muscle involved. Testing force production in the manner in which the muscle has been trained reflects the morphologic and neurologic adaptations.

CLASSIFICATION OF RESISTANCE EXERCISE

Resistive exercise can be broadly classified into categories comparing the force generated by a muscle or muscle group relative to an external load. This external load can be applied by numerous mechanisms such as a machine, a resistive band, hand-held equipment, a person (manual resistance), a stationary object or body weight. Exercises where the internal force generated matches the externally applied load are considered to be **isometric** exercises. In isometric exercise, no joint motion takes place, although muscle activation occurs. All other activities are **dynamic** involving joint motion. When the external load is less than the force generated by the muscle **concentric** contractions result, whereas when external loads exceed the internally generated force, **eccentric** contractions are produced. Resistance applied at a constant velocity is termed *isokinetic*.

Isometric Exercise

Isometric exercise is commonly used to increase muscle performance. Although no joint movement occurs and technically no work is performed (work = force × distance and distance = 0), isometric exercise is considered functional because it provides a strength base for dynamic exercise and because many postural muscles work primarily in an isometric fashion (see **Self-Management 5-1**, for an example of isometric exercise for postural muscles). Before an eccentric muscle contraction, a concentric or an isometric contraction must occur first, presetting tension in the muscle. For example, the quadriceps muscles isometrically preset tension to stabilize the knee in full extension before initial contact during the gait cycle; the same happens when the knee is in near full extension prior to landing from a jump. These isometric contractions allow a subsequent quadriceps eccentric contraction to decelerate the flexing knee to absorb shock. Therefore, isometric contractions are an essential component of many functional activities.

> SELF-MANAGEMENT 5-1
>
> **Isometric Cervical Spine Extensor Strengthening**
>
> **Purpose:** To strengthen cervical extensors.
>
> **Position:** Lying on your stomach with fists positioned under your forehead and a pillow under your trunk; a small towel roll under your chin may be necessary to keep your head in neutral.
>
> **Movement Technique:** Remove your hands from your forehead and hold your head in a proper neutral position.
>
> Hold for 10 seconds, breathe normally.
>
> **Dosage:**
>
> Repetitions: ____________________
> per set ____________________ sets
>
> Frequency: ____________________
> sessions per day, ____________ sessions per week
>
> 

Indications

Isometric exercise is a valuable rehabilitation tool in many situations. For example, isometrics are:

- A foundational exercise, an isometric training often precedes dynamic muscle training
- Used to pretension muscles before any eccentric muscle contraction
- Preferred over dynamic exercise when joint motion is uncomfortable or contraindicated, such as postoperatively or with an unstable joint
- Essential to maintain muscle strength and prevent significant declines during immobilization
- Combined with dynamic exercise to focus strengthening at a weak point in the ROM
- Frequently used for muscle reeducation purposes
- An important component of stabilization programs

One of the benefits of isometric exercise is the ability to perform repetitive submaximal contractions as "reminder" or reeducation exercises. Following lower extremity injury or surgery, recruiting and activating the quadriceps muscles can be difficult; similarly, recruiting and activating the rotator cuff musculature following shoulder surgery or injury can be equally challenging. Quadriceps setting and rotator cuff isometric exercises at a low, submaximal level can maintain connective tissue mobility (i.e., patellar mobility, ligament, tendon, and fascial mobility), and muscle mobility and function. Quadriceps and gluteal sets are also used to enhance circulation and maintain mobility and muscle performance throughout the lower extremity during periods of bed rest.

Isometric setting exercises area prerequisite for more advanced dynamic exercises, particularly those requiring eccentric muscle contractions. This is a more complex neuromuscular activity than one might think. *Neuromuscularly, isometric tension is set at an appropriate and predetermined level before commencing an eccentric muscle contraction*. For example, if one were to catch an object being tossed at them, or to jump down from a given height, the brain must first signal the necessary muscles to preset isometric tension in order to decelerate the object upon catching, or the body upon landing, *respectively*. The brain determines how much isometric tension to preset based upon previous experience and estimates of the object weight or distance to landing (**Fig. 5-10**). One of the significant challenges is teaching the patient *how* much tension to preset to accomplish a given task. In this case, isometric training at different percentages of maximal activation is useful.

Isometric exercise also functions as a component of dynamic exercise when weakness exists at a specific point in the ROM. Proprioceptive neuromuscular facilitation (PNF) techniques include isometric contractions as part of a dynamic program to enhance stability and to strengthen muscles in a weak portion of the range (see Chapter 15). For example, while performing a diagonal pattern, the therapist may stop and apply an isometric contraction at a weaker portion of the ROM.

A B

FIGURE 5-10 Landing from a jump requires presetting isometric quadriceps muscle contraction **(A)** prior to landing **(B)**.

Isometric contractions are also an important component of stabilization programs. **Stabilization** programs are a progressive series of exercises and activities designed to increase a patient's ability to dynamically control movement at a joint or series of joints. Stabilization exercises are an important component of treatment programs for shoulder, knee, and ankle instability, as well as the basis of treatment for many spinal problems (**Fig. 5-11**). For example, PNF techniques such as alternating isometrics and rhythmic stabilization use isometric contractions as the basis for stability training.

This resistive mode is easy to understand and perform correctly, requires no equipment, and can be performed in almost any setting. Isometric exercise is most effective when individuals are in a low state of training, because the benefits of isometric exercise decrease as the state of training increases. Most gains are made within the first 5 weeks of the onset of training.[170]

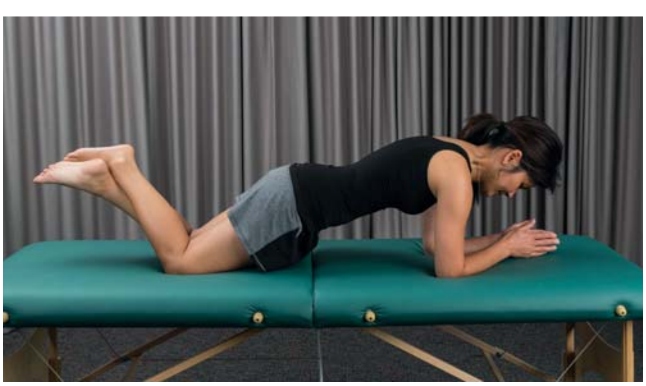


FIGURE 5-11 Plank on elbows and knees is a common isometric stabilization exercise.

Considerations in Isometric Training

Some factors are important in choosing isometric exercise for rehabilitation. Isometric strength is specific to the joint angle. Studies have demonstrated isometric joint angle specificity, noting that strength gained at one joint angle did not predictably carry over to other joint angles.[171] Neuromuscular changes accounted for the joint-angle–dependent effects, and obtaining generalized strength gains required multiangle training programs. Whitley[172] found significantly increased strength at all joint angles after 10 weeks of training at specific joint angles. Others have found this general transfer, although only after training was well advanced.[173] In the beginning training phase, the strength gains were transferred only when the muscle was at shorter than resting length.

Dosage

Like most resistive exercise programs, dosing the exercise is the most challenging aspect. Dosing for strength differs from dosing for muscle reeducation, and this differs from dosing for stabilization. Isometric exercise for these different therapeutic goals requires a specific approach for each.

Dosing for strength training has two important variables: intensity and ROM. Because of the angle specificity, multiangle isometric training is recommended whenever possible. Muscle contraction should be maximal or nearly maximal and should be performed to fatigue. Exercise may be performed at a low frequency. Sample dosage parameters for isometric exercise prescription for strength are as follows:

- Perform isometric contractions every 15 to 20 degrees throughout the ROM.

- Hold each contraction approximately 6 seconds, which is long enough to fully activate all motor units. The first few seconds of the first maximum contraction appears to trigger the major training effect—after the first few seconds, the ability to maintain a maximal contraction drops off dramatically.[23]
- Repeat frequently throughout the day.
- Have their greatest effect near maximal contraction, although this may not be possible in many clinical situations.

Dosing for muscle reeducation requires a different prescription. Contraction intensity is submaximal and can vary from very low intensity (<20% maximum voluntary contraction or MVC) to >50% MVC depending on the situation:

- Exercise at the lowest intensity immediately after injury or surgery serves as a reminder to contract the muscle.
- Following back surgery, perform abdominal muscle contractions at a very low level.
- Following a patellar dislocation, perform low level quadriceps contractions.
- A patient who needs improved thoracic and cervical posture might perform scapular retraction isometrics at 50% or more of MVC throughout the day.

  Because intensity and volume are inversely related, isometric contractions for muscle reeducation are performed at a high volume. Activities that are performed for postural awareness may be put "on cue" asking the patient to perform a set of isometrics on cue, such as every time the phone rings, or every time a new e-mail message arrives. Progress these exercises to dynamic strengthening, isometrics at a higher percentage of MVC, and/or isometric exercise with external resistance, such as holding a position against elastic resistance or with a free weight.

Isometric dosage for stabilization will vary depending on the patient's current strength, injury or pathology and current pain levels. Stabilization exercises are like muscle reeducation in that one of the goals is to train the muscles to dynamically maintain a joint or series of joints within a small range of optimal postures. An additional goal is to simultaneously strengthen the muscles required to do this. Thus the dosage is more flexible and is specific to each patient situation. For stabilization activities, a common pattern would be initial training for muscle reeducation, where the emphasis is on contracting the right muscle group and avoiding the "overflow" phenomenon where the patient globally activates all muscles in the region. For example, in attempting to perform a quadriceps set, the patient may "overflow" activating the hamstring and gluteal muscles in addition to the quadriceps. In the core, the patient may activate all abdominal muscles when trying to activate only the deep trunk stabilizers. Once the correct activation has been achieved, progress the program to strengthening followed again by a muscle reeducation program to teach the patient to activate just enough motor units to accomplish the functional task safely. Thus, the program might look like this:

1. Teach patient how to activate the muscle(s) of interest without overflow.
2. Once isolated, strengthen the muscle(s) of interest.
3. Reeducate to activate only to the level necessary to accomplish the task at hand.

Precautions

Use caution when prescribing isometric exercise for patients with hypertension or known cardiac disease. Isometric exercise can produce a pressor response, increasing blood pressure. Perform isometric exercise without breath holding or a Valsalva maneuver. Individuals with hypertension may benefit from simple, repeated contractions held only 1 to 2 seconds. Encourage the patient to "count aloud while exhaling" to avoid breath holding.

Dynamic Exercise

Dynamic resistive exercise can be performed in a variety of modes, postures, and dosages, as well as with a variety of contraction types (i.e., concentric, eccentric). Dynamic exercise implies joint motion and a shortening or lengthening contraction of the working muscle. Dynamic exercises have been called *isotonic exercises* in the past and the term is still in common usage today despite the technical shortcomings of the term.

Body weight, elastic bands, free weights, pulleys, manual resistance, and weight machines are a few modes of dynamic resistive exercise (see **Patient-Related Instruction 5-2**). Concentric and eccentric contractions can be used in different combinations depending on the mode of exercise chosen (i.e., most weight machines use concentric and eccentric contraction of the same muscle groups whereas manual resisted exercise can use concentric and/or eccentric contractions of opposing or same muscle groups). As with isometric exercise, each type of dynamic exercise has risks and benefits, and the training mode should match the identified activity limitations and participation restrictions. The ACSM recommends that for novice and intermediate training, both free weights and machines be used, whereas the advanced and elite athletes' emphasis should be primarily with free weights.[37]

Although isokinetic exercise is a type of dynamic exercise, it is often considered in a different category from isotonic exercise. Although isotonic exercise can be performed at a constant velocity, it is performed against a constant load. Isokinetic

Patient-Related Instruction 5-2

Purchasing Resistive Equipment

Before purchasing resistive equipment for home use, the following information should be considered:

1. Is the equipment safe? Is it approved by a reputable organization?
2. How easy is the equipment to use? How long will it take to learn how to use it?
3. Is the equipment versatile? Can it be used to train a number of different muscle groups?
4. Will the equipment suit your needs as your training progresses?

Before purchasing equipment, consider joining a health club for a month or two to see:

1. Which equipment you tend to use regularly
2. What features you like about some equipment
3. What features you dislike or seem to be lacking

exercise is performed at a constant velocity with accommodating resistance; that is, the isokinetic device "matches" the resistance applied by the subject. Specific indications and dosage for each type of dynamic exercise will be considered in the next section.

METHODS OF RESISTANCE TRAINING

The specific activities and dosage chosen to improve muscle performance depend on many factors, including the individual's age and medical condition, muscles involved, activity level, current level of training, goals (i.e., strength, power, and endurance), and cause of decreased muscle performance. The following sections describe the activities used to increase muscle performance and their relative risks and benefits. Be sure to match the appropriate training mode to the patient's impairments, activity limitations, and participation restrictions.

Manual Resistance

Manual resistance can be applied by the clinician, the patient, or a family member. It is one of the most longstanding forms of resistance training in the rehabilitation profession. This is likely due to its ease of application and its versatility. Manual resistance can be applied at a variety of intensities, speeds, ranges, and contraction types. The speed, intensity, contraction type, and movement pattern can be varied during a given exercise. Several well-known techniques such as PNF are applied predominantly with manual resistance.

Indications

Manual resistance can be performed in almost any situation where resistance for rehabilitation is required. However, it becomes challenging in situations requiring high force levels, as in training for fitness, wellness, or sports. Manual resistance is especially effective when strength varies throughout the ROM. A patient may have a portion of the ROM that is either weak or painful; the therapist can modulate the resistance more easily with manual techniques than with resistive equipment. The therapist can also apply specific tactile cues to facilitate recruitment at a weak portion of the ROM. Similarly, manual techniques work well if a patient needs assistance through a portion of the ROM, followed by resistance at other positions.

Manual techniques are quite useful when teaching proper movement patterns, as manual assistance/resistance can facilitate proper firing patterns. For example, a PNF technique called *rhythmic initiation* teaches proper movement patterns before the addition of resistance. Manual resistance is indicated when manual contacts are necessary to ensure the proper muscle activation. For example, in some situations synergists may substitute for the desired primary muscle action. Palpation, combined with manual contacts and tactile cues, can facilitate the proper muscle activation and stabilization. Manual cues with one hand can facilitate isometric stabilization contractions while the other hand facilitates and resists a dynamic contraction. PNF techniques, such as alternating isometrics or rhythmic stabilization, are very effective for enhancing specific muscle activation patterns. With these techniques, the agonist and antagonist are alternately activated within a small ROM and at progressively higher speeds until cocontraction provides stability. The alternating aspect of this activity makes manual techniques the optimal form of resistance. Finally, when a variety of speeds is necessary, manual resistance offers the flexibility to change rapidly, enhancing motor learning opportunities.

Considerations

Manual resistance has the benefit of being readily available in the clinic and does not require specific positioning against gravity to achieve resistance. Benefits include the following:

- The amount of resistance can be modified as the exercise session progresses, with decreasing resistance as the patient fatigues. The resistance can be more finely adjusted through the ROM and with every repetition to ensure maximum resistance through the exercise.
- The therapist is able to feel the change in force offered by the patient and can adjust the applied resistance appropriately. That way the patient can obtain the maximum resistance tolerated through the entire exercise set.
- The therapist's hand position is also easily modified to change the lever arm and resistance offered.
- Manual resistance also allows manual contact between the therapist and patient. For many patients, this tactile contact provides comfort and increases ease.

Although there are a number of benefits to manual resistance techniques, there are also some drawbacks including:

- The labor intensive nature of manual resistance
- Its impracticality for many home programs
- Difficulties measuring and quantifying manual resistance

Manual resistance requires the time, energy, and physical strength of a therapy provider. Depending on the body part being exercised and the relative strengths, manual resistance can be physically taxing. Performing PNF diagonal patterns for the lower extremity can be physically difficult and could potentially result in injury to the therapist using poor body mechanics. Be sure to use proper body mechanics, maximizing hand positioning, base of support, and lever arms to minimize the stress and risk of injury.

Manual resistance is not practical for many home programs. Caregiver assistance is required and may place the caregiver at risk of injury. For all but the lightest of manual resistance applications (i.e., hand, wrist, foot) the resistance is too great and the body mechanics challenging. Few homes have sufficient tables or supports at the right height and firmness to allow the caregiver to use good body mechanics.

Measuring and defining manual resistance is difficult. Therapists use terms like *minimum*, *moderate*, and *maximal* but these are poorly defined and vary from one person to another. For situations where documentation needs to be precise, verifying the dosage of manual resistance can be difficult.

Techniques

Techniques for performing manual resistance require attention to patient positioning, therapist positions, manual contact, grading of resistance, and verbal cues. Attention to these details provides the safest experience for both the patient and therapist. Consider the following points, essential to manual resistance:

- Make sure that the patient's clothing allows you to see the muscles or joints associated with the exercise.
- Position the patient so that full excursion of the movement is possible without restrictions.
- Make sure that the patient is comfortable and as stable as necessary as dictated by the exercise goal.
- Position yourself in the plane of the movement, using a wide base of support; shift your weight and step as necessary with the movement to maintain good body mechanics.
- Use as wide a contact area as possible to prevent discomfort at the point of resistance or stabilization application.
- Using a wide, gentle grip, take the patient's limb through the exercise ROM to teach them the movement pattern (PNF rhythmic initiation).
- While continuing to move through the range, tell your patient that you will be gradually applying some resistance to the movement.
- Be sure to gradually apply and slowly release the resistance to avoid sudden muscle contractions that might cause injury or pain.

Video clips of some commonly used manual resistance patterns can be found on thePoint.lww.com/BrodyHall4e.

Dosage

Dosing manual resistance can be challenging due to the inability to quantify the intensity of the exercise. The therapist is able to document sets and repetitions as well as a nominal description of the amount of resistance (i.e., minimum resistance, maximum resistance). Like all forms of resistance, manual resistance is applied with a specific goal in mind (i.e., strength, endurance, stabilization), and the sets, repetitions, and relevant rest intervals are derived from the goal. Stop the exercise when form fatigue becomes evident. Exercises can be varied by speed, muscle contraction type (concentric, eccentric, isometric) ROM, and resistance. Manually resisted exercises can be performed in an open chain or a closed chain (see **Fig. 5-12A** and **B**).

A

B

FIGURE 5-12 **(A)** Manually resisted open-chain leg press and **(B)** manually resisted rise from a chair.

Pulley System

Many pieces of exercise equipment are based on a pulley system where a weight plate is attached via a cable and pulley to a handle or lever that is controlled by the patient. In a standard pulley system, the cable attaches over a single or double round pulley. In other situations, the pulley or cam itself is elliptical, thereby providing variable resistance as they rotate through the cable's excursion. These are called *variable resistance* machines and will be considered in the next section. This section will focus on traditional pulley devices without an elliptical cam.

Most pulley systems consist of a simple cable and pulley attached to a weight stack of variable weight increments (i.e., 2.5, 5, or 10 lb). Most pulley systems are a single stack of weights that are freestanding or attached to a wall (**Fig. 5-13**). The other end of the pulley typically contains a clip or hook to which a number of different implements can be attached. These attachments may include a straight bar, cuff, handgrips, or various sizes and grips of implements designed to allow a wide range of exercises. Activities such as triceps pulls, biceps curls, latissimus pull-downs, rows, shoulder rotations, shoulder press, leg lifts, and abdominal crunches are some of the many activities that can be performed with a pulley. Thus, a pulley is a versatile piece of equipment that allows someone to perform a large variety of activities with a single piece of equipment.

A pulley system is indicated anytime resistive exercise though a ROM is necessary. Pulleys are prescribed after baseline strength is established, as most pulley systems start with a minimum of 2.5 lb of resistance. Few pulley systems provide stabilization such as chairs or benches. Therefore, most exercises require dynamic stabilization from the person performing the exercise. Chairs or benches can be set up to provide support or stabilization for specific exercises. For example, someone with

FIGURE 5-13 A standard pulley system.

FIGURE 5-14 Variable resistance machine.

limited standing tolerance or balance may be safer performing biceps curls seated rather than standing.

The most fundamental disadvantage of this type of system is the constant load provided by the equipment. When performing an exercise through a full ROM, the muscle will be maximally loaded only in the weakest portion of the range. The remaining portion of the ROM will be underloaded, failing to achieve the criteria necessary for strengthening. One technique to accommodate for this shortcoming is to train different portions of the ROM at different intensities. For example, the patient may train through the full ROM at a lower intensity, then perform an additional set at a higher intensity in the mid-portion of the ROM, where the muscle requires higher resistance to overload.

Variable Resistance Machines

Resistive exercise machines are commonly found in rehabilitation clinics and health clubs. Historically, most weight machines were designed to isolate a specific muscle group such as the quadriceps femoris or biceps brachii. Some equipment trains multiple muscle groups in combination patterns such as a leg press or pull-up machine. Those machines using weight stacks have plates weighing 5 to 20 lb each. The weight stack configuration varies with the specific muscle action trained. A pin placed in the weight stack selects the amount of weight to be lifted. The muscle contraction type is concentric during the lifting phase and eccentric during the lowering phase (**Fig. 5-14**).

The type of system—either the pulley or cam—is an important component of the weight machine. In contrast to a simple pulley system that provides a constant load through the ROM, a variable resistance machine contains an elliptical cam and pulley system that varies the resistance through the ROM. The kidney-shaped cam is an attempt to account for changes caused by varying length–tension relationships through the ROM. Variable resistance devices provide less resistance at the beginning and end of the ROM, and more resistance midrange.

Other machines use hydraulics to provide variable resistance through the range. Again, the machine is designed to provide more resistance in the mid-ROM, replicating "typical" length–tension ratios. In contrast to pulleys which provide alternating concentric–eccentric contractions of the same muscle groups, the hydraulic resistance machines typically provide reciprocal concentric contractions of opposing muscle groups (i.e., biceps–triceps). This is an important distinction to consider when designing a rehabilitation program; hydraulic machines provide only concentric resistance.

Weight machines also differ in their adjustability. Lever arms and seat positions should be adjustable for a variety of body sizes. This ensures the ability to align the joint axis with the axis of the machine and prevent injury from poor posture or exercise mechanics. Stops and range-limiting devices should be available and easily adjustable.

An **advantage** of weight machines over other types of resistance is safety. Patients are stabilized effectively by the equipment, and the risk of falls or injury resulting from instability is minimized. It takes less time to learn weight machine exercises. After the adjustments are learned, the equipment is relatively easy to use, and novice weight lifters are less intimidated by the equipment. Weight machines are also relatively time efficient because the machines are already setup. Only a few simple adjustments are necessary, and the patient is ready to begin. These machines frequently isolate a specific muscle group to be trained, and the variable resistance accommodates for changing length–tension relationships better than other types of resistance.

One of the **disadvantages** of weight machines is their expense and ability to perform only a single exercise. For example, an expensive machine may train only biceps, whereas this could be done inexpensively with a couple of free weights and a bar. Another disadvantage is that weight increases are restricted to fixed increments (i.e., weight plates) on weight machines. Smaller changes of 1 or 2 lb are not possible on most machines. Despite the many size adjustments on weight machines, they still do not fit everyone. Most also have a fixed, two-dimensional movement pattern. Because the machine guides the patient through the ROM, little proprioception, balance, or coordination is learned from the experience. The stabilization helps with isolation but limits the patient from learning self-stabilization. Most machines are designed to perform bilateral exercise. In some cases, performing unilateral exercise is difficult, if not impossible.

Elastic Resistance

Elastic resistance in a form of elastic bands or tubing, improved greatly from its origins, as "dental dam" used in dental procedures. Use of elastic resistance has increased significantly since its first appearance. It is relatively inexpensive, easy to use, small and light making it ideal for home and travel use and can be used in an infinite variety of exercises. However, the trade-off for ease of use is the difficulty in quantifying and dosing an exercise program. Research suggests that the amount of resistance varies with the band thickness, attachment technique, and the specific exercise performed.[174,175–177]

Elastic resistance is a dynamic exercise but cannot be classified as isotonic or isokinetic. The variability in load through the ROM does not allow it to be classified as isotonic and the variability in speed does not allow classification as isokinetic. It has unique characteristics that require it to be considered independent of other types of resistance. Elastic resistance is often compared with an isotonic pulley system. However, the unique characteristics of elastic do not allow a direct comparison with a pulley system.[178]

Unlike a pulley system which has a fixed load, the resistance provided by an elastic band varies with the thickness of the band and the elongation.[173,179,180] Any elastic material's resistance to stretch is proportional to its original cross-sectional area.[178] Therefore, doubling the cross-sectional area by folding (effectively doubling) the elastic doubles the resistance. Additionally, elastic resistance has unique force-elongation characteristics. The force increases as the elastic is stretched from 0% to 250% of its resting length. The force-elongation curve of Thera-Band (The Hygenic Corporation, Akron, OH, USA) elastic bands as well as the force in lb can be found in **Figure 5-15** and **Table 5-7**, *respectively*.

This force development is distinct from the torque created when functionally using elastic bands through a ROM with changing moment arms. Like all elastic materials, the force developed when pulling that material in a linear fashion will increase as the material is lengthened until failure is reached. However, the actual amount

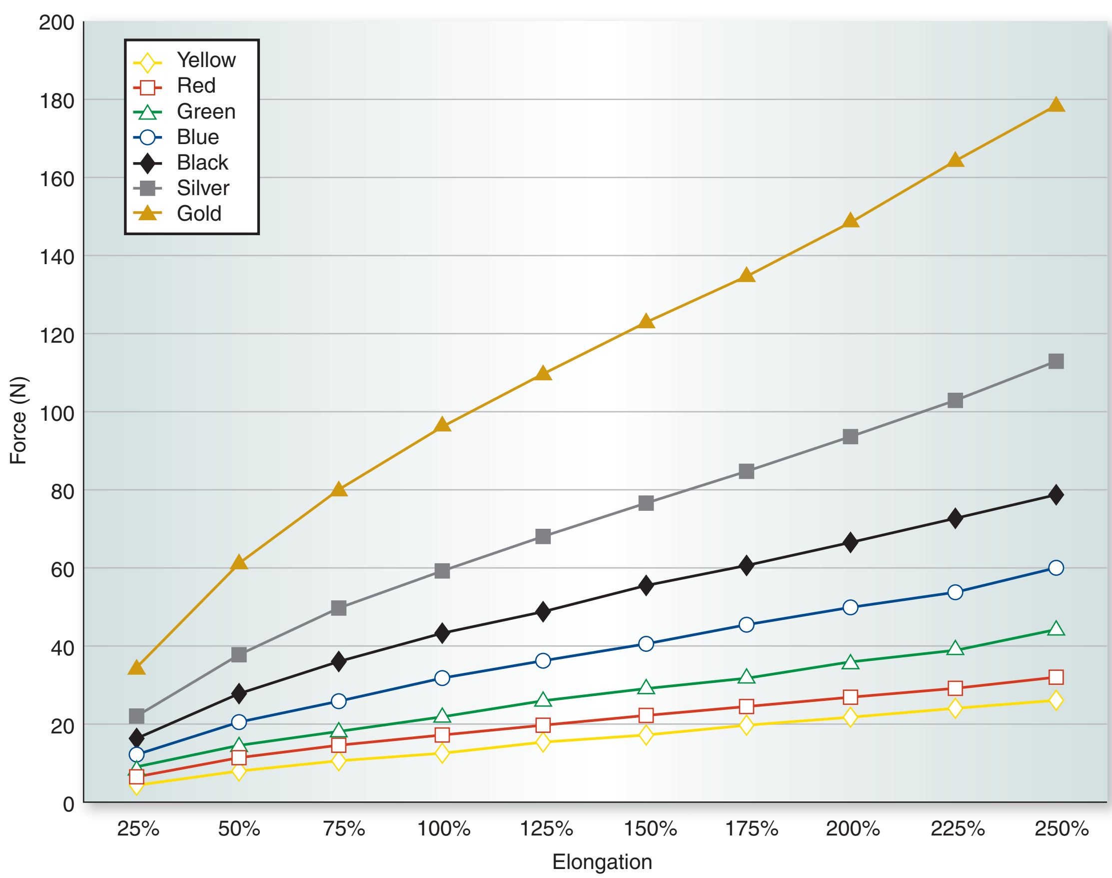


FIGURE 5-15 Force-elongation of Thera-Band elastic bands. (Used with permission of The Hygenic Corporation. Data from Page P, Labbe A, Topp R. Clinical force production of Thera-Band elastic bands [Abstract]. J Orthop Sports Phys Ther 2000; 30(1):A47–A48.)

TABLE 5-7

Force-Elongation for Thera-Band Elastic Bands (Force in lb)

ELONGATION (%)	YELLOW	RED	GREEN	BLUE	BLACK	SILVER	GOLD
25	1.1	1.5	2	2.8	3.6	5	7.9
50	1.8	2.6	3.2	4.6	6.3	8.5	13.9
75	2.4	3.3	4.2	5.9	8.1	11.1	18.1
100	2.9	3.9	5	7.1	9.7	13.2	21.6
125	3.4	4.4	5.7	8.1	11	15.2	24.6
150	3.9	4.9	6.5	9.1	12.3	17.1	27.5
175	4.3	5.4	7.2	10.1	13.5	18.9	30.3
200	4.8	5.9	7.9	11.1	14.8	21	33.4
225	5.3	6.4	8.8	12.1	16.2	23	36.6
250	5.8	7	9.6	13.3	17.6	25.3	40.1

Used with permission of the Hygenic Corporation. Data from Page P, Labbe A, Topp R. Clinical force production of Thera-Band elastic bands [Abstract]. J Orthop Sports Phys Ther 2000;30(1):A47–A48.

of torque developed when using elastic bands through a ROM (such as shoulder abduction) follows an ascending–descending pattern. That is, the torque increases from 0 to 90 degrees abduction as the moment arm increases, then decreases again as the moment arm decreases as the shoulder approaches 180 degrees. An example of strength curves can be found in **Figure 5-16**.

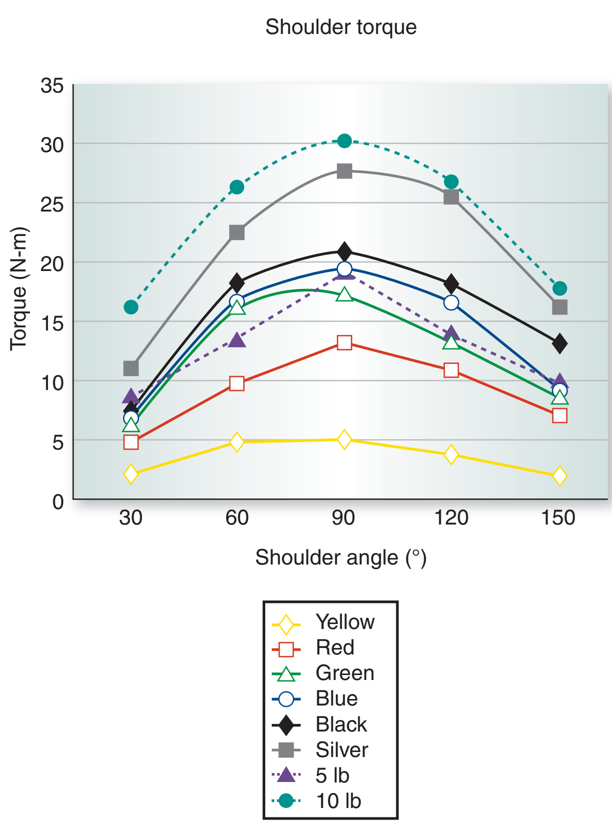


FIGURE 5-16 Strength curves of Thera-Band elastic tubing compared to free weights. (Used with permission of The Hygenic Corporation. Data from Page P, Labbe A, Topp R. Clinical force production of Thera-Band elastic bands [Abstract]. J Orthop Sports Phys Ther 2000;30(1):A47–A48.)

Indications

Elastic bands are indicated anytime strengthening but an external resistance is required. Elastic resistance can be used in the clinic under a therapist's supervision. It also works well for home programs utilized in conjunction with in-house rehabilitation. Because it is lightweight and easily transported, elastic resistance works well for those needing to perform exercise while at work or traveling. Resistive bands can be used for fitness or wellness training, providing challenges to muscle strength, power, endurance, as well as plyometric training, balance, and stabilization (**Evidence and Research 5-8**). Bands can be integrated into a practice or training session to provide additional activity-specific, open, or closed chain training. Resistive bands work well for individuals who have limited mobility, as the resistance can be applied in a variety of positions or postures. The resistance variation provides people with low physical capacity the opportunity to train and improve strength and function.[189–192]

EVIDENCE and RESEARCH 5-8

The effects and outcomes of elastic band training compared with other forms of strength training have supported the use of elastic bands in a variety of situations. Plasma creatine kinase levels, muscle soreness, and magnetic resonance imaging demonstrated equivalent responses when comparing elastic band resistance to Nautilus machine training.[181] Elastic band training has shown equivalent results when compared with dumbbell training,[182] free weights, and variable resistance devices.[183,184] Improvements in strength and power following elastic band training have been shown in adults with and without musculoskeletal pain,[185] in patients with COPD[186] females with knee osteoarthritis,[187] and in women performing squat activities.[188]

Considerations

There are some issues to be considered when prescribing elastic band resistive exercises. First, although there is some data about the amount of resistance provided from different colors of elastic bands, patient implementation variables render it an inexact quantity. The amount of resistance varies with the elongation, so if the patient grasps the band at a different location, or initiates the exercise at a greater percent elongation, the torque may vary from one session to the next. The patient may not understand why the exercise seems easier 1 day and harder the next.

Although the reproducibility of testing or exercise with elastic bands may be questioned due to issues of cross-sectional area, length, and origin/stabilization, the reliability and validity of elastic band use has been established under controlled conditions. Researchers found a 30-second elastic band elbow flexion test to be significantly correlated with a 30-second elbow flexion test using dumbbells ($r = 0.62$) and maximal isokinetic testing ($r = 0.46$). The test–retest reliability was high as well ($ICC = 0.89$).[179]

Another consideration is the impact of cyclic loading. Like any other elastic medium, loading the material results in changes such as creep. Additionally, cyclic loading (repeatedly stretching and relaxing the bands or tubing) can result in fatigue to the material. Over time, this fatigue can decrease the performance of the elastic and can eventually lead to failure. Research has shown that elastic bands stretch to 100% elongation for 500 cycles, resulting in a 5% to 12% decrease in force.[177] More importantly, the majority of the change occurred within the first 50 cycles. If patients are performing sets of 30 or more repetitions, the elastic can fatigue quickly. Therefore, it is important to replace elastic bands frequently.

Like pulleys, elastic resistance exercises can be performed with or without external stabilization. If no stabilization is provided, be sure the patient is performing the exercise without substitution.

Dosage

Like any resistive exercise, the proper dosage is necessary to ensure achievement of rehabilitation goals. Dosage is more difficult with elastic resistance because of the number of variables associated with this resistance mode. The length of the band, the percentage elongation, the color of band, and the origin of the elastic resistance all impact the torque developed.

Elastic resistance typically comes in a variety of colors and each color provides a different amount of resistance. Research on Thera-Band elastic bands showed a 20% to 30% increase in force production between colors.[176] Increases in intensity should be accomplished by moving to the next higher level of resistance rather than doubling the elastic band. Doubling the elastic band will double the resistance, whereas increasing to the next higher level will provide only a 20% to 30% increase, a safer intensity increase.

Another important variable in dosing elastic band exercise is the **length of the band** or tubing. The band should be elongated to no more than 250% of its original length.[178] To maintain the optimal ascending–descending torque curve, the length of the elastic should be equal to the length of the lever arm. In the case of exercise at the shoulder (i.e., abduction or flexion), the tubing should be equal to the length of the arm. This way, the elongation through the full ROM will be twice the length of the lever (a 200% elongation) resulting in an optimal torque curve for the shoulder musculature.

The **angle of the origin** of the tubing also impacts the torque curve and the subsequent resistance. An angle that is too acute will shift the torque curve to the left, increasing torque earlier in the ROM. An angle that is too obtuse will shift the torque curve to the right, increasing torque later in the ROM. This may be desirable in specific rehabilitation situations, but in general does not reproduce the torque curve of a normal muscle–joint interaction. The therapist should be aware of the impact of this angle on torque production. The origin of the elastic should be in the plane of the axis of rotation and in the direction of the desired motion.[178]

Finally, the **resistance arm angle** should be considered during exercise prescription. The resistance arm angle is the angle produced by the band or tubing and the lever arm (i.e., the hand and the band in the shoulder abduction example). The band and the limb should be aligned to ensure a normal physiologic ascending–descending torque curve. If this alignment is incorrect, excessive torque may be produced at end range, where the least amount is available. It is recommended that the band or tubing be aligned with the ending lever arm at a resistive arm angle of 15 degrees to 0 degree.[178] For example, in shoulder flexion, the band should be placed under the foot so that in the full 180 degrees overhead position, the band pulls nearly straight down, with the wrist:band angle at <15 degrees. A higher angle would place excessive load on the wrist extensor muscles.

Once the patient is properly positioned and the band or tubing color (resistance) and length determined, the number of sets and repetitions should be determined. The patient should start with slight tension on the band (approximately 25% elongation) and perform the exercise through the desired ROM. Depending on the patient's goals (strength, power, endurance, etc.) an increase or decrease in the band color might be indicated. Like free weights or weight machines, the resistance and number of repetitions depend on the goal. For traditional strength or endurance training, repetitions at approximately 6 to 10 RM would be appropriate. For those doing power training, the intensity would be greater, with intensity at 90% of a 3 RM.[178]

As with any resistive exercise, substitution, form fatigue, and stabilization are factors to be considered. Do not sacrifice form for additional resistance or repetitions. Training programs can be designed similar to those with traditional weights. As the patient fatigues, consider performing additional sets at a lower elastic band resistance, just as one might to a decreasing training schedule with free weights.

Free Weights

Free-weight training is the resistive exercise technique of choice for body builders and power lifters. Free weights and cuff weights are also commonly used in rehabilitation. Free-weight training is usually performed with hand-held weights that range from 0.5 to 75 lb or more. Free weights can also be combined on a bar with weight plates. Cuff weights typically range from 0.5 to 25 lb.

Free-weight training allows more discrete increases in resistance, and resistance can differ from one side to the other (see **Self-Management 5-2**). For example, reciprocal biceps curls can be performed with 10 lb on the injured side and 15 lb on the uninjured side. Incremental increases of 1 to 2 lb or less are available, allowing a more gradual overload. Free-weight equipment is affordable, and a multitude of exercises can be performed with the same free weights. These exercises can include simple strengthening and endurance activities or power training techniques.

Free-weight exercises can be performed in a multitude of different ways that meet the needs of individual patients or clients. For example, a variety of positions are available and are not restricted by the design of the machine. Biceps curls can be performed in standing, sitting, supine or even prone. They can be performed symmetrically or reciprocally and the patient may have different weights in each hand. The exercise can be performed at a variety of different speeds and the working ROM can be altered. Changing the position and/or ROM can alter the relationship with gravity, affecting the working muscle group and contraction type. For example, a hamstring curl performed in standing provides concentric resistance during shortening and eccentric resistance while lengthening, both to the hamstring muscle group. This same exercise performed in prone provides concentric resistance with a decreasing moment arm against gravity until the knee approaches the 90-degree angle. At this position, there is no moment arm against gravity and no significant resistance. Continuing into further flexion produces an eccentric contraction of the quadriceps as they are lengthened while trying to slow the flexing knee (**Fig. 5-17A** and **B**). Free-weight exercises provide a multitude of possibilities to match the exercise with the patient's goals.

One of the biggest advantages of free-weight training is the neural component of balance. Compared with the external stabilization provided by a weight machine, the free weight usually has little external stabilization. These exercises require postural muscle stabilization beyond the work required to

SELF-MANAGEMENT 5-2
Standing Biceps Curls

Purpose: To strengthen the biceps muscles.

Position: Standing position, with shoulder girdles, spine, and pelvis in neutral. Hold a weight in each hand, palms facing toward your thighs.

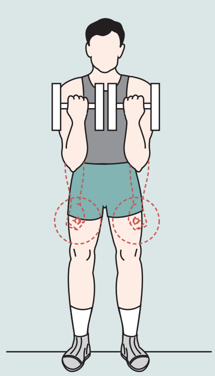
Movement Technique: Level 1: Alternately bend your elbows, turning your palms upward as the weights clear your hips; bend your elbows so your hands come within 4 inches of your shoulder; slowly straighten your elbows, turning your palms sideways again as you move lower your forearms. Maintain your neutral shoulder, spine, and pelvic position as you lift and lower the weight.
Level 2: Bend and straighten your elbows simultaneously.

Hold _____ lb in each hand.

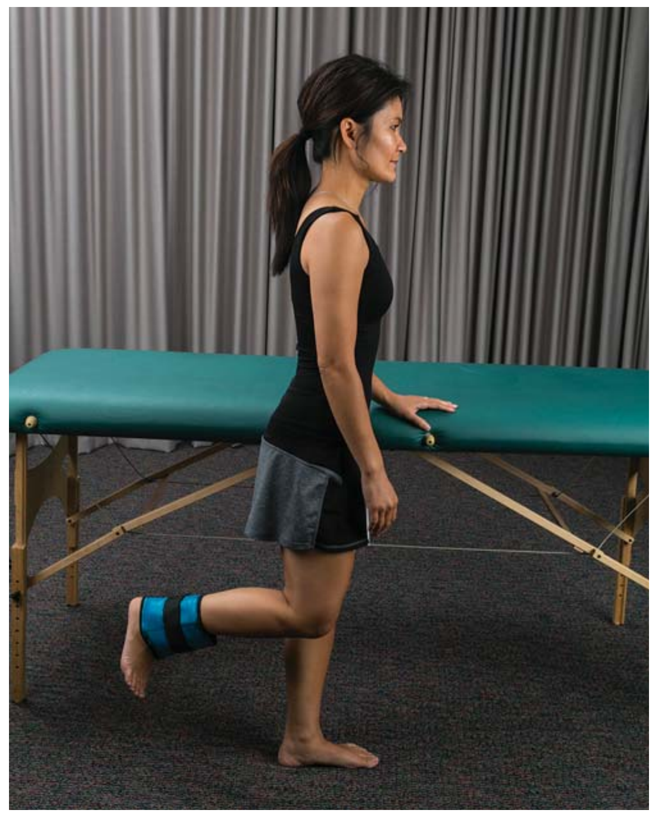
Dosage:

Repetitions: ________________________________
per set, ________________________________ sets

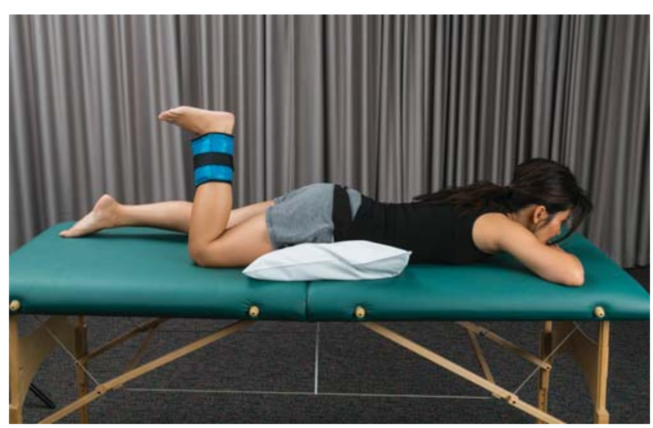
Frequency: ________________________________
sessions per day, ____________________ sessions per week



Level 2



A



B

FIGURE 5-17 **(A)** Hamstring curl in standing and **(B)** hamstring curl in prone.

move the weight. The individual lifting with free weights must understand proper posture and spinal stabilization to prevent injury to the back. If balance is a rehabilitation goal, free-weight exercise may be indicated.

The neural demands of free-weight exercise are a disadvantage for some. It takes longer to learn free-weight exercise, because the free-weight tasks usually are more complex than those with weight machines. Novice lifters may be at greater risk for injury because of poor technique (**Fig. 5-18A** and **B**). Spotters are necessary for many of the free-weight lifts, increasing the personnel demands of this resistive technique. Because of the time required to load and unload bars, free-weight training can be less time efficient. However, for those using smaller hand-held weights, these can be more time efficient than weight machines, due to the lack of setup time.

Safety for individuals training with free weights includes working with a knowledgeable partner who can spot safely. Collars should always be used to lock the weights on the bar and prevent movement of the plates on the bar. Correct form and technique, including proper breathing, should be mastered before performing the exercise with load.

Free weights are used in a similar fashion to elastic bands, tubing, and pulleys. However unlike bands and pulleys, free-weight exercises still need to be positioned with regard to gravity (see **Self-Management 5-3**). Free weights, resistive bands, and pulleys have the advantage of movement in a variety of three-dimensional patterns without fixed movement patterns. This allows highly specific training that matches individual needs. For example, resisted lunging patterns forward, backward, laterally, or diagonally can be performed with elastic bands, pulleys, or free weights. These movement patterns can be performed in whatever range is necessary for the individual, rather than in ranges dictated by a weight machine.

SELF-MANAGEMENT 5-3
Supine Shoulder Flexion

Purpose: To increase the strength of the shoulder muscles, especially serratus anterior.

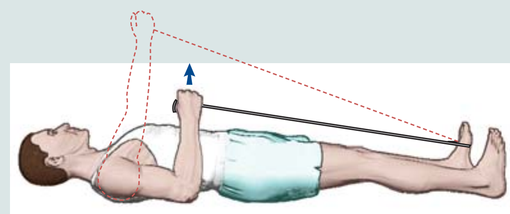
Position: Lying on your back with the band tied around your foot. Hold the band in the ipsilateral hand with the arm next to your side and elbow bent to 90 degrees.

Movement Technique: Level 1: Keeping your elbow bent, punch your hand toward the ceiling until your elbow is straight, then move your straight arm upward toward your head. Press backward into the surface you are lying on or pillow(s) as needed to support you at the end of your ROM. Push back with an isometric contraction for 10 seconds. Return arm in reverse movement pattern. Repeat as prescribed.
Level 2: Perform level 1 with a straight arm.

Dosage:

Repetitions: ____________________
per set ____________________ sets

Frequency: ____________________
sessions per day, ____________________ sessions per week



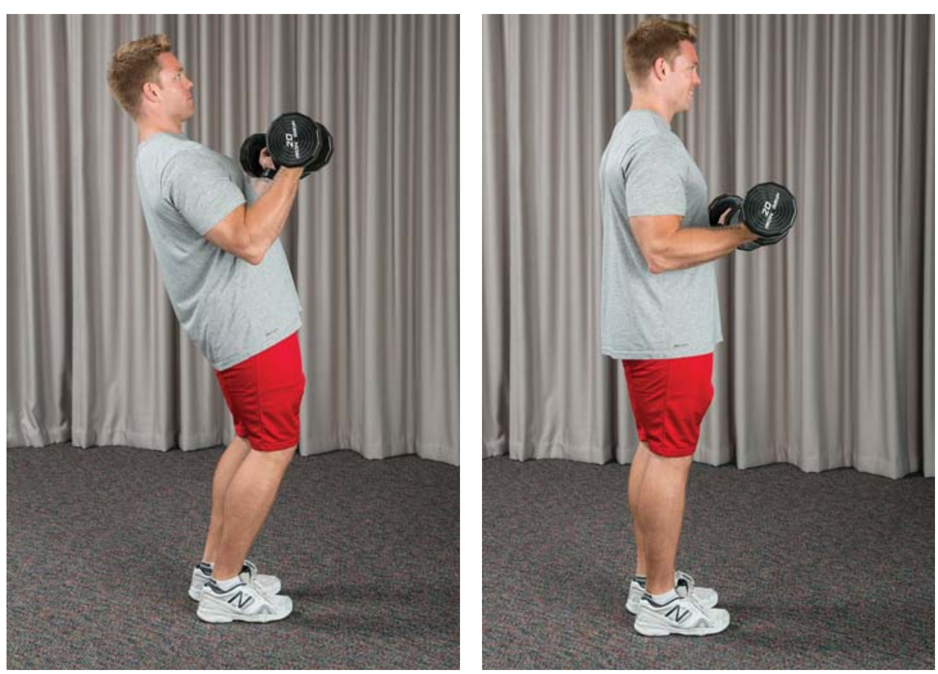

A B

FIGURE 5-18 Biceps curl performed **(A)** incorrectly with lumbar extension and **(B)** correctly with lumbar stabilization.

Isokinetic Devices

Isokinetic dynamometers are designed to provide maximum resistance through the entire ROM. The resistance provided by these devices is termed *accommodating*, because once the preset speed is achieved, the dynamometer "matches" the force applied by the patient. The dynamometer provides a counterforce equal to the force applied by the patient. Therefore, the patient can obtain the maximum amount of resistance tolerated throughout the ROM. If a patient has pain or weakness in a specific portion of the ROM, the remaining portion can still be fully challenged. Additionally, patients can train at a variety of speeds.

Currently, isokinetic devices are active computerized training and testing devices that are capable of actively moving the patient's limb for him or her. These dynamometers provide reciprocal concentric resistance at fixed speeds, and they provide multiangle isometric resistance, fixed resistance concentric and eccentric contractions, passive motion, and fixed speed concentric and eccentric contractions. Because these dynamometers now function in a variety of modes, they have become multipurpose testing and training devices. Although many dynamometers are capable of providing isometric and isotonic resistance, most providers still refer to these devices as isokinetic dynamometers and emphasize the isokinetic capabilities of these devices.

Indications

The isokinetic mode is used most frequently for muscle performance testing and training. The dynamometers are capable of testing and training muscle groups around most major joints of the body. Muscles around the shoulder, elbow, forearm, and wrist in the upper extremity and the hip, knee, and ankle in the lower extremity are all readily tested and trained using an isokinetic dynamometer. Adaptive attachments allow training for pediatric patients, industrial medicine (i.e., lifting and work simulation attachments) and closed chain exercise and testing. Isokinetic testing is frequently performed as an alternative to 1-RM testing due to the computerized capabilities of the devices and safety issues. The dynamometer matches the patient's force output, thereby minimizing the chance of injury that may be found when performing 1-RM testing, particularly in the presence of an injury. Tests can be performed in a limited ROM and at a fixed speed to assess muscle strength or endurance. Test results are stored in the computer and can be compared with the results of future tests or to population-based norms.

Isokinetic testing is performed to assess muscle performance against some standard. The standard may be the contralateral side, a population norm, or a percentage of the antagonist muscle performance. Testing is performed to assess progress after injury or surgery and to determine readiness to advance the rehabilitation program or to return to activity. In some situations, testing is performed pre-season to provide guidance for the training program or to provide a baseline measure in the case of a future injury.

Testing is typically performed at two or three different speeds to capture speed-specific muscle impairments. Each company that produces dynamometers has specific testing protocols and standards to follow to ensure validity and test–retest reliability. The data are captured in a computer file and can be examined and manipulated in a variety of different ways (**Fig. 5-19**). Several important terms are used to describe isokinetic data results.

- *Peak torque* is the most common variable measured and is the maximum torque generated regardless of where in the ROM it is achieved.
- *Work* is the total amount of work performed under the torque curve, regardless of ROM, time, or speed.
- *Average power* is the amount of work (total work under the curve) performed per time unit (P = W/T).
- *Time to peak torque* is the amount of time it takes to achieve peak torque.
- *Peak torque angle* is the joint angle at which peak torque occurred.

Other important and common comparisons are bilateral comparisons and agonist–antagonist ratios. In bilateral comparisons, one extremity is compared with the other to determine the absolute and/or relative difference from side to side. In agonist–antagonist ratios, the opposing muscle groups (i.e., quadriceps and hamstrings) are compared with the antagonist given as a proportion of the agonist (i.e., the hamstrings are 70% of the quadriceps). Normative standards for some agonist–antagonist ratios exist.

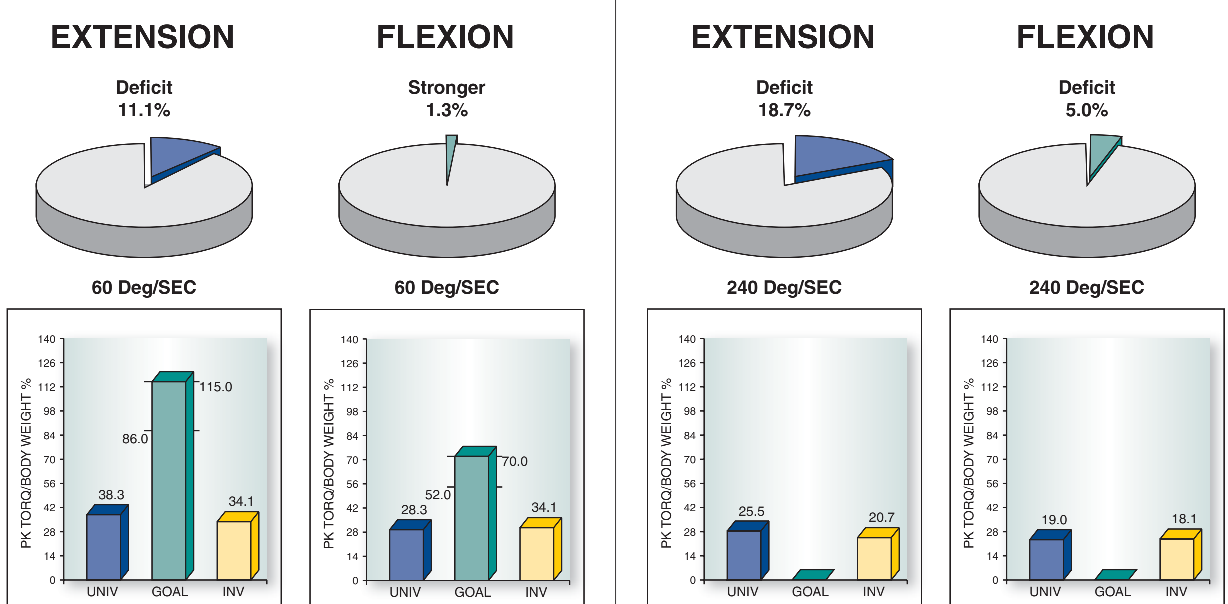
Isokinetic training is indicated any time the patient needs muscle activation throughout the ROM. Isokinetics works well when there are fluctuations in torque production due to changes in the length–tension relationships or due to pain or pathology causing significant variation in torque production through the range. Unlike a fixed, constant load (i.e., isotonic), there is no minimum load to lift to complete the activity. If the patient is unable to continue the exercise, he or she can simply stop without worrying about dropping a weight. Isokinetic training also works well when a variety of speeds need to be trained. Velocity spectrum training (VSRP, velocity spectrum rehabilitation program), or training through a variety of speeds, is a commonly used training regimen. Patients may start at a slow velocity (i.e., 60 degrees per second) and increase speed by 30 degrees per second up to a maximum velocity (i.e., 300 degrees per second), and then decrease speed incrementally until the starting speed is reached. A variety of training programs can be designed using this technique.

The passive mode on an isokinetic dynamometer can be used to train isokinetically as well. The passive mode does precisely what the name implies: it passively moves the limb at a preselected velocity. The patient can use this mode in a variety of different ways. The patient might be instructed to relax and let the machine move and mobilize the joint. Alternatively, the patient might be asked to assist the machine in the direction it is moving (a concentric contraction) or to resist against it (an eccentric contraction). Why choose resisting against the passive movement rather than the active isokinetic or isotonic concentric and eccentric contractions? In the active modes, the patient must still generate enough torque to actively move the dynamometer arm and match the preset speed of the machine. In some cases, such as a postoperative surgery or an acute injury, this amount of force may still exceed the muscle's capacity. In the passive mode, the machine moves continuously, and the patient can provide resistance at the level and in the appropriate ROM given the current injury status.

General Evaluation

Name:		Session:		Windowing:	**None**
ID:		Involved:	**Left**	Protocol:	**Isokinetic Bilateral**
Birth Date:	**(M/d/yyyy)**	Clinician:		Pattern:	**Extension/Flexion**
Ht:		Referral:		Mode:	**Isokinetic**
Wt:		Joint:	**Knee**	Contraction:	**CON/CON**
Gender:		Diagnosis:		GET:	**18 FT-LBS at 30 Degrees**

		EXTENSION 60 DEG/SEC			FLEXION 60 DEG/SEC			EXTENSION 240 DEG/SEC			FLEXION 240 DEG/SEC		
# OF REPS (60/60): 5		UNINVOL	INVOLVED	DEFICIT	UNINVOL	INVOLVED	DEFICIT	UNINVOL	INVOLVED	DEFICIT	UNINVOL	INVOLVED	DEFICIT
# OF REPS (240/240): 15		RIGHT	LEFT		RIGHT	LEFT		RIGHT	LEFT		RIGHT	LEFT	
PEAK TORQUE	FT-LBS	92.0	81.8	11.1	68.0	68.9	-1.3	61.2	49.8	18.7	45.7	43.4	5.0
PEAK TQ/BW	5	38.3	34.1		28.3	28.7		25.5	20.7		19.0	18.1	
MAX REP TOT WORK	FT-LBS	113.1	76.4	32.4	69.5	69.8	-0.4	70.0	50.3	28.1	35.6	38.2	-7.2
COEFF. OF VAR.	%	6.6	6.8		5.5	6.2		9.6	12.5		16.0	7.9	
AVG. POWER	WATTS	83.5	60.0	28.1	52.6	56.0	-6.4	164.5	116.1	29.4	75.9	79.8	-5.2
TOTAL WORK	FT-LBS	496.8	346.5	30.3	304.4	317.2	-4.2	917.2	643.1	29.9	440.9	445.5	-1.0
ACCELERATION TIME	MSEC	30.0	30.0		40.0	40.0		50.0	50.0		80.0	80.0	
DECELERATION TIME	MSEC	40.0	100.0		80.0	90.0		80.0	90.0		100.0	80.0	
ROM	DEG	106.2	96.2		106.2	96.2		104.1	95.8		104.1	95.8	
AVG PEAK TQ	FT-LBS	84.0	76.8		64.9	64.6		54.7	41.3		37.1	35.9	
AGON/ANTAG RATION	%	74.0	84.3	G: 61.0				74.6	87.2	G: N/A			



Comments:

PEAK TORQUE:	Highest muscular force output at any moment during a repetition. Indicative of a muscle's strength capabilities.
PEAK TQ/BW:	Represented as a percentage normalized to bodyweight and compared to an established goal
MAX REP TOT WORK:	Total muscular force output for the repetition with greatest amount of work. Work is indicative of a muscle's capability to produce force throughout the range of motion.
AVG POWER:	Total work divided by time. Power represents how quickly a muscle can produce force.
ACCELERATION TIME:	Total time to reach Isokinetic speed. Indicative of a muscle's neuromuscular capabilities to move the limb at the beginning of the range of motion.
DECELERATION TIME:	Total time to go from Isokinetic speed to zero speed. Indicative of a muscle's neuromuscular capability to eccentrically control the limb at the end of the range of motion.
AGON/ANTAG RATIO:	The Reciprocol muscle group ratio. Excessive imbalances may predispose a joint to injury.
DEFICITS:	1 to 10% No significant difference between extremities. 11 to 25% Rehabilitation recommended to improve muscle performance balance.

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FIGURE 5-19 Isokinetic test data analysis.

Considerations

The major advantage of isokinetic resistive training is its ability to fully activate more muscle fibers for longer periods. Because the machine matches the torque provided by the patient, it "accommodates" the patient's changing abilities throughout the ROM. In contrast, free weights (i.e., fixed resistance training) overload only the weakest portion of the range, but the stronger portion (usually the middle third) is not overloaded. For testing purposes, isokinetic dynamometers allow individuals to be tested at a variety of speeds, potentially identifying deficits at more functional speeds. Compared to a 1-RM strength measure, the isokinetic dynamometer produces a force curve through the ROM rather than a single measure. This allows more detailed evaluation of muscle function characteristics (i.e., time to peak torque, total work performed, etc.).

Isokinetic devices allow training at a variety of speeds. The positive effect of fast-speed training on performance is highlighted with isokinetic training. Training at faster speeds can assist the return to functional activities that require less muscle torque development but faster speeds of contraction. Speeds that more closely match the patient's function can be chosen to match functional velocities. Higher speeds can decrease joint compression forces in areas such as the patellofemoral joint, decreasing the pain and discomfort often seen with heavy resistance exercises. Although less torque is generated at high speeds, the decrease in pain and more functional speeds may produce better results.

Studies assessing the speed variable favor slow-speed isokinetic training over fast-speed training for the development of strength.[193] High muscular tension is necessary for generating strength gains and is achieved when the isokinetic speed is slow enough to allow full recruitment and generation of a high resisting force.

Isokinetic dynamometers with computer interface also provide feedback for training purposes. This feedback can take many forms, such as visual when trying to reproduce a torque curve or producing enough force to raise a bar to a preset level. Feedback can be auditory with bells when a preset goal is met. Isokinetics can also provide neuromuscular training by requiring the patient to resist at a specific level that is submaximal, a relatively challenging task. Although it may be easy for patients to push as hard as they can to achieve maximum torque production, it is often harder to regulate torque production at lower levels.

Isokinetic resistive training also has disadvantages. These devices are expensive to purchase and maintain. They require trained personnel for setting up patient training programs, testing, and data interpretation. From a biomechanical perspective, most training is done in a single plane, with a fixed axis at a constant velocity in an open kinetic chain. Testing and training in a single plane improve test reproducibility but do not necessarily carry over to function. We rarely move at a constant velocity in functional activities, although this feature provides for maximal loading through the ROM. Some isokinetic devices offer closed-chain components, which have the advantage of testing a functional movement pattern but the disadvantage of being unable to tell where the muscle performance impairment lies.

Dosage

Isokinetic exercise is dosed similarly to other types of quantitative resistive training. Isokinetic devices have the advantage of computerized data reduction, which helps to see and manage resistive exercise volume and intensity. The computerized system allows for storage of exercise training programs, which can be programmed and executed with minimal setup. This data can then be tracked over time. Like any resistive exercise program, the volume of activity must be balanced with intensity and viewed within the context of the patient's daily activities.

Body Weight

Body weight can be effectively used as resistance. Resistive exercises for the lower extremity are the most obvious application of body weight as resistance, due to the high number of functional activities that require the lower extremity muscles to move body weight. Walking, running, sports, stair climbing, and transfers of all sorts are examples of activities requiring the movement of body weight. Examples of upper extremity exercises using body weight include push-ups, planks, pushing or pulling oneself out of bed or a chair, suspension exercises, or sporting activities such as gymnastics. Many exercises using body weight as the primary resistance are classified as **closed chain** exercises. Closed chain exercises are those activities where the distal segment is fixed on a rigid or semi-rigid surface. Squats, lunges, step-ups, or push-ups are considered closed chain exercises. **Open chain** exercises are those where the distal segment is free, as in performing a straight leg raise, resistive knee extension, or biceps curl.

Body weight can be decreased by altering the position of the body (i.e., push-ups from the knees rather than the feet), using a harness unweighting system, or using a pool. An advantage of using body weight as resistance is that it is always available and rarely requires equipment. A disadvantage is that it is difficult to isolate specific muscles that need strengthening, and the multijoint nature of closed chain exercises lends itself to subtle substitution. See more on closed and open chain exercise in Chapter 14.

THERAPEUTIC EXERCISE INTERVENTION FOR IMPAIRED MUSCLE PERFORMANCE

Therapeutic activities to enhance muscle performance are at the core of the intervention program for many patients. The clinician is faced with a multitude of variables to consider when designing this program. These variables are found in the intervention model in Chapter 2. Prioritizing and balancing all these variables to achieve the best patient outcome requires both knowledge and experience. The following sections will highlight the key variables to consider when designing a resistive exercise program for patients with impairments.

Program Initiation

One of the first variables to consider is the initial physical or training status of the patient. Realize that recommendations about the intervention model variables will change with the training status of the individual patient. Two patients with identical impairments related to an inflammatory shoulder condition may present very differently: one who is a regular exerciser, lifting weights 5 days per week and working construction, whereas the other is a sedentary individual, working at a desk job. The initial exercise prescription and progression plan will differ based on the difference in their initial physical condition and training status. The initial examination and evaluation is used to determine the starting point for the therapeutic exercise program. Once the starting point is determined, progress the rehabilitation program based upon the goals established and the gains made. Based upon the initial examination, the following questions should guide the therapist in determining the appropriate starting point for the program:

- What muscle or muscle group(s) need training? What type of muscle contraction does that muscle utilize to perform the functional activities that are limited?
- What type of training is required (i.e., strength, endurance, power, etc.) at this stage of the rehabilitation program? Should the muscle be isolated or worked as a synergist?
- What activity will best accomplish this goal? What range should be exercised?
- What is their current performance/training/strength status? Is strength above or below fair? Are the manual muscle tests normal? Approximately what resistance do you think they will tolerate and for how many repetitions?
- Given the patient's strength, what is the best mode to perform the exercise (i.e., manual resistance, free weights, body weight, isokinetics, etc.)?
- Are there any precautions necessary (i.e., blood pressure, diabetes, joint instability)?
- What is the injury, pathology, and stage of healing? Other medical comorbidities?

Answering these questions will provide the therapist with a starting place for the rehabilitation program (**Table 5-8**). If the patient reports increased symptoms or is unable to perform the exercise at the level chosen based upon the initial evaluation, a number of opportunities to decrease the exercise challenge exist. Many of these possibilities can be found in Chapter 2 and in Display 2-13. In general, decreasing the intensity, volume, complexity, or environment/stabilization can increase exercise tolerance. Once a set of exercises that do not exacerbate symptoms is developed, then the therapist can consider how to progress the exercise program.

Oftentimes, using palpation combined with manual resistance in the clinic for 1 to 2 sets of 10 to 12 repetitions can help the therapist appropriately dose the exercise. The therapist can monitor for improper muscle recruitment and assess how the muscle(s) of interest are recruited throughout the range of movement, and it assists the therapist determine the appropriate resistance to provide the patient for their home program.

TABLE 5-8

Template for Determining Initial Therapeutic Exercise Prescription

EXAMINATION QUESTION	THERAPEUTIC EXERCISE INTERVENTION MODEL DIMENSION	THERAEPEUTIC EXERCISE PRESCRIPTION OBTAINED
What muscle is impaired?	Muscle or muscle group	Muscle group to be trained
How does this muscle function primarily in this patient's activities? Is this the appropriate contraction type to begin with?	Movement	Type of muscle contraction for initial rehabilitation program, as well as contraction type to be progressed toward (if different)
In what range does the muscle function and does it need to be trained through that full range?	Movement	Working ROM
What is the best mode for applying the resistance?	Mode	Exercise mode such as manual, pulley, elastic band, variable resistance equipment, etc.
What posture or position is this muscle used in functionally for this patient? Is this the best position to initiate training?	Posture	Beginning exercise posture as well as postural goal (if different)
At what speed does this muscle typically function? Is this the best speed to initiate training?	Speed	Beginning exercise speed as well as speed goal (if different)
What is the patient's baseline strength? What are the functional strength demands?	Intensity	Initial training resistance and resistance goals
What muscle function is the primary requirement? (i.e., power, strength, endurance) and at what frequency?	Frequency/duration	Initial training sets and repetitions and sets and repetition goal
What other associated muscle or muscle groups need training? How do they work with the muscle group of interest? (i.e., synergist)	Sequence	Other supportive muscle groups to be trained and sequence for training
Are there any medical precautions or contraindications?	Overarching	Precautions and contraindications to exercise
What is the stage of healing?	Overarching	Volume and intensity limitations

Program Progression

Once the rehabilitation goals and the initial rehabilitation program are determined, the next step is determining the appropriate exercise progression. Exercises can be progressed in a multitude of different ways, ranging from the most obvious of increasing the exercise intensity to changing the exercise to a more complex activity. It is possible to achieve continual advancement toward rehabilitation goals with the appropriate manipulation of program variables. Advancing an exercise program in a healthy individual training for health and wellness follows a more predictable pattern. However, progression in the presence of pathology or deficits is much more challenging.

The goal inpatient progression is to narrow or eliminate the gap between the patient's current status and the desired functional status. How the therapist guides the patient to bridge that gap will likely vary from one individual to the next. The progression from program initiation to discharge requires a balance between exercise load and the loads applied with daily activities.

- *Exercise load* is the amount of stress and strain applied to the tissue of interest as a result of the rehabilitation program.
- *Daily activity load* is the stress and strain applied to the same tissue as a result of daily activities.

The daily activity load may change from 1 day to the next depending on the patient's activities on a given day. The therapist must teach the patient how to modify the exercise load based upon that activity level. This will ensure that the total load placed on the tissue stays within the tissue tolerance. If not, then the likely result is an increase in symptoms.

Display 2-13 (Chapter 2) describes exercise modification parameters that can be used to increase or progress the program. Similarly, if a patient reports an increase in symptoms following program initiation, or the patient is not tolerating the activities at the level they were initiated, the display provides suggested modifications that can decrease the exercise challenge. The overarching goal is to continuously challenge the patient and to expand the training volume to bridge the gap between current and desired functional status. **Figure 5-20** shows the relationship between progression variables/opportunities and expanding exercise volume. By systematically alternating expanding volume and increasing intensity, patients can continue progressing toward their goals.

How much the volume is increased depends on the discrepancy between current and desired function. If a patient is functioning at a very low level due to injury, surgery, or pathology, then the increase in their total quantity of activity may be substantial. For others who may be very physically

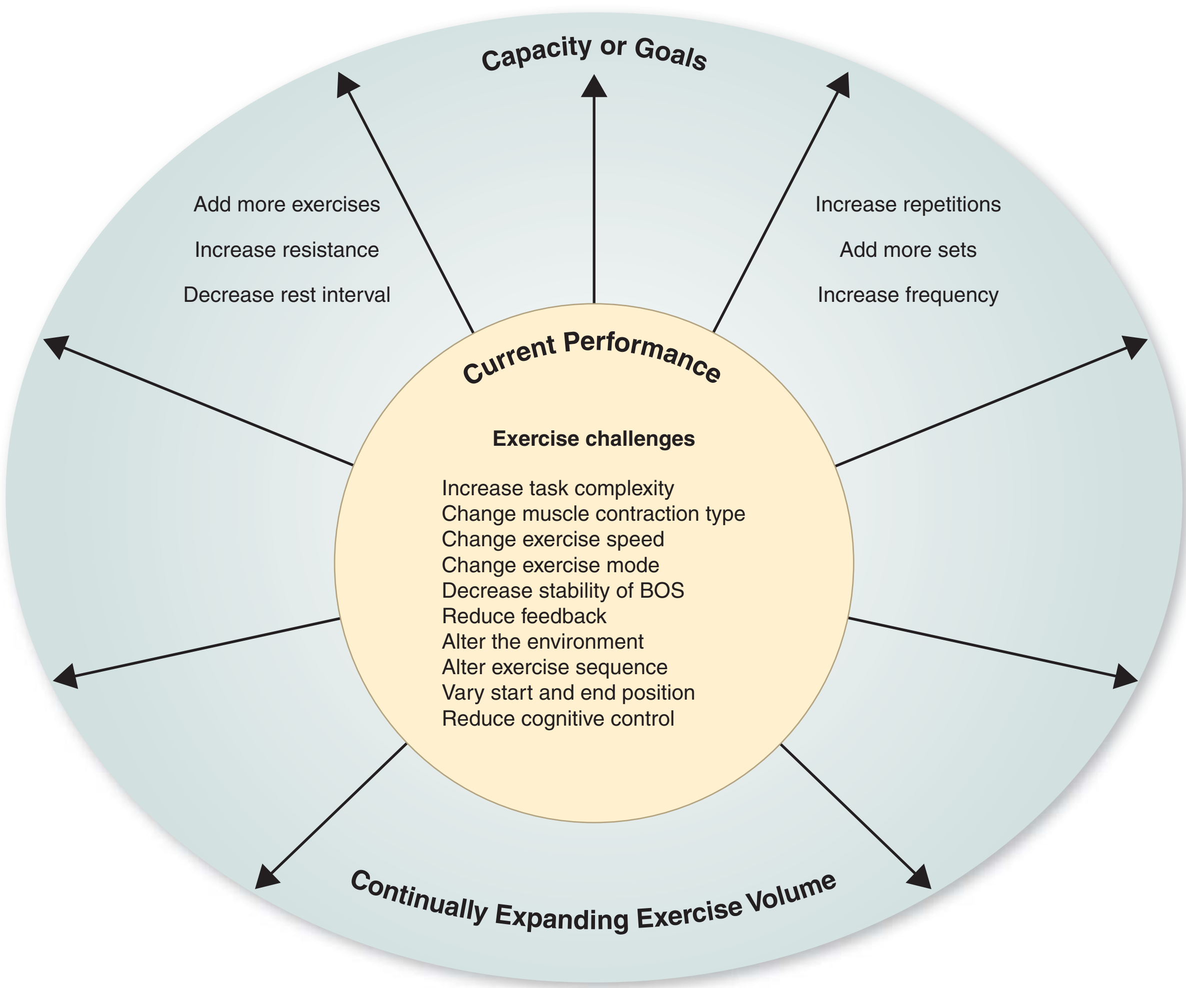

FIGURE 5-20 Exercise progression model.

active but who still have pain, changing the exercise parameters within the same exercise volume may be preferable. For most patients trying to restore a previous level or to obtain a higher level of function, program progression likely follows a variable course with volume increases balanced with exercise parameter changes. For example, a patient recovering from rotator cuff tendinosis may alternate exercise volume increases with changes from isometric or concentric contractions to eccentric, changes from slow speed to fast, and mode changes from free weights to elastic resistance and variable resistance machines (see **Building Block 5-5**). A variety of options exist depending on patient goals and preferences. The therapist must use solid clinical decision-making skills to best fit the appropriate type of exercise progression to the patient's goals.

BUILDING BLOCK 5-5

A 22-year-old marathon runner has had Achilles tendinitis for 6 weeks. She is currently able to run only 3 miles per day every other day before the symptoms prevent her from running any further. Describe how you might progress her strength program to prepare her to return to marathon training. The patient is unwilling to decrease her running at this point.

Another consideration during program progression is the difference between current performance and current capacity. Although a higher capacity or level of function is the long-term goal, the program should be viewed in phases, each with a short-term goal. For example, a patient who sustained a second degree ankle sprain 2 weeks previously may desire to return to long-distance running. However, at this stage of healing, she is doing a series of rehabilitative exercises, deep water running and walking and standing intermittently as part of her job. She is experiencing some increased pain and swelling at the end of the day. It resolves by morning, and overall is making steady improvement. At this point, she is likely performing close to her current physical capacity given the stage of healing. Therefore, increasing her exercise volume might be inappropriate at this point as it may overwork the healing tissue. Rehabilitative exercise changes within the same working volume may be more appropriate at this stage of healing. Looking at the model in Figure 5-20, consider alternative changes to progress her program that do not include increasing exercise volume.

Options to increase the total volume are relatively clear; adding new exercises, resistance, sets, or repetitions are obvious ways to expand the exercise volume. Within a given volume, exercise parameter changes allow exercise progression toward a specific goal without (or with, if that is preferred) a change in total volume. **Increasing task complexity** can be accomplished in a number of different ways. Increasing the number of body segments, the cognitive challenge, or the number of steps are examples of increasing task complexity. For example, increased coordination might be a patient goal. Rather than performing several exercises independently of several repetitions (blocked exercise), different exercises might be combined into a single task (i.e., rise out of a chair, walk across the room around a series of cones, reach up five times, then turn and sit down).

Changing **muscle contraction type** is another way to change and progress the exercise challenge. For someone recovering from knee surgery, changing from isometric quadriceps sets to straight leg raises and knee extension exercises is an exercise progression. For someone recovering from tendinosis, progressing from isometric contractions to eccentric contractions is another way to progress the exercise program without increasing the exercise volume. For general training purposes, it is important to train both concentric and eccentric muscle actions unless one type of action is preferred based on the pathology, impairments, or activity limitations. For example, patients who have difficulty descending stairs because of poor quadriceps control, but no trouble ascending stairs, should emphasize eccentric muscle contractions.

Altering **exercise speed** can change the exercise impact. For many exercises, resistance varies with speed. For example, in the pool, increasing the speed increases resistance, whereas with isokinetic concentric exercise, decreasing the speed increases the resistance. When treating tendinosis, the rehabilitation program often progresses from exercises performed slowly to higher speeds.

Changing the **exercise mode** can alter the exercise challenge. Moving from isotonic resistance to isokinetic can provide more challenge through the ROM. Changing from variable resistance machines to free weights can encourage more balance and stability. Likewise, decreasing stabilization in any way (with or without changing the mode) will place more challenge on the patient as he or she must provide internal stabilization to maintain balance and control in the exercise. Similarly, decreasing feedback requires the patient to rely on internal memory trace of correct motor performance rather than on external feedback provided by the therapist.

Changing the **environment** can provide numerous differing challenges to the patient. One important environmental change is moving from performing exercises in the pool in a minimally or unweighted environment to performing similar exercises on land, or vice versa. Another example is progressing from the structured environment of the clinic where the patient is used to focusing solely on the exercises at hand to a community environment where there are many competing stimuli. Similarly, changing the exercise sequence can be a form of progression. **Sequence** preferences were discussed earlier in this chapter. A sample sequence progression might be performing two exercises training the same muscle group back to back rather than alternating the exercises with a different activity. For example, the patient might perform resisted knee extension immediately followed by resisted straight leg lifts rather than performing a hamstring curl or an upper body exercise in between.

For many individuals, changing the **movement pattern or posture** can significantly alter the activity. For example, patients with spinal stenosis may need to perform exercises in slight flexion in the early stages. As symptoms improve, progression might include performing the same exercises closer to neutral or neutral toward an extended position. The movement for trunk stabilization exercises might progress from performing an exercise bilaterally (where the bilateral nature of the exercise provides balance and some stability) to performing the same movement unilaterally with the contralateral limb held close to the side. This asymmetric pattern would provide increase trunk stability challenge.

Finally, removing **cognitive control** asks the patient to progress the exercise from the cognitive motor control stage to the autonomous stage (see Chapter 3). This is simply done by engaging the patient cognitively while asking him or her to perform a motor skill. Thus the same task becomes more challenging as the patient is no longer allowed to cognitively focus on the exercise demands.

Finding the right balance of expanding volume and program changes within the same volume is no easy task. However, taking smaller incremental steps to progress the patient will minimize any significant regression should the program changes be too challenging. Ongoing communication and close monitoring either face to face or by other means can help ensure continuous forward progress toward goals. This communication should include patient education on the expected response to the exercise program and instructions for modification should symptoms increase.

THERAPEUTIC EXERCISE INTERVENTION FOR PREVENTION, HEALTH PROMOTION, AND WELLNESS

Patients who successfully complete a rehabilitation program may want to continue a resistive exercise program to further the gains they have made and/or to prevent a recurrence of their injury. These individuals can transition into a fitness exercise program. Exercise progression following a rehabilitation program, or designing a program for injury prevention or wellness, must consider the current training level of the individual.

The ACSM defines a *novice* as someone with no training experience, *intermediate* as someone with 6 months of consistent resistance training experience, and *advanced* as someone with years of resistive training experience.[37] *Elite* individuals are highly competitive athletes. Strength gains vary considerably among these training groups. You can expect muscle strength gains of approximately 40% in untrained individuals, 16% to 20% gains in intermediate, 10% in advanced, and 2% in elite athletes.[37] These gains can be expected over the course of 4 weeks to 2 years, with the majority of gains (especially in the untrained) occurring in the first 4 to 8 weeks. For untrained individuals, the responses to just about any training program will be profound, whereas making gains in intermediate, advanced, or elite athletes is much more difficult. Exercise prescription will need to be more creative and variable in these individuals.

Although strength gains in the short-term (4 to 8 weeks) can be encouraging for the participant, this rate of progress will level off after an initial period of training. At this point, program changes must be considered to continue progression toward exercise goals. The ACSM defines **progression** as the continued improvement in a desired variable (i.e., strength, power, endurance, muscle hypertrophy, etc.) over time until the individual goal has been achieved.[30] Continuing the initial training program for several months following program initiation is unlikely to sustain forward progress. Changes to the resistive training program are necessary to minimize training plateaus and to sustain forward progress. Like resistive training for rehabilitation, progressive overload can occur by increasing the exercise load, repetitions, or volume, or by changing the exercise speed, decreasing rest intervals, or by any combination of these variables. A periodized program to systematically vary exercise volume and intensity has been shown to be most effective for long-term progression.[37,194,195]

Dosage for Strength Training

For strength development, the ACSM recommends that novice and intermediate lifters train at an intensity of 60% to 70% of 1 RM for 8 to 12 repetitions.[37] All lifters should use both concentric and eccentric contractions. Untrained individuals require very little load to improve strength. Loads as little as 45% to 50% of 1 RM and less have been shown to increase strength in previously untrained individuals.[195,196] Novices should train the entire body 2 to 3 days per week whereas intermediate lifters should train similarly, unless desiring to progress to split workouts (upper body 1 day and lower another). In this case, the frequency should be 3 to 4 days per week, allowing training of each muscle group 1 to 2 days per week. The volume prescription should include either single or multiple sets initially (such as the DeLorme or DAPRE) and progressed to periodized training using multiple sets. Advanced lifters should train at 80% to 100% of 1 RM in a periodized plan.[37] Apply an approximately 2% to 10% increase in load when the individual can perform the current intensity for one to two repetitions over the desired number on two consecutive training sessions.[37] Base the intensity progression on the muscle group and activity.

The total training volume should be varied and progressed to continue strength gains. The training volume can be varied by changing the number of exercises performed in a session, by changing the number of repetitions performed in a set or the number of sets of exercise. Training volume dose–response recommendations for different populations have been made.[33] For untrained individuals, maximum strength gains were achieved at an intensity of 60% of 1 RM, 3 days per week with a mean training of four sets per muscle group. Recreationally trained athletes showed maximum strength gains at a dosage of 80% of 1 RM, 2 days per week also training four sets per muscle group. For athletes, maximal strength gains were made when training at 85% of 1 RM, 2 days per week at a mean training volume of eight sets per muscle group.[33,196]

Some ongoing debate surrounds the question of single- versus multiple-set resistance training programs.[197–201] Many gen exercisers, either single- or eral strength training programs include a single exercise set of 8 to 12 repetitions.[102] For novice exercisers, either single- or multiple-set resistance programs will achieve strength gains, although multiple sets produced superior gains in some research.[37,200,201] However, for trained individuals, multiple sets are more effective for strength building.[37,198,199]

Slow to moderate velocities are recommended for novice trainers unless the patient has difficulty generating torque or controlling movement at a specific functional speed. The ACSM recommends moderate velocities for intermediate training, and a spectrum of velocities from unintentionally slow to fast to maximize training gains in the advanced and elite athlete.[37] Unintentionally slow velocities are those where the load is so high that it requires the individual to lift slowly due to loading and/or fatigue. This type of training produces overload and a training response, whereas intentionally slow lifting, or submaximal lifting performed at a slow velocity (i.e., 5- to 10-second concentric, 5-second eccentric), do not produce sufficient overload.[203,204]

For novice, intermediate, or advanced training, the ACSM recommends rest intervals of 2 to 3 minutes for multijoint exercises using heavy loads.[37] For other exercises (including weight machines), they recommend a shorter rest interval of 1 to 2 minutes. This recommendation is the same for developing both strength and power.

Dosage for Power Training

Power requires a combination of strength, speed, and skill and the training program should reflect these variables. Effective use of power requires baseline strength at both fast and slow speeds, the ability to generate force quickly, efficient use of the SSC, and good neuromuscular coordination.

For power development, one to three sets of 30% to 60% of 1 RM for three to six repetitions should be incorporated into the intermediate training program.[37] Progression should use various loads planned in a periodized fashion. Advanced training should include a three- to six-set (one to six repetitions per set) power program incorporated into the strength program. Progression of power training requires both heavy loading (85% to 100% of 1 RM) for force development, and light to moderate loading (30% to 60% of 1 RM) performed at high velocity for increasing fast force production.[37] Focus only on heavy loading may actually decrease power output if not accompanied by quick, explosive-type exercises such as the loaded jump squat.[94] Rest period recommendations are the same as for strength training (see **Building Block 5-6**).

BUILDING BLOCK 5-6

A sprint athlete would like advice on how to increase performance for the 220-yard hurdles. Please provide some suggested strategies.

Plyometric Exercise

Functional activity seldom involves pure forms of isolated isometric, concentric, or eccentric actions, because the body is subjected to impact forces (**Fig. 5-21**), as in running or jumping, or because some external force, such as gravity, lengthens the muscle. In these movement patterns, the muscles are acting eccentrically and then concentrically. By definition of eccentric action, the muscle must be active during the lengthening phase. The SSC is the combination of an eccentric action followed by a concentric action. Training techniques that employ the SSC are called *plyometrics*. Examples of plyometric exercises include hopping, skipping, bounding, and jumping drills for the lower extremity, and plyometric ball or elastic resistive exercises for the upper extremity. However, not all jumping or resistive band exercises are plyometric. Plyometrics are done with a specific goal in mind: to increase power and speed.

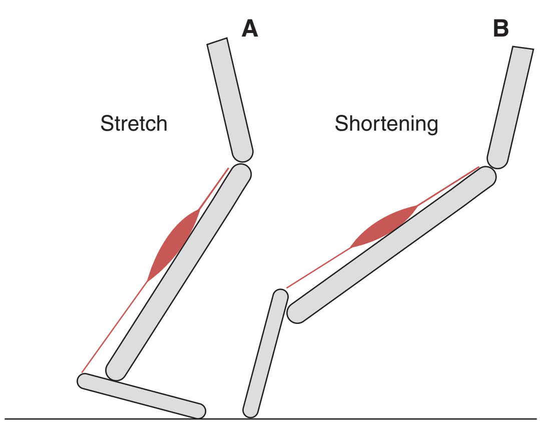

FIGURE 5-21 The SSC cycle in daily activities. At contact, the muscle is stretched and contracts in a lengthening action (eccentric) **(A)**. The stretch phase is followed by a shortening (concentric) action **(B)**. The figure demonstrates the SSC, which is the natural form of the muscle function.

Plyometrics are quick, powerful movements that are used to increase the reactivity of the nervous system. Plyometrics enhance work performance by storing elastic energy in the muscle–tendon unit during the stretch phase and reusing it as mechanical work during the concentric phase. Bosco et al.[205] found that the amount of elastic energy stored in a muscle during eccentric work determines the recoil of elastic energy during positive work. Part of the developed tension during the stretching phase is taken up by the elastic elements arranged in series with sarcomeres (i.e., series elastic component or tendon). This mechanical work is stored in the sarcomere cross-bridges and can be reused during the following positive work if the muscle is contracted immediately after the stretch. The muscle's ability to use the stored energy is determined by the timing of the eccentric and concentric contractions and by the velocity and magnitude of stretch. A quick transition from eccentric to concentric (i.e., undamped landings) along with a high-velocity stretch of high magnitude produces the greatest benefits. The transition time between the eccentric and concentric contractions is called the amortization phase, and the distinction between plyometrics and other impact activities is the goal of decreasing this phase as much as possible.

Plyometrics are high-level activities. Because of the stored energy in the series elastic component, the tendon is susceptible to overuse injury when performing plyometric exercises. The individual should be in an advanced training stage before these techniques are employed. In an advanced exercise program, these techniques develop power and speed, the key muscle performance elements of athletics. Jumping from or to different heights, bounding (i.e., jumping for distance), progressive throwing programs, and throwing for speed or distance are methods of using SSC for enhancing speed or power performance. Before performing lower-extremity plyometrics, the individual must be able to squat his or her body weight, perform a standing long jump equal to his or her height, and balance on a single leg with eyes closed. Programs should be well planned and progressed slowly and appropriately for the individual and the goals. An example of a plyometric program can be found in **Display 5-3**. See Additional Reading for more plyometric materials.

DISPLAY 5-3

Sample Plyometric Activities

Easy

- Ankle bounces in place
- Ankle bounces side to side
- Ankle bounces with 90-degree turn
- Ankle bounces in stride
- Single leg push offs from box
- Lateral hopping over cones
- Forward hopping over cones

Intermediate

- Jump ups on box
- Side jumps on to box

DISPLAY 5-3

Sample Plyometric Activities (*continued*)

- Tuck jump
- Multiple jumps forward
- Multiple jumps sideways
- Split squat jump
- Cone hops with turn
- Cone hops with land and sprint

Advanced

- Multiple box jumps with single leg land
- Squat jumps to multiple boxes
- Depth jumps with ball catch
- Standing long jump with 90-degree turn and sprint
- Depth jump with 90-degree turn and sprint
- Single leg bounding
- Bounding and vertical jump combination

Dosage for Endurance Training

Muscle endurance is necessary for a variety of activities and muscle groups. For example, postural muscles must provide sustained or repetitive contractions for long periods during prolonged standing, walking, or work activities. Many lower extremity muscles need endurance distance running, tennis, or other sports and leisure activities. Repetitive work activities such as carpentry, factory work, or other manual labor require local muscle endurance to fulfill job requirements during 8- to 12-hour work shifts.

For development of muscular endurance in novice and intermediate training, the ACSM recommends relatively light loads with moderate to high volume (10 to 15 repetitions). For advanced training, various loading strategies should be used for multiple sets per exercise (10 to 25 repetitions) using a periodization scheme.[37]

Use shorter rest periods such as 1 to 2 minutes for high repetition (15 to 20 repetitions) and <1 minute for moderate (10 to 15 repetitions) sets.[37] The training frequency is the same as for strength training, and the training velocity should be slow when doing a moderate (10 to 15) number of repetitions, and moderate or fast velocities when performing higher numbers of repetitions (15 to 25 or more).

Dosage for the Advanced or Elite Athlete

The following techniques are used by those who train competitive athletes. These techniques can be used to provide variety, increase resistance, or maximize the workout time in daily workouts. These specific techniques provide the recommended variability necessary for training the advanced or elite athlete. They are introduced to familiarize the therapist with the terminology used in training these athletes. Use good judgment based on scientific principles when using these techniques.

A **superset** consists of two sets of exercise involving opposing muscles that are performed in sequence without a rest between sets (e.g., a biceps curl followed by a triceps extension, without rest, proceeding to the remaining sets). Supersets can reduce workout time or allow more exercise to be performed during the same period.

A **triset** is a group of three exercises, each done after the other with little rest between muscle groups. Trisets can be used to exercise three different muscle groups or three angles of a complex muscle (e.g., flat, incline, decline bench press for the different fiber directions of the pectoralis major).

Pyramid training is a modification of the DeLorme training program. The regimen starts with a high number of repetitions and low weight (to warm up), but instead of maintaining the repetitions constant and increasing the weight, the repetitions are reduced and weight is increased. After the series is completed, the individual works backward, taking off weight and adding repetitions. The number of repetitions and sets is arbitrarily established as long as the high-repetition, low-weight progression to a heavier-weight, low-repetition regimen is followed (**Table 5-9**).

A typical **split routine** consists of a series of exercises that usually emphasize two or three major muscle groups or body parts. This allows the individual to train on two consecutive days without overtraining muscle groups, because one muscle group is resting, whereas the other is exercising. Body builders often follow a double-split routine, in which two sessions are performed on each day (**Table 5-10**).

Matveyev[206] described the basic ideas of periodized training programs for these athletes. A program is periodized when it is divided into phases, each of which has primary and secondary goals. The program is based on the premise that maximum strength gains are not made by constant heavy training but are made possible by different training cycles or periods. These

TABLE 5-9

Sample Pyramid Training for a Squat Exercise for a Highly Trained Individual

SETS	REPETITIONS	WEIGHT
1	12	100
1	8	135
1	6	185
1	4	225
1	2	250
1	1	275

TABLE 5-10

Example of a Split Routine for Total-Body Resistive Training

FOUR-DAY PROGRAM[a]	SIX-DAY, TWO SESSIONS PER DAY PROGRAM[a]
Monday: upper body	Monday AM: chest
Tuesday: lower body	Monday PM: back
Wednesday: rest	Tuesday AM: shoulders
Thursday: upper body	Tuesday AM: upper legs
Friday: lower body	Wednesday AM: triceps
Saturday: rest	Wednesday PM: biceps
Sunday: repeat sequence	Thursday AM: chest
Thursday PM: back	

[a]Abdominal and calf muscles are exercised each day.

cycles allow the athlete to reach maximum performance level at a predesignated time, usually the day of competition.

In his original model, Matveyev[206] suggested that the initial phase of a strength-power program should contain a high volume (i.e., many repetitions) with lower intensity (i.e., low average weight lifted relative to maximum possible in each movement). Typical high-volume phases for weight lifters contain more training sessions per week (6 to 15), more exercises per session (3 to 6), more sets per exercise (4 to 8), and more repetitions per set (4 to 6). As weeks pass, the volume decreases and intensity increases. The resulting higher intensity and lower volume represent the characteristics of a basic strength phase of training. Typical high-intensity phases for weight lifters contain fewer training sessions per week (5 to 12), fewer exercises per workout session (1 to 4), fewer sets per exercise (3 to 5), and fewer repetitions per set (1 to 3). A third, optional phase may include low volume (low repetitions) with high intensity (heavy weights) to work on power. The final phase is considered an active rest phase with very low volume and very low intensity.

Each phase may be several weeks to several months long. Two or more complete cycles may fit into a training year.

Stone et al.[207] proposed and successfully tested a periodized model of strength-power training with sequential phases that change rather drastically. An example is a phase to increase muscle size (5 sets of 10 RM in core exercises), a phase to improve specific strength (3 to 5 sets of 3 RM), and a phase to "peak" for competition (1 to 3 sets of 1 to 3 repetitions). The use of 10 RM is higher than typically recommended in the early preparation phase but has proved to be successful in a number of studies.[207]

PRECAUTIONS AND CONTRAINDICATIONS

Be sure to consider certain precautions and contraindications when prescribing resistive exercise. Avoid using the Valsalva maneuver during resistive training, especially by patients with cardiopulmonary disease or after recent abdominal, intervertebral disk, or eye surgery. Educate patients to breathe properly during exercise, typically exhaling on exertion. Use isometric exercise with caution by persons at risk for pressor response effects (e.g., high blood pressure after an aneurysm).

Overwork phenomena may exist even at moderate training regimens over an extended period. Overtraining may lead to mood disturbances and reduce the effect of training by a decrease in performance. Avoid fatigue and overtraining by patients with metabolic diseases (e.g., diabetes, alcoholism), neurologic diseases, or severe degenerative joint diseases because of the risk of further joint damage. Overtraining may be the reason for a lack of progress, decreased performance, or development of joint pain and swelling.

Use thoughtful consideration when developing resistive exercise programs for prepubertal and pubertal children and adolescents. Emphasize correct form and technique over weight lifted and develop comprehensive exercise programs to avoid muscle imbalances and overtraining specific tissues.

An absolute contraindication to resistive exercise is acute or chronic myopathy, as occurs in some forms of neuromuscular disease or in acute alcohol myopathy. Resistive exercise in the presence of myopathy may stress and permanently damage an already compromised muscular system.

Scientific knowledge and common sense should be applied in prescribing resistive exercise. Caution should be taken with exercise in the presence of pain, inflammation, and infection. Although resistive exercise may be indicated, the mode and dosage should be carefully chosen.

KEY POINTS

- The term *muscle performance* includes strength, power, and endurance.
- The term *strength* should be clarified in terms of force, torque, and work.
- Muscle actions are static and dynamic. Static muscle actions are called *isometric*.
- A thorough knowledge of muscle morphology is necessary for effective/efficient therapeutic exercise prescription to improve muscle performance.
- *Dynamic action* is the preferred term over *isotonic*. Dynamic actions can be further divided into concentric and eccentric actions.
- Overload training produces changes in the size of the muscle primarily through hypertrophy but also through hyperplasia.
- Muscle strength must be evaluated relative to the muscle's length because of length–tension relationships.
- Muscle architecture can significantly affect muscle force production.
- Specificity of training exists, especially relative to training velocity.
- Eccentric muscle contractions are the most energy-efficient contraction type and can develop the greatest tension of any muscle contraction type.
- Adaptations to resistive training are partially neurologic in that changes in performance often precede morphologic changes.
- *Form fatigue* is the point at which the individual must discontinue the exercise or sacrifice technique.
- Although dosage and goals differ, resistive training is beneficial from late childhood through old age.
- Impaired muscle performance can result from neurologic pathology, muscle strain, muscle disuse, or length-associated changes.
- Adaptations to resistive training extend beyond the muscle to include connective tissues, the cardiovascular system, and bone.
- Activities to improve muscle performance include isometric, dynamic, plyometric, and isokinetic exercise.
- Dynamic exercise can be performed with a variety of modes, including free weight, resistive bands, pulleys, weight machines, or body weight, including various combinations of concentric and eccentric contractions.
- Plyometric activities use the SSC to enhance muscle performance.
- The dosage of exercise to improve muscle performance depends on the goal (i.e., strength, power, and endurance) as well as the initial fitness level of the individual (i.e., novice, intermediate, advanced, and elite).
- Precautions and contraindications to resistive exercise must be known to ensure safety to the patient/client.

LAB ACTIVITIES

1. A series of musculoskeletal conditions is listed from i to viii. For each condition, perform the following:
   a. Determine which muscles are involved. Include possible underused synergists that may lead to overuse of the muscle involved. List each muscle and describe its specific action.
   b. Design and perform one exercise for each muscle (group) given the manual muscle test grade of fair minus (3—/5). Include complete dosage parameters.
   c. Design and perform two exercises for each muscle (group) given the manual muscle test grade of good (4/5). Use an elastic band for one and a free weight for the other, and include complete dosage parameters.
   d. Progress the exercises in question 1c to two functional activities.

Musculoskeletal and Neuromuscular Conditions

i. Achilles tendinopathy
ii. Iliotibial band fascitis
iii. Patellar tendinopathy
iv. Hamstring strain
v. Peroneal nerve palsy (i.e., common peroneal nerve; list muscles innervated)
vi. Supraspinatus tendinopathy
vii. Middle trapezius strain resulting from overstretch
viii. Lateral epicondylitis

2. Using free weights or a weight machine, determine the 1, 6, and 10 RM for a bench press and leg extension. Determine the dosage for Oxford, DeLorme, and DAPRE programs.
3. Pick three muscle groups throughout your body (one upper quarter, one lower quarter, and one trunk). Design two different resistive exercises for each muscle group using a variety of equipment, including elastic bands, free weights, and pulleys and weight machines if available. Determine the dosage for a DeLorme program.

CRITICAL THINKING QUESTIONS

1. Consider each of the questions in the Lab Activities in the next section. How would your dosage differ if you were training for:
   a. strength
   b. power
   c. muscle endurance

How would your training differ for:
   d. an adolescent cross-country runner who wanted to improve performance
   e. a preadolescent: gymnast, dancer, football player, soccer player
   f. an elderly man who was training for a 10-day hike in the mountains
2. Design a muscle performance program for a woman confined to bed rest for 3 weeks after an acute lumbar fracture without neurologic involvement. Include dosage parameters for strength and endurance.
3. Consider Case Study No. 5 in Unit 7. List muscles with impaired muscle performance. Determine whether the muscle requires strength, endurance, or power training. Decide on one activity for each muscle and determine the dosage relative to the goal (i.e., strength, power, and endurance) and initial fitness level for this patient. Develop the sequence of exercise for each session and include the frequency in the dosage parameters.

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