Seventh Edition

Advanced Fitness Assessment and Exercise Prescription

Muscular Fitness Assessment and Prescription

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Contents

Preface

Muscular strength and endurance are two important components of muscular fitness. Minimal levels of muscular fitness are needed to perform activities of daily living, to maintain functional independence as one ages, and to partake in active leisure-time pursuits without undue stress or fatigue. Adequate levels of muscular fitness lessen the chance of developing low back problems, osteoporotic fractures, and musculoskeletal injuries.

Muscular strength and endurance are important to the overall health and physical fitness of your clients, enabling them to engage in physically active leisure-time pursuits, to perform activities of daily living more easily, and to maintain functional independence later in life. Resistance training is a systematic program of exercise for development of the muscular system. Although the primary outcome of resistance training is improved strength and muscular endurance, a number of health benefits are also derived from this form of exercise.

While resistance training has long been widely used by bodybuilders, powerlifters, and competitive athletes to develop strength and muscle size, participation in weightlifting by individuals of all ages and levels of athletic interest has increased dramatically over the past 30 yr. The popularity and widespread appeal of weightlifting exercise for general muscle conditioning challenge exercise specialists and personal trainers to develop resistance training programs that can meet the diverse needs of their clients.

Chapter 6 describes a variety of laboratory and field tests for assessing all forms of muscular strength and endurance. In addition, the chapter compares types of exercise machines, addresses factors affecting muscular fitness tests, discusses sources of measurement error, and provides guidelines for testing muscular fitness of children and older adults.

Chapter 7 shows you how to apply basic training principles to the design of resistance training programs for novice, intermediate, and advanced weightlifters. The chapter also presents guidelines for developing muscle strength, muscle endurance, muscle size, and muscle power. The chapter addresses various models of periodization, functional training exercise progressions, and guidelines for youth resistance training.

These chapters and the accompanying appendix are full excerpts from *Advanced Fitness Assessment and Exercise Prescription, Seventh Edition*. The book's full glossary and reference list are also provided at the end of the e-book.

CHAPTER 6

Assessing Muscular Fitness

KEY QUESTIONS

- How are strength and muscular endurance assessed?
- How does the type of muscle contraction (concentric, eccentric, or isokinetic) affect force production?
- What test protocols can be used to assess a client's muscular fitness?
- What are the advantages and limitations of using free weights and exercise machines to assess muscular strength?
- What are sources of measurement error for muscular fitness tests, and how are they controlled?
- What are the recommended procedures for administering 1-RM strength tests?
- Is it safe to give 1-RM strength tests to children and older adults?
- What tests can be used to assess the functional strength of older adults?

Muscular strength and endurance are two important components of muscular fitness. Minimal levels of muscular fitness are needed to perform activities of daily living, to maintain functional independence as one ages, and to partake in active leisure-time pursuits without undue stress or fatigue. Adequate levels of muscular fitness lessen the chance of developing low back problems, osteoporotic fractures, and musculoskeletal injuries.

This chapter describes a variety of laboratory and field tests for assessing all forms of muscular strength and endurance. In addition, the chapter compares types of exercise machines, addresses factors affecting muscular fitness tests, discusses sources of measurement error, and provides guidelines for testing muscular fitness of children and older adults.

DEFINITION OF TERMS

Muscular strength is defined as the ability of a muscle group to develop maximal contractile force against a resistance in a single contraction. The force generated by a muscle or muscle group, however, is highly dependent on the velocity of movement. Maximal force is produced when the limb is not rotating (i.e., zero velocity). As the speed of joint rotation increases, the muscular force decreases. Thus, *strength for dynamic movements* is defined as the maximal force generated in a single contraction at a specified velocity (Knuttgen and Kraemer 1987). **Muscular endurance** is the ability of a muscle group to exert submaximal force for extended periods.

Both strength and muscular endurance can be assessed for static and dynamic muscular contractions. If the resistance is immovable, the muscle contraction is **static or isometric** ("iso," same; "metric," length), and there is no visible movement of the joint. **Dynamic contractions**, in which there is visible joint movement, are either concentric, eccentric, or isokinetic (see figure 6.1, *a* and *b*).

Video 6.1

Video 6.2

Video 6.3

If the resistance is less than the force produced by the muscle group, the contraction is **concentric**, allowing the muscle to shorten as it exerts tension to move the bony lever. The muscle is also capable of exerting tension while lengthening. This is known as **eccentric contraction**, and it typically occurs when the muscles produce a braking force to decelerate rapidly moving body segments or to resist gravity (e.g., slowly lowering a barbell). Both concentric and eccentric contractions are sometimes called **isotonic** ("iso," same; "tonic," tension). The term *isotonic contraction* is a misnomer because the tension produced by the muscle group fluctuates greatly even though the resistance is constant throughout the range of motion (ROM). This fluctuation in muscular force is due to the change in muscle length and angle of pull as the bony lever is moved, creating a strength curve that is unique for each muscle group. For example, the strength of the knee flexors is maximal at 160° to 170° (see figure 6.2).

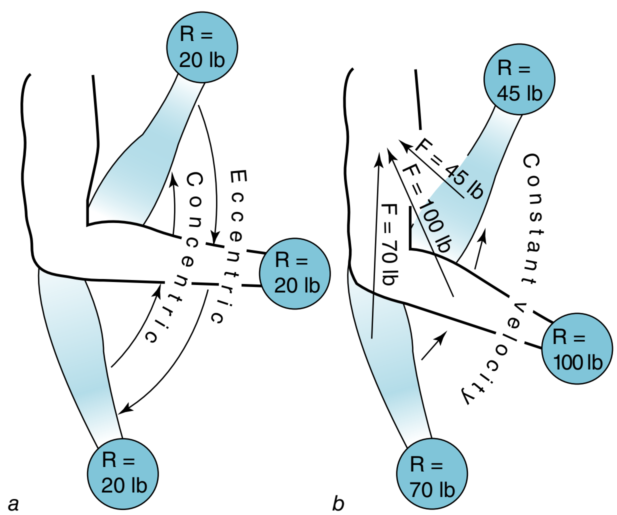


FIGURE 6.1 Types of muscle contraction.

In regular (concentric and eccentric) dynamic exercise, because of the change in mechanical and physiological advantage as the limb is moved, the muscle group is not contracting maximally throughout the ROM. Thus, the greatest resistance that can be used during regular, dynamic exercise is equal to the maximum weight that can be moved at the weakest point in the ROM.

Isokinetic contraction (see figure 6.1*b*) is a maximal contraction of a muscle group at a constant velocity throughout the entire range of joint motion ("iso," same; "kinetic," motion). The velocity of contraction is controlled mechanically so that the limb rotates at a set velocity (e.g., 120°·sec^{-1}). Electromechanical devices vary the resistance to match the muscular force produced at each point in the ROM. Thus, isokinetic exercise machines allow the muscle group to encounter variable but maximal resistances during the movement.

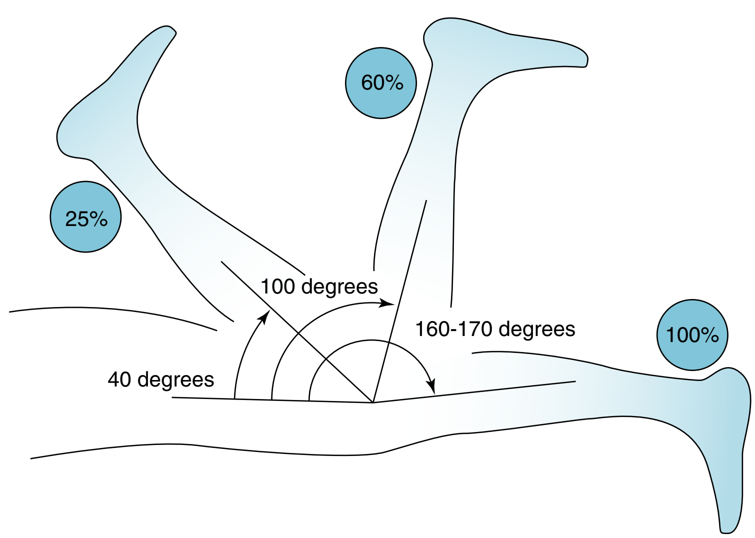


FIGURE 6.2 Strength variations in relation to knee joint angle.

STRENGTH AND MUSCULAR ENDURANCE ASSESSMENT

Measures of static or dynamic strength and endurance are used to establish baseline values before training, monitor progress during training, and assess the overall effectiveness of resistance training and exercise rehabilitation programs. Static strength and muscular endurance are measured using dynamometers, cable tensiometers, strain gauges, and load cells. Free weights (barbells and dumbbells), as well as constant-resistance, variable-resistance, and isokinetic exercise machines, are used to assess dynamic strength and endurance (see table 6.1). The testing procedures vary depending on the type of test (i.e., strength or endurance) and equipment.

ISOMETRIC MUSCLE TESTING USING SPRING-LOADED DYNAMOMETERS

Isometric strength is measured as the maximum force exerted in a single contraction against an immovable resistance (i.e., maximum voluntary isometric contraction, or MVIC). For many years, spring-loaded dynamometers have been used to measure static strength and endurance of the grip squeezing muscles and leg and back muscles (see figure 6.3). The handgrip dynamometer has an adjustable handle to fit the size of the hand and measures forces between 0 and 100 kg in 1 kg increments

FIGURE 6.3 Spring-loaded dynamometers for measuring static strength and endurance: (*a*) handgrip dynamometer and (*b*) back and leg dynamometer.

Table 6.1 Strength Training Modes

Testing mode	Equipment	Measure*
Static	Isometric dynamometers, cable tensiometers, strain gauges, load cells, and handheld dynamometers	MVIC (kg or N)
Dynamic		
Constant resistance	Free weights (barbells and dumbbells) and exercise machines	1-RM (lb or kg)
Variable resistance	Exercise machines	NA
Isokinetic and omnikinetic	Isokinetic and omnikinetic dynamometers	Peak torque (Nm or ft-lb)

*MVIC = maximal voluntary isometric contraction; NA = not applicable; N = newton; Nm = newton-meter; ft-lb = foot-pound.

(0 and 220 lb in 2.2 lb increments). The back and leg dynamometer consists of a scale that measures forces ranging from 0 to 2500 lb in 10 lb increments (0–1134 kg in 4.5 kg increments). As force is applied to the dynamometer, the spring is compressed and moves the indicator needle a corresponding amount.

Grip Strength Testing Procedures

Video 6.4

Before using the handgrip dynamometer, adjust the handgrip size to a position that is comfortable for the individual. Alternatively, you can measure the hand width with a caliper and use this value to set the optimum grip size (Montoye and Faulkner 1964). The individual stands erect, with the arm and forearm positioned as follows (Fess 1992): shoulder adducted and neutrally rotated, elbow flexed at 90°, forearm in the neutral position, and wrist in slight extension (0° to 30°). For some test protocols, however, the client must keep the arm straight and slightly abducted for measurement of the grip strength of each hand (Canadian Society for Exercise Physiology [CSEP] 2003). The individual squeezes the dynamometer as hard as possible using one brief maximal contraction and no extraneous body movement. Administer three trials for each hand, allowing a 1 min rest between trials, and use the best score as the client's static strength.

Grip Endurance Testing Procedures

Video 6.5

Once the grip size is adjusted, instruct the client to squeeze the handle as hard as possible and to continue squeezing for 1 min. Record the initial force and the final force exerted at the end of 1 min. The greater the endurance, the lower the rate and degree of decline in force. The relative endurance score is the final force divided by the initial force times 100.

Alternatively, you can assess static grip endurance by having your client exert a submaximal force, which is a given percentage of the individual's **maximum voluntary isometric contraction (MVIC)** strength (e.g., 50% MVIC). The relative endurance score is the amount of time that this force level is maintained. During the test, the client must watch the dial of the dynamometer and adjust the amount of force exerted as necessary in order to maintain the appropriate submaximal force level.

Leg Strength Testing Procedures

Using the back and leg dynamometer, the individual stands on the platform with trunk erect and the knees flexed to an angle of 130° to 140°. The client holds the hand bar using a pronated grip and positions it across the thighs by adjusting the length of the chain (see figure 6.3*b*). If a belt is available, attach it to each end of the hand bar after positioning the belt around the client's hips. The belt helps to stabilize the bar and to reduce the stress placed on the hands during the leg lift. Without using the back, the client slowly exerts as much force as possible while extending the knees. The maximum indicator needle remains at the peak force achieved. Administer two or three trials with a 1 min rest interval. Divide the maximum score (in pounds) by 2.2 to convert it to kilograms.

Back Strength Testing Procedures

Using the back and leg dynamometer, the individual stands on the platform with the knees fully extended and the head and trunk erect. The client grasps the hand bar using a pronated grip with the right hand and a supinated grip with the left. Position the hand bar across the client's thighs. Without leaning backward, the client pulls the hand bar straight upward using the back muscles. Before lifting, instruct the client to roll the shoulders backward during the pull, to avoid flexing the trunk, and to keep the head and trunk erect during the test. Administer two trials with a 1 min rest between the trials. Divide the maximum score (in pounds) by 2.2 to convert it to kilograms.

Static Strength Norms for Spring-Loaded Dynamometers

Table 6.2 provides age-gender norms for evaluating the static grip strength of the right and left hands combined. Grip strength norms for each hand are presented in table 6.3. You can also use norms developed for men and women to assess your client's static strength for each dynamometric test item (see table 6.3). Calculate your client's total strength score by adding the right grip, left grip, leg strength, and back strength scores. Before doing this, convert the leg and back strength scores (measured in pounds)

Table 6.2 Age-Gender Norms for Combined Isometric Grip Strength

Rating	GRIP STRENGTH (KG)*											
	15-19 yr		20-29 yr		30-39 yr		40-49 yr		50-59 yr		60-69 yr	
	M	F	M	F	M	F	M	F	M	F	M	F
Excellent	≥108	≥68	≥115	≥70	≥115	≥71	≥108	≥69	≥101	≥61	≥100	≥54
Very good	98-107	60-67	104-114	63-69	104-114	63-70	97-107	61-68	92-100	54-60	91-99	48-53
Good	90-97	53-59	95-103	60-62	95-103	58-62	88-96	54-60	84-91	49-53	84-90	45-47
Fair	79-89	48-52	84-94	52-59	84-94	51-57	80-87	49-53	76-83	45-48	73-83	41-44
Needs improvement	≤78	≤47	≤83	≤51	≤83	≤50	≤79	≤48	≤75	≤44	≤72	≤40

*Combined right- and left-hand grip strength scores.

M = males; F = females.

Source: *Canadian Physical Activity Guidelines,* © 2011, 2012. Used with permission from the Canadian Society for Exercise Physiology, www.csep.ca/guidelines.

Table 6.3 Static Strength Norms

Classification	Left grip (kg)	Right grip (kg)	Back strength (kg)	Leg strength (kg)	Total strength (kg)	Relative strength*
MEN						
Excellent	>68	>70	>209	>241	>587	>7.50
Good	56-67	62-69	177-208	214-240	508-586	7.10-7.49
Average	43-55	48-61	126-176	160-213	375-507	5.21-7.09
Below average	39-42	41-47	91-125	137-159	307-374	4.81-5.20
Poor	<39	<41	<91	<137	<307	<4.81
WOMEN						
Excellent	>37	>41	>111	>136	>324	>5.50
Good	34-36	38-40	98-110	114-135	282-323	4.80-5.49
Average	22-33	25-37	52-97	66-113	164-281	2.90-4.79
Below average	18-21	22-24	39-51	49-65	117-163	2.10-2.89
Poor	<18	<22	<39	<49	<117	<2.10

*Relative strength is determined by dividing total strength by body mass (kg).

For persons over age 50, reduce scores by 10% to adjust for muscle tissue loss due to aging.

Data from Corbin and colleagues 1978.

to kilograms. To calculate the relative strength score, divide the total strength score by body mass (expressed in kilograms).

ISOMETRIC MUSCLE TESTING USING HYDRAULIC DYNAMOMETERS, CABLE TENSIOMETERS, AND STRAIN GAUGES

You can use hydraulic dynamometers to measure the isometric grip strength of your clients. These instruments have a sealed hydraulic system that measures force (in lb or kg) on a gauge dial. The Jamar grip dynamometer is widely used and has excellent validity and reliability (Roberts et al. 2011). The American Society of Hand Therapists (ASHT; 1992) recommends the following standardized testing procedures:

1. Client is seated.
2. Shoulders are adducted and neutrally rotated, with elbow flexed at 90° and forearm in a neutral position.
3. Wrist is dorsiflexed between 0° and 30°.
4. Administer 3 trials for each hand and record the mean of 3 trials.

However, Roberts and colleagues (2011) reported that testing protocols for assessing grip strength vary widely. Therefore, they proposed a more detailed testing protocol based on the ASHT guidelines. This revised protocol standardizes leg and forearm position, encouragement and assessor training, and summary measures (i.e., use the best score from 6 trials). Norms for the Jamar grip dynamometer are available for women and men, ages 20 to 80+ yr (Bohannon et al. 2006; Peters et al. 2011).

Additionally, you can use cable tensiometry and strain gauges to assess the static strength of various muscle groups throughout the body. For cable tensiometry, standardized testing procedures have been described in detail and should be followed closely to ensure the validity and reliability of the test results (see Clarke 1966). The instrumentation includes a tensiometer, steel cables, testing table, wall hooks, straps, and goniometer. Attach one end of the cable to the wall or table hooks and, using a strap, attach the other end to the body part to be tested. Always position the cable at a right angle to the pulling bony lever. Use a goniometer to measure the appropriate joint angle. Place the tensiometer on a taut cable. As the individual exerts force on the cable, the riser of the tensiometer is depressed and a maximum indicator needle registers the static strength score. Tensiometers measure forces ranging between 0 and 400 lb (0–180 kg). However, the larger tensiometers are less accurate in the lower range; therefore, you should use a small tensiometer, which measures forces between 0 and 100 lb (0–45.4 kg), to obtain greater accuracy in the lower range.

Cable tensiometry tests can be used to assess strength impairment at specific joint angles and to monitor progress during rehabilitation. As with all forms of static strength testing, you should be aware that strength is specific to the joint angle and muscle group being tested. Therefore, test at least three muscle groups to provide an adequate estimation of static strength.

Test batteries and norms have been developed for males and females 9 yr old through college age (Clarke 1975; Clarke and Monroe 1970). The test battery for males of all ages includes the same three strength tests: shoulder extension, knee extension, and ankle plantar flexion. For elementary and junior high school girls, the test battery includes shoulder extension, hip extension, and trunk flexion. The three test items in the battery developed for senior high school and college women are shoulder flexion, hip flexion, and ankle plantar flexion.

Maximum voluntary isometric contraction testing using strain gauge systems requires the joint being tested to be in gravity neutral position and the strain gauge and strap to be perpendicular to the line of force. Detailed testing procedures and age-gender norms for 11 muscle groups are available (see Meldrum et al. 2003, 2007).

ISOMETRIC MUSCLE TESTING USING DIGITAL HANDHELD DYNAMOMETRY

Hand-held dynamometry is a convenient method for measuring the isometric strength of the upper and lower body musculature. Compared to isokinetic testing (Kin-Com, Biodex, and Cybex), handheld dynamometry has moderate-to-good validity (Stark et al. 2011) and excellent reliability for most muscle groups (Lu et al. 2011). You can use handheld dynamometers that provide a digital display of force production to assess the isometric strength of 11 muscle groups (see figure 6.4, *a* and *b*). This handheld dynamometer digitally displays force measurements up to a maximum of 440 newtons (100 lb in 0.1 lb increments). For this type of testing, place the dynamometer on the limb and hold it stationary while the client exerts maximum force against it. Administer two trials and use either the average or best score for each muscle group. Appendix C.1 describes standardized test protocols for 11 muscle groups. Performance norms for adults (20–79 yr) and children (4–16 yr) are available (see Andrews, Thomas, and Bohannon 1996; Beenakker et al. 2001; Bohannon 1997; van den Beld et al. 2006).

ISOMETRIC MUSCLE TESTING USING CLINICAL METHODS

Several clinical tests have been developed to measure the isometric endurance of core muscles used to stabilize the spine. Two of the most popular tests are the Kraus-Weber test for the trunk flexors and the Sorensen test for the trunk extensors (Biering-

a

b

FIGURE 6.4 (*a*) Handheld dynamometer for measuring isometric strength and (*b*) the hand being tested.

Courtesy of Hoggan Industries.

Sorensen 1984; Kraus 1970). For these tests, clients must maintain their trunk and lower extremities in a certain position for as long as possible. Over the years, these tests have been modified to reduce the risk of low back pain or injury resulting from hyperextension of the lumbar spine during these tests (Ito et al. 1996; McGill, Childs, and Liebenson 1999; Reiman et al. 2010).

Video 6.6

To assess the isometric endurance of the trunk flexors, you can use the V-sit test. For this test, the trunk is reclined 60° above the horizontal plane, the knees and hips are flexed 90°, and the feet are stabilized. A wooden triangular supporting wedge is positioned behind the client to ensure that the torso is reclined to 60°. To start the test, the supporting wedge is moved away from the client. The client maintains the V-sit position for as long as possible. Endurance time (in sec) is measured with a stopwatch (McGill et al. 1999). The test-retest reliability of the V-sit test is high ($r = 0.92$).

For the trunk extensor test, the client lies prone on the bench with the lower body strapped to the bench at the ankles, knees, and hips. The upper body is extended over the edge of the bench. The bench height is 25 cm. The arms are folded across the chest and the upper body is lifted until the trunk is horizontal to the floor. The client maintains this position for as long as possible. Endurance time (in sec) is measured with a stopwatch. The test is terminated when the client's upper body touches the floor (McGill et al. 1999).

Video 6.7

In addition to the trunk flexors and extensors, the lateral flexors of the spine are important for lumbar stabilization. The side bridge test can be used to assess the isometric endurance of the lateral flexors. For this test, the client elevates the torso from a side-lying position and supports this position on one elbow and forearm. The upper leg crosses in front of the lower leg for additional support. The non-weight-bearing arm is held across the chest with the hand placed on the opposite shoulder. The client maintains a straight line position with the hips off the mat for as long as possible. Endurance time (in sec) is measured with a stopwatch. The test is terminated when the hips return to the mat.

One disadvantage of the side bridge test is that some clients terminate the test due to upper extremity fatigue or pain. To avoid this shortcoming, Greene and colleagues (2012) developed a novel side-support test with the feet elevated on a 15 cm padded stool. To ensure that the torso is aligned properly, a horizontal reference rod of the alignment apparatus is placed on the greater trochanter of the top leg and fixed at this height. The client is instructed to maintain contact with the reference rod and hold this position for as long as possible during the test. The test is terminated when contact with the rod is lost for longer than 2 sec or when the client lowers the hips to the mat. Moderate-to-high correlations ($r = 0.59–0.75$) were reported between this test and the traditional side bridge test, and the test-retest reliability was good. This modification of side bridge test may be a suitable alternative for clients with upper extremity pain or weakness.

Table 6.4 presents average endurance times for the trunk flexor, trunk extensor, and trunk lateral

Table 6.4 Mean Endurance Times (sec) and Ratios[a] for Trunk Extensors, Flexors, and Lateral Flexors

	MEN			WOMEN		
Muscle group	**Mean**	**SD**	**Ratio**	**Mean**	**SD**	**Ratio**
Trunk extensors[b]	146	51	1.00	189	60	1.00
Trunk flexors[c]	144	76	0.99	149	99	0.79
Lateral flexors[d], right	94	34	0.64	72	31	0.38
Lateral flexors[d], left	97	35	0.66	77	35	0.40

[a]Ratios are normalized relative to the trunk extensors.

[b]Modified Biering-Sorensen test.

[c]V-sit test.

[d]Side bridge test.

Adapted from *Archives of Physical Medicine and Rehabilitation,* Vol. 80, S.M. McGill, A. Childs, and C. Liebenson, "Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database," pp. 941-944, copyright 1999, with permission of Elsevier.

flexor tests for healthy men and women (McGill et al. 1999). In addition, average ratios of endurance times, normalized to the trunk extensor, may be used to identify muscle endurance imbalances around the torso.

DYNAMIC MUSCLE TESTING USING CONSTANT-RESISTANCE AND VARIABLE-RESISTANCE MODES

Although either a **constant-resistance** or a **variable-resistance exercise** mode can be used to assess dynamic (concentric and eccentric) muscle strength and endurance, you will be better served if you use either free weights or constant-resistance exercise machines.

A major disadvantage of free weights, dumbbells, and constant-resistance exercise machines, however, is that they measure dynamic strength only at the weakest point in the ROM. The reason is that the resistance cannot be varied to account for fluctuations in muscular force caused by the changing mechanical (angle of pull of muscle) and physiological (length of muscle) advantage of the musculoskeletal system during the movement.

In an attempt to overcome this deficiency, equipment manufacturers have designed variable-resistance machines that vary the resistance during the ROM. Variable-resistance machines have a moving connection (i.e., lever, cam, or pulley) between the resistance and the point of force application. As the weight is lifted, the mechanical advantage of the machine decreases. Therefore, more force must be applied to continue moving the resistance. The variable-resistance mode of exercise attempts to match the force capability of the musculoskeletal system throughout the ROM. However, many variable-resistance exercise machines fail to match the strength curves of different muscle groups. Also, with variable-resistance machines, it is difficult to assess the client's maximal force or strength because the resistance is modified by the levers, pulleys, and cams, causing the movement velocity to vary. Variable-resistance exercise machines, therefore, have limited usefulness for maximal testing. Still, these types of machines are well suited for resistance training.

Although free weights and constant-resistance exercise machines are generally recommended for muscular fitness testing, there are advantages and limitations to each of these modalities. Compared to exercise machines, free weights require more neuromuscular coordination in order to stabilize body parts and maintain balance during lifting of the barbell or dumbbell. While exercise machines may reduce the need for spotting during the test, these machines limit the individual's range of joint motion and plane of movement. Also, some exercise machines have relatively large weight plate increments, so you must attach smaller weights to the weight stack in order to measure your client's strength accurately.

Lastly, some machines cannot accommodate individuals with short limbs; you may need to use child-sized machines to standardize their starting positions for testing. Clients with long limbs or large body and limb circumferences (e.g., some bodybuilders or obese clients) also may have difficulty using standard exercise machines. Body size and weight increments are less of a problem with free weights.

To overcome some of these limitations, **free-motion machines** that provide constant and variable resistance in multiple planes have been developed. These machines have adjustable seats, lever arms, and cable pulleys that can be set to exercise muscle groups in multiple planes. These machines are easy to get in and out of, and they can accommodate smaller or larger individuals and have smaller weight increments (5 lb or 2.3 kg) than do older standard machines (typically 10 lb or 4.5 kg). When using free-motion exercise machines for muscular fitness testing, take care to adjust the plane of movement and the seat so that you simulate the starting and ending body positions that were used to develop test norms for older constant-resistance machines. If you use free-motion machines to monitor the progress of your clients, make certain that you use the same settings (i.e., seat and plane-of-movement adjustments) for each test session.

Dynamic Strength Tests

Force plates paired with linear transducers are used to obtain direct (i.e., gold standard) measures of muscular force and power. Cost of equipment, however, limits the usefulness of this method beyond the laboratory setting. With improved technology, new devices for assessing dynamic muscle force and power are being developed and validated against gold standard measures. One such device is the Myotest accelerometer. This triaxial accelerometer has the potential to measure force production in three different planes of movement. The Myotest accelerometer has excellent validity ($r = 0.85 - 0.99$) for calculating force, velocity, and power during dynamic exercise (Castertelli, Muller, and Maffiuletti 2010; Crewther et al. 2011; Thompson and Bemben 1999). This accelerometer also demonstrated high concurrent validity and reliability for measuring dynamic strength and power of men and women performing squat and bench press exercises (Comstock et al. 2011). In light of its small size, ease of use, and portability, the Myotest accelerometer is a practical device that you can use in the field to evaluate muscle force and power.

However, more commonly in field settings, dynamic strength is measured as the **one-repetition maximum (1-RM)**, which is the maximum weight that can be lifted for one complete repetition of the movement. The 1-RM strength value is obtained through trial and error.

Although 1-RM strength tests can be safely administered to individuals of all ages, you should take precautions to decrease the risk of injury when clients attempt to lift maximal loads. Be certain that your clients warm up before attempting the lift and start with a weight that is below their expected 1-RM. When you administer these tests, you should spot your clients and closely monitor their lifting technique and breathing. The National Strength and Conditioning Association (2008) recommends the following "Tips for Spotting Free Weight Exercise."

The American College of Sports Medicine (ACSM 2014) recommends the bench press and leg press (upper plate of constant-resistance exercise machine) for assessing strength of the upper and lower body, respectively. To determine **relative strength**, divide the 1-RM values by the client's body mass. Norms for men and women are provided in tables 6.5 and 6.6.

Another test of dynamic strength includes six test items: bench press, arm curl, latissimus pull, leg press, leg extension, and leg curl. For each exercise, express and evaluate the 1-RM as a percentage of body mass. For example, if a 120 lb (54.5 kg) woman bench presses 60 lb (27.2 kg), her ratio of strength to body mass is 0.50 (60 divided by 120), and she scores 3 points for that exercise. Follow this procedure for each exercise, then add the total points to determine the overall strength and fitness category of the individual. Strength-to-body-mass ratios with corresponding point values for college-age men and women are presented in table 6.7.

TIPS FOR SPOTTING FREE WEIGHT EXERCISE (NATIONAL STRENGTH AND CONDITIONING ASSOCIATION 2008)

1. The primary role of the spotter is to help protect the client from injury.
2. With the exception of power exercises, free weight exercises performed with the bar moving over the head, on the back, in front of the shoulders, or passing over the face require one or more spotters (e.g., bench press, lying triceps extensions, and front squat).
3. The spotter should be at least as strong and at least as tall as the client performing the exercise.
4. Overhead exercises and exercises where the bar is placed on the back or in front of the shoulders should be performed inside a power rack.
5. When spotting over-the-face exercises, use an alternated grip that is narrower than the client's when grasping the bar to lift or lower it. Use a supinated grip to spot the bar during the exercise.
6. When spotting heavy loads, establish a stable base of support and a flat-back position.
7. For dumbbell exercises, spot as close to the dumbbell as possible (e.g., for dumbbell flys, spot at the wrists, not at the elbows).
8. Spotters typically help position the barbell or dumbbells to the proper starting position (i.e., liftoff or moving the bar from the upright supports to client's hands and extended elbows).
9. Most clients need just enough help to successfully complete a repetition. During 1-RM attempts, however, the spotter should be prepared to take the bar immediately if the client cannot complete the repetition.

Video 6.8

Table 6.5 Age-Gender Norms for 1-RM Bench Press (1-RM/BM)

Percentile rankings* for men	AGE				
	20-29	30-39	40-49	50-59	60+
90	1.48	1.24	1.10	0.97	0.89
80	1.32	1.12	1.00	0.90	0.82
70	1.22	1.04	0.93	0.84	0.77
60	1.14	0.98	0.88	0.79	0.72
50	1.06	0.93	0.84	0.75	0.68
40	0.99	0.88	0.80	0.71	0.66
30	0.93	0.83	0.76	0.68	0.63
20	0.88	0.78	0.72	0.63	0.57
10	0.80	0.71	0.65	0.57	0.53

Percentile rankings* for women	AGE					
	20-29	30-39	40-49	50-59	60-69	70+
90	0.54	0.49	0.46	0.40	0.41	0.44
80	0.49	0.45	0.40	0.37	0.38	0.39
70	0.42	0.42	0.38	0.35	0.36	0.33
60	0.41	0.41	0.37	0.33	0.32	0.31
50	0.40	0.38	0.34	0.31	0.30	0.27
40	0.37	0.37	0.32	0.28	0.29	0.25
30	0.35	0.34	0.30	0.26	0.28	0.24
20	0.33	0.32	0.27	0.23	0.26	0.21
10	0.30	0.27	0.23	0.19	0.25	0.20

*Descriptors for percentile rankings: 90 = well above average; 70 = above average; 30 = below average; 10 = well below average.

Data for women provided by the Women's Exercise Research Center, The George Washington University Medical Center, Washington, D.C., 1998.

Data for men provided by The Cooper Institute for Aerobics Research, *The physical fitness specialist manual,* The Cooper Institute, Dallas, TX, 2005.

Table 6.6 Age-Gender Norms for 1-RM Leg Press (1-RM/BM)

Percentile rankings* for men	AGE				
	20-29	30-39	40-49	50-59	60+
90	2.27	2.07	1.92	1.80	1.73
80	2.13	1.93	1.82	1.71	1.62
70	2.05	1.85	1.74	1.64	1.56
60	1.97	1.77	1.68	1.58	1.49
50	1.91	1.71	1.62	1.52	1.43
40	1.83	1.65	1.57	1.46	1.38
30	1.74	1.59	1.51	1.39	1.30
20	1.63	1.52	1.44	1.32	1.25
10	1.51	1.43	1.35	1.22	1.16

Percentile rankings* for women	AGE					
	20-29	30-39	40-49	50-59	60-69	70+
90	2.05	1.73	1.63	1.51	1.40	1.27
80	1.66	1.50	1.46	1.30	1.25	1.12
70	1.42	1.47	1.35	1.24	1.18	1.10
60	1.36	1.32	1.26	1.18	1.15	0.95
50	1.32	1.26	1.19	1.09	1.08	0.89
40	1.25	1.21	1.12	1.03	1.04	0.83
30	1.23	1.16	1.03	0.95	0.98	0.82
20	1.13	1.09	0.94	0.86	0.94	0.79
10	1.02	0.94	0.76	0.75	0.84	0.75

*Descriptors for percentile rankings: 70 = above average; 50 = average; 30 = below average; 10 = well below average.

Data for women provided by the Women's Exercise Research Center, The George Washington University Medical Center, Washington, D.C., 1998.

Data for men provided by The Cooper Institute for Aerobics Research, *The physical fitness specialist manual,* The Cooper Institute, Dallas, TX, 2005.

Steps for 1-RM Maximum Testing

The following basic steps are recommended for 1-RM testing.

- Have your client warm up by completing 5 to 10 repetitions of the exercise at 40% to 60% of the estimated 1-RM.
- During a 1 min rest, have the client stretch the muscle group. This is followed by 3 to 5 repetitions of the exercise at 60% to 80% of the estimated 1-RM.
- Increase the weight conservatively, and have the client attempt the 1-RM lift. If the lift is successful, the client should rest 3 to 5 min before attempting the next weight increment. Follow this procedure until the client fails to complete the lift. The 1-RM typically is achieved within three to five trials.
- Record the 1-RM value as the maximum weight lifted for the last successful trial.

Table 6.7 Strength-to-Body-Mass Ratios for Selected 1-RM Tests

Bench press	Arm curl	Lat pull-down	Leg press	Leg extension	Leg curl	Points
			MEN			
1.50	0.70	1.20	3.00	0.80	0.70	10
1.40	0.65	1.15	2.80	0.75	0.65	9
1.30	0.60	1.10	2.60	0.70	0.60	8
1.20	0.55	1.05	2.40	0.65	0.55	7
1.10	0.50	1.00	2.20	0.60	0.50	6
1.00	0.45	0.95	2.00	0.55	0.45	5
0.90	0.40	0.90	1.80	0.50	0.40	4
0.80	0.35	0.85	1.60	0.45	0.35	3
0.70	0.30	0.80	1.40	0.40	0.30	2
0.60	0.25	0.75	1.20	0.35	0.25	1
			WOMEN			
0.90	0.50	0.85	2.70	0.70	0.60	10
0.85	0.45	0.80	2.50	0.65	0.55	9
0.80	0.42	0.75	2.30	0.60	0.52	8
0.70	0.38	0.73	2.10	0.55	0.50	7
0.65	0.35	0.70	2.00	0.52	0.45	6
0.60	0.32	0.65	1.80	0.50	0.40	5
0.55	0.28	0.63	1.60	0.45	0.35	4
0.50	0.25	0.60	1.40	0.40	0.30	3
0.45	0.21	0.55	1.20	0.35	0.25	2
0.35	0.18	0.50	1.00	0.30	0.20	1

Total points	Strength fitness category[a]
48-60	Excellent
37-47	Good
25-36	Average
13-24	Fair
0-12	Poor

[a]Based on data compiled by V. Heyward from 250 college-age men and women.

Dynamic Muscle Endurance Tests

You can assess your clients' dynamic muscle endurance by having them perform as many repetitions as possible using a weight that is a set percentage of their body weight or maximum strength (1-RM). Pollock, Wilmore, and Fox (1978) recommend using a weight that is 70% of the 1-RM value for each exercise. Although norms for this test have not been established, these authors suggest, on the basis of their testing and research findings, that the average individual should be able to complete 12 to 15 repetitions.

The YMCA (Golding 2000) and ACSM (2014) recommend using a bench press test to assess dynamic muscular endurance of the upper body. For this absolute endurance test, use a flat bench and barbell. The client performs as many repetitions as possible at a set cadence of 30 repetitions per minute. Use a metronome to establish the exercise cadence. Male clients lift an 80 lb (36.4 kg) barbell, whereas female clients use a 35 lb (15.9 kg) barbell. Terminate the test when the client is unable to maintain the exercise cadence. Table 6.8 presents norms for this test.

Alternatively, you can use a test battery consisting of seven items to assess dynamic muscular endurance. Select the weight to be lifted using a set percentage of the individual's body mass. The client lifts this weight up to a maximum of 15 repetitions. Table 6.9 provides percentages for each test item, as well as the scoring system and norms for college-age men and women.

Table 6.8 Muscular Endurance Norms for Bench Press[a]

	AGE GROUP (YR)					
Percentile	18-25	26-35	36-45	46-55	56-65	>65
MEN						
95	49	48	41	33	28	22
75	34	30	26	21	17	12
50	26	22	20	13	10	8
25	17	16	12	8	4	3
5	5	4	2	1	0	0
WOMEN						
95	49	46	41	33	29	22
75	30	29	26	20	17	12
50	21	21	17	12	9	6
25	13	13	10	6	4	2
5	2	2	1	0	0	0

[a]Score is number of repetitions completed using 80 lb barbell for men and 35 lb barbell for women.

Data from YMCA of the USA 2002.

Table 6.9 Dynamic Muscular Endurance Test Battery

	% BODY MASS TO BE LIFTED		
Exercise	Men	Women	Repetitions (max = 15)
Arm curl	0.33	0.25	_______
Bench press	0.66	0.50	_______
Lat pull-down	0.66	0.50	_______
Triceps extension	0.33	0.33	_______
Leg extension	0.50	0.50	_______
Leg curl	0.33	0.33	_______
Bent-knee sit-up			_______
			Total repetitions (max = 105) = _______

Total repetitions	Fitness category[a]
91-105	Excellent
77-90	Very good
63-76	Good
49-62	Fair
35-48	Poor
<35	Very poor

[a]Based on data compiled by V. Heyward from 250 college-age men and women.

DYNAMIC MUSCLE TESTING USING ISOKINETIC AND OMNIKINETIC EXERCISE MODES

Isokinetic dynamometers provide an accurate and reliable assessment of strength, endurance, and power of muscle groups (see figure 6.5). The speed of limb movement is kept at a constant preselected velocity. Any increase in muscular force produces an increased resistance rather than increased acceleration of the limb. Thus, fluctuations in muscular force throughout the ROM are matched by an equal counterforce or **accommodating resistance**.

Isokinetic dynamometers measure muscular torque production at speeds of 0 to 300°·sec^{-1}. From the recorded output, you can evaluate peak torque, total work, and power. Some less expensive isokinetic dynamometers lack this recording capability, but these are suitable for training and rehabilitation exercise.

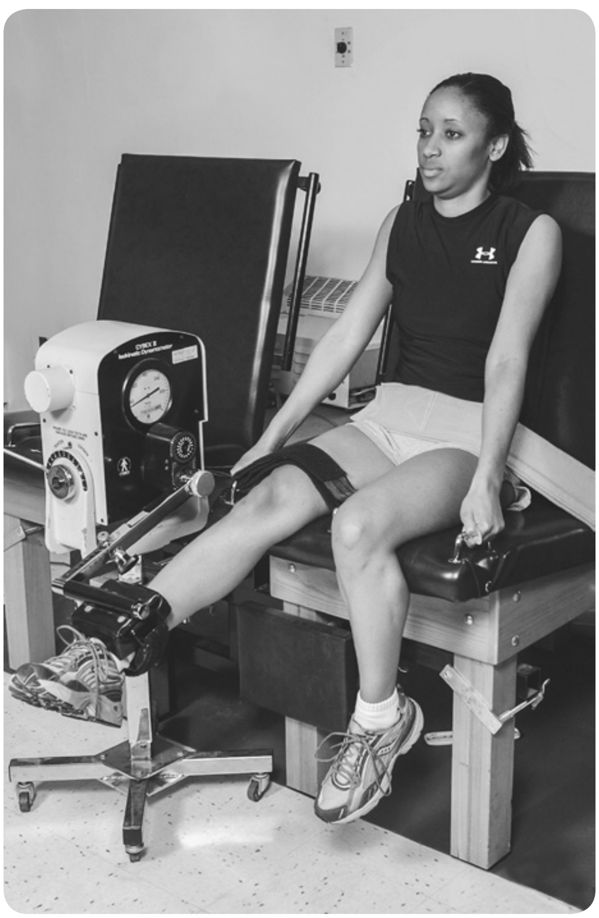


FIGURE 6.5 Cybex II isokinetic dynamometer.

Omnikinetic exercise dynamometers provide maximum overload at every joint angle throughout the ROM at whatever speed the individual is capable of generating. This testing system provides an accommodating resistance that adjusts to both the force and velocity output of the individual; it is not limited to a preset velocity of limb movement. Thus, at any one setting, the individual maximally overloads both the force and velocity production capabilities of the contractile elements. The stronger the individual, the faster the speed of limb movement at any given setting. Also, increasing limb velocity results in increased resistance. Even as the muscle fatigues, the individual receives optimal overload with each repetition because the limb speed and resistance decrease. Theoretically, movement at slower speeds will allow recruitment of motor units that were not contributing to the total force production in earlier repetitions performed at faster speeds. Thus, self-accommodating, variable-resistance–variable-velocity exercise devices assess the isokinetic strength and endurance of both fast-twitch and slow-twitch motor units in the muscle group.

Table 6.10 summarizes isokinetic and omnikinetic test protocols for assessing strength, endurance, and power. For detailed descriptions of isokinetic test protocols and test norms, see Perrin 1993. Appendix C.2, "Average Strength, Endurance, and Power Values for Isokinetic (Omni-Tron) Tests," provides omnikinetic performance norms for young and middle-aged men and women, as well as male and female weight trainers.

CALISTHENIC-TYPE STRENGTH AND MUSCULAR ENDURANCE TESTS

In certain field situations, you may not have access to dynamometers, free weights, or exercise machines to assess muscular fitness. As an alternative, you may use calisthenic-type strength and endurance tests to assess your client's strength and muscular endurance.

Table 6.10 Isokinetic and Omnikinetic Test Protocols

Isokinetic tests	Speed setting	Protocol	Measure*
Strength	30 or 60°·sec^{-1}	Two submax practice trials followed by three maximal trials	Peak torque (ft-lb or Nm)
Endurance	120–180°·sec^{-1}	One maximal trial	Number of repetitions until torque reaches 50% of initial torque value
Power	120–300°·sec^{-1}	Two submax practice trials followed by three maximal trials	Peak torque (ft-lb or Nm)
Omnikinetic tests	**Resistance setting**	**Protocol**	**Measure***
Strength	10	Three submax trials at resistance setting 2, followed by five maximal trials	Peak torque (ft-lb)
Endurance	3	Three practice trials at resistance setting 2, followed by 20 maximal repetitions	Total work output (ft-lb)
Power	6	Three submax trials followed by one maximal trial	Peak torque or total work (ft-lb)

*ft-lb = foot-pound; Nm = newton-meter; 1 ft-lb = 0.138 Nm.

Dynamic Strength Tests

You can measure dynamic strength using calisthenic-type exercises by determining the maximum weight, in excess of body mass, that an individual can lift for one repetition of the movement. Because strength is related to the size and body mass of the individual, Johnson and Nelson (1986) recommend using relative strength scores. For each test, attach weight plates (2.5, 5, 10, and 25 lb or 1, 2.3, 4.5, and 11.4 kg) to the individual. The relative strength score is the amount of additional weight divided by the body mass. For example, if a 150 lb (68.2 kg) man successfully performs one pull-up with a 30 lb (13.6 kg) weight attached to the waist belt, his relative strength score is 0.20 (30 lb/150 lb). Test protocols and performance norms for the pull-up, dip strength, sit-up, and bench squat are described elsewhere (Johnson and Nelson 1986).

Dynamic Endurance Tests

You can assess dynamic muscular endurance by measuring the maximum number of repetitions of various calisthenic exercises. Pull-up, push-up, and trunk curl (partial curl-up) tests are widely used for this purpose.

Pull-Up Tests

Video 6.9

Pull-up tests may be used to measure the dynamic endurance of the arm and shoulder girdle muscles for individuals who are able to lift their body weight. For clients who are unable to perform even one pull-up, you can use modified pull-up and flexed-arm hang tests. Baumgartner (1978) developed a modified pull-up that uses an incline board (at a 30° angle to the floor) with a pull-up bar at the top. A modified scooter board slides along garage door tracks attached to the incline board (Baumgartner et al. 1984). While lying prone on the scooter board, the client pulls up until the chin is over the pull-up bar. Detailed testing procedures, equipment designs, and performance norms for children, adolescents, and college-age women and men are available (see Baumgartner 1978; Baumgartner et al. 1984).

The flexed-arm hang test is scored as the amount of time the client maintains the flexed-arm hanging position (i.e., supporting the body weight with the chin over the pull-up bar). Traditionally, a pronated grip on the pull-up bar is used (i.e., overgrip); however, variations of the flexed-arm hang test include using a supinated grip (i.e., undergrip). Although the flexed-arm hang tests isometric endurance of the arm and shoulder girdle musculature, it has been used for more than three decades as a measure of upper body strength. One study of college women showed that flexed-arm hang time relates more to relative strength (1-RM/body mass) than to absolute strength (1-RM) or to dynamic muscle endurance (measured as repetitions to failure at 70% 1-RM) (Clemons et al. 2004).

Video 6.10

Push-Up Tests

The ACSM (2014) and CSEP (2003) recommend using a push-up test to assess endurance of the upper body musculature. To start, clients lie prone on the mat with their legs together and hands pointing forward under the shoulders. Clients push up from the mat by fully extending the elbows and by using either the toes (for males) or the knees (for females) as the pivot point. The upper body should be kept in a straight line and the head should be kept up. The client returns to the down position, touching the chin to the mat. The stomach and thighs should not touch the mat. Clients perform as many consecutive repetitions (no rest between repetitions) as possible; there is no time limit. Repetitions not meeting the stated criteria should not be counted. Terminate the test when the client strains forcibly or is unable to maintain proper push-up technique over two consecutive repetitions, and record the total number of correctly executed repetitions. Table 6.11 provides age-gender norms for the push-up test.

Video 6.11

Trunk Curl Tests

Abdominal muscle endurance tests (e.g., trunk curls, partial curl-ups, and sit-ups) are commonly included in health-related fitness test batteries to identify clients at risk for low back pain or injury due to weak abdominal muscles. However, the validity of these tests as measures of abdominal strength or endurance and as predictors of low back pain is questionable. Most trunk curl tests are poorly related to abdominal strength ($r_{x,y}$ = −0.21–0.36) and only moderately related to abdominal endurance ($r_{x,y}$ = 0.46–0.50) (Knudson 2001; Knudson and Johnston 1995). Also, Jackson and colleagues (1998) found no relationship between sit-up test scores and incidence of low back pain. Keep these findings in mind when interpreting the results of these tests.

Trunk curl tests differ in duration (60–120 sec), cadence (20–25 reps·min^{-1}), and difficulty. The CSEP (2003) recommends using a timed (1 min) curl-up test with a cadence of 25 reps·min^{-1} to assess the endurance of the abdominal muscles. For this test, the client lies supine on a mat with the knees flexed to 90°, the legs hip-width apart, and the arms fully extended at the sides with the middle finger of both hands touching a piece of masking tape (the zero mark). Place a second piece of masking tape 10 cm (4 in.) beyond the zero mark, and set the metronome to 50 bpm (25 curl-ups per min). Shoes should be worn for this test. Instruct clients to slowly lift their shoulder blades off the mat in time with the metronome. Clients should flex their trunks (curl up) until their fingertips touch the 10 cm mark or their trunk makes a 30° angle with the mat. During the curl-up, the palms of the hands and the heels of the feet must remain in contact with the mat. On the return, the shoulder blades and head must contact the mat, and the fingertips of both hands must touch the zero mark. Score the curl-up test as the total number of consecutive repetitions up to a maximum of 25 in 1 min. Table 6.12 provides age-gender norms for the partial curl-up test.

Table 6.11 Age-Gender Norms for Push-Up Test

	AGE (YR)					
	15-19	20-29	30-39	40-49	50-59	60-69
MEN						
Excellent	≥39	≥36	≥30	≥25	≥21	≥18
Very good	29-38	29-35	22-29	17-24	13-20	11-17
Good	23-28	22-28	17-21	13-16	10-12	8-10
Fair	18-22	17-21	12-16	10-12	7-9	5-7
Needs improvement	≤17	≤16	≤11	≤9	≤6	≤4
WOMEN						
Excellent	≥33	≥30	≥27	≥24	≥21	≥17
Very good	25-32	21-29	20-26	15-23	11-20	12-16
Good	18-24	15-20	13-19	11-14	7-10	5-11
Fair	12-17	10-14	8-12	5-10	2-6	2-4
Needs improvement	≤11	≤9	≤7	≤4	≤1	≤1

Source: *Canadian Physical Activity Guidelines*, © 2011, 2012. Used with permission from the Canadian Society for Exercise Physiology, www.csep.ca/guidelines.

Table 6.12 Age-Gender Norms for Partial Curl-Up Test

	AGE (YR)					
	15-19	20-29	30-39	40-49	50-59	60-69
MEN						
Excellent	25	25	25	25	25	25
Very good	23-24	21-24	18-24	18-24	17-24	16-24
Good	21-22	16-20	15-17	13-17	11-16	11-15
Fair	16-20	11-15	11-14	6-12	8-10	6-10
Needs improvement	≤15	≤10	≤10	≤5	≤7	≤5
WOMEN						
Excellent	25	25	25	25	25	25
Very good	22-24	18-24	19-24	19-24	19-24	17-24
Good	17-21	14-17	10-18	11-18	10-18	8-16
Fair	12-16	5-13	6-9	4-10	6-9	3-7
Needs improvement	≤11	≤4	≤5	≤3	≤5	≤2

Source: *Canadian Physical Activity Guidelines,* © 2011, 2012. Used with permission from the Canadian Society for Exercise Physiology, www.csep.ca/guidelines.

The trunk curl-up test, recommended by the ACSM (2014), differs from the CSEP (2003) test. The client is positioned on the mat in the same way as described previously; however, the two strips of masking tape are placed on the mat 12 cm apart for clients younger than 45 yr and 8 cm apart for clients 45 yr or older. Also, the metronome is set at 40 bpm (20 curl-ups per min). For each curl-up, the client must flex the trunk to 30°. The test ends when the client reaches 75 curl-ups or the cadence is disrupted. Age-gender norms for this variation of the trunk curl-up test are available elsewhere (ACSM 2014).

Other trunk curl tests use a bench (0.46 m or 18 in. high) to protect the lower back by isolating the abdominal muscles. For these tests, the lower legs rest on the top of the bench and the backs of the thighs contact the bench. Instruct your clients to cross their arms so that each hand holds the opposite elbow. During each curl, their forearms must touch the thighs (concentric phase) and their shoulder blades must touch the floor (eccentric phase). The score is the number of correct repetitions completed in 60, 90, or 120 sec. Use a longer duration (90 or 120 sec) for very fit clients and athletes; use 60 sec for individuals of low or average fitness (Knudson and Johnston 1998).

Core Stability Tests

The Sahrmann Core Stability Test (Sahrmann 2002) is an excellent tool for assessing the core stability of your clients. Core stability is the ability of the trunk musculature to stabilize the spine and maintain optimal spinal alignment during movement. The transversus abdominis and multifidus are two deep-seated abdominal and spinal muscles. Weakness in these muscles may be linked to low back pain and injury.

The Sahrmann Core Stability Test (see table 6.13) may be used to assess and grade your client's level of core stability. The test consists of series of movements that are performed while maintaining lumbopelvic stability in a neutral position. You may use a blood pressure cuff under the client's back to determine if there is any movement of the spine by watching for pressure changes during the movement. Alternatively, you can have your client place the hands beneath the lower back to feel for any changes in pressure during the movement.

SOURCES OF MEASUREMENT ERROR IN MUSCULAR FITNESS TESTING

The validity and reliability of strength and muscular endurance measures are affected by client factors, equipment, technician skill, and environmental factors. You must control each of these factors to ensure the accuracy and precision of muscular fitness scores.

Table 6.13 Sahrmann Core Stability Test

Level 1	Begin in supine, hook-lying position while hollowing abdomen. Slowly raise 1 leg to 100° of hip flexion with comfortable knee flexion. Bring opposite leg up to same position.
Level 2	From hip-flexed position, slowly lower 1 leg until heel contacts ground. Slide out leg to fully extend the knee. Return to starting flexed position.
Level 3	From hip-flexed position, slowly lower 1 leg until heel is 12cm above ground. Slide out leg to fully extend the knee. Return to starting flexed position.
Level 4	From hip-flexed position, slowly lower both legs until heel contacts ground. Slide out legs to fully extend the knee. Return to starting flexed position.
Level 5	From hip-flexed position, slowly lower both legs until heels are 12cm above ground. Slide out leg to fully extend the knee. Return to starting flexed position.

*Subsequent levels begin in this hip-flexed position.

CLIENT FACTORS

Before measuring your client's strength or muscular endurance, familiarize the individual with the equipment and testing procedures. Clients with limited or no prior weightlifting experience need time to practice each lift to control for the effects of learning on performance. You should give even experienced weightlifters time to practice so that you can correct any improper lifting techniques prior to testing.

Muscular fitness tests require clients to give a maximal effort. Therefore, clients should get adequate sleep before performing these tests, and you should restrict the use of drugs and medications that may adversely affect their performance. It is also important that you motivate your clients during testing by encouraging them to do their best and giving them positive feedback after each trial. Adequate rest between trials is necessary in order for clients to obtain scores that truly represent their maximal effort.

EQUIPMENT

The design of testing equipment may also affect your client's test scores. Most of the dynamic strength and muscular endurance protocols and norms presented in this chapter were developed using constant-resistance exercise machines. Therefore you should not use free weights or variable-resistance machines when administering these tests. It is also important to calibrate the equipment and make sure that it is in proper working condition prior to testing. Inspection and maintenance of equipment will increase accuracy and decrease risk of accidents. When selecting exercise machines, make sure that the equipment can be properly adjusted to accommodate varying limb lengths and body sizes. Use equipment specifically designed for smaller individuals when testing children and smaller adults.

TECHNICIAN SKILL

All strength testing should be done by qualified, trained technicians who are knowledgeable about proper lifting and spotting techniques and familiar with standardized testing procedures. Explain and demonstrate the proper lifting technique and then correct any performance errors you see as the client practices. During the test, clients may inadvertently cheat by moving extraneous body parts to help lift the weight. Carefully observe the client during the test, focusing on the grip used and the starting position. The type of grip (pronated vs. supinated) has a substantial effect on performance. For example, using a narrow grip instead of a wide grip during a lat pull-down exercise increases the amount of weight that can be lifted. Likewise, the client will be able to produce more force during an arm curl using a supinated grip compared to a pronated grip. The client's starting position may also affect strength scores. During the bench press, for example, eccentric movement (i.e., lowering the weight) prior to the concentric phase of the lift will increase maximal muscular force due to the stretch reflex and the tendency for the client to bounce the weight off the chest. To obtain accurate assessments of your client's strength, it is important to standardize starting positions and to follow all testing procedures carefully.

ENVIRONMENTAL FACTORS

Factors such as room temperature and humidity may affect test scores. The room temperature should be 70° to 74° F (21° to 23° C) to maximize subject comfort during testing. Ideally, you want a quiet, clean environment with limited distractions (not an overcrowded weight room, for example). When assessing improvements due to training, remember to pretest and posttest your client at the same time of day to control for diurnal variations in strength.

ADDITIONAL CONSIDERATIONS FOR MUSCULAR FITNESS TESTING

This section addresses a number of additional factors and questions regarding the testing and evaluation of your client's muscular fitness.

How can I estimate my client's 1-RM?

Although 1-RM tests can be safely administered to clients of all ages, sometimes it is preferable to estimate the 1-RM. One-repetition maximum testing can be time-consuming, especially for a large group of clients. Some clients may take 15 min to complete a 1-RM test (multiple attempts and rests). Also, the 1-RM may be underestimated for clients with little or no exercise experience because they are unaccustomed to or may be apprehensive about lifting heavy loads. In these cases, it may be more suitable and practical to estimate 1-RM.

You can estimate the 1-RM of your clients from submaximal muscle endurance tests. Research demonstrates a strong relationship between muscle endurance (measured as the number of repetitions to fatigue) and the percentage of 1-RM lifted (Brzycki 1993). Muscular strength (1-RM) therefore can be predicted from muscular endurance tests with a fair degree of accuracy (Ball and Rose 1991; Braith et al. 1993; Desgorces et al. 2010; Invergo, Ball, and Looney 1991; Kuramoto and Payne 1995; Mayhew et al. 1992). The most frequently used prediction equations assume an inverse linear relationship between the %1-RM and number of repetitions performed, and they are typically based on the number of repetitions to fatigue in one set. For example, the Brzycki (1993) equation can be used to estimate 1-RM of men. This equation can be used for any combination of submaximal weights and repetitions to fatigue providing that the repetitions to fatigue do not exceed 10.

$$\text{1-RM} = \text{weight lifted (lb)} / [1.0278 - (\text{reps to fatigue} \times 0.0278)]$$

For example, if your client completes seven repetitions to fatigue during a bench press exercise using a 100 lb (45 kg) barbell, the estimated 1-RM is calculated as follows:

$$\text{1-RM} = 100 \text{ lb} / [1.0278 - (7 \text{ reps} \times 0.0278)] = 120 \text{ lb (54.5 kg)}$$

Brzycki (2000) also suggested using a prediction equation based on the number of repetitions to fatigue obtained in two submaximal sets to estimate 1-RM. Any two submaximal sets can be used as long as the number of reps to fatigue does not exceed 10. For example, you can determine your client's 5-RM value, or the maximum weight that can be lifted for 5 reps (e.g., 120 lb [55 kg] for 5 reps), and the 10-RM value (e.g., 80 lb [36 kg] for 10 reps) and use them in the following equation:

$$\text{predicted 1-RM} = [(SM_1 - SM_2) / (REP_2 - REP_1)] \times (REP_1 - 1) + SM_1$$
$$= [(120 - 80) / (10 - 5)] \times (5 - 1) + 120$$
$$= 152 \text{ lb}$$

In this equation, SM_1 and REP_1 represent the heavier submaximal weight (120 lb) and the respective number of repetitions (5 reps) completed, and SM_2 and REP_2 correspond to the lighter submaximal weight (80 lb) and the respective number of repetitions (10 reps) performed.

Alternatively, you can use the average number of repetitions corresponding to various percentages of 1-RM (see table 6.14). This technique and the Brzycki (1993) equation yield similar 1-RM estimates for lifts between 2-RM and 10-RM. To estimate the 1-RM from 2-RM to 10-RM values, divide the weight lifted by the respective %1-RM,

Table 6.14 Average Number of Repetitions and %1-RM Values

Repetitions	%1-RM[a]
1	100
2	95
3	93
4	90
5	87
6	85
7	83
8	80
9	77
10	75

[a]These values may vary slightly for different muscle groups and ages.

Data from Baechle, Earle, and Wathen 2000.

expressed as a decimal (%1-RM/100). For example, a client lifting 100 lb (45.4 kg) for 8 repetitions would have an estimated 1-RM of 125 lb (56.7 kg):

$$\text{1-RM} = 100 \text{ lb} / 0.80 \text{ or } 125 \text{ lb } (56.7 \text{ kg})$$

Also, gender-specific prediction equations can be used to estimate upper body strength (i.e., the 1-RM bench press) from the YMCA bench press test (see table 6.8) in younger clients (22–36 yr) (Kim, Mayhew, and Peterson 2002):

For Men

$$\text{predicted 1-RM (kg)} = (1.55 \times \text{YMCA test repetitions}) + 37.9$$

$$r = 0.87 \text{ and } SEE = 8.0 \text{ kg.}$$

For Women

$$\text{predicted 1-RM (kg)} = (0.31 \times \text{YMCA test repetitions}) + 19.2$$

$$r = 0.87 \text{ and } SEE = 3.2 \text{ kg.}$$

For example, if a 25 yr old female's YMCA bench press test score is 30 reps, her estimated 1-RM bench press strength is calculated as follows:

$$\text{predicted 1-RM (kg)} = (0.31 \times 30 \text{ reps}) + 19.2$$

$$= 28.5 \text{ kg } (62.8 \text{ lb})$$

Additionally, Desgorces and colleagues (2010) developed equations to predict %1-RM from the number of repetitions to failure for bench press exercise. They noted that predictive accuracy was improved using a model based on a nonlinear relationship (curve fitting two-function exponential decay) between %1-RM values and number of repetitions to failure, with a reduced number of repetitions (1–12 reps), performed at relatively high intensities (75–85% 1-RM), yielding the best prediction. They developed two specific %1-RM prediction equations for male athletes—one for high-strength (powerlifters and racketball) athletes and another for high-endurance (swimmers and rowers) athletes. A third equation based on the total population combined was also developed ($r^2 = 0.97$; $SEE = 3.4$).

$$\text{\%1-RM} = 79.3412^{\exp(-0.0302 \times \text{reps to failure})} + 20.7706$$

$$r = 0.98 \text{ and } SEE = 3.4 \text{ \%1-RM}$$

Recently, Mayhew and colleagues (2011) reported that the Desgorces prediction equation accurately (<5% error) predicted strength changes (%1-RM bench press) of untrained men and women following a 12 wk periodization resistance training program.

How is muscle balance assessed?

Muscle strength is important for joint stability; however, a strength imbalance between opposing muscle groups (e.g., quadriceps femoris and hamstrings) may compromise joint stability and increase the risk of musculoskeletal injury. For this reason, experts recommend maintaining a balance in strength between agonist and antagonistic muscle groups.

Muscle balance ratios differ among muscle groups and are affected by the force-velocity of muscle groups at specific joints. To control limb velocity during muscle balance testing, you will do best to use isokinetic dynamometers. In field settings, however, you may obtain a crude index of muscle balance by comparing 1-RM values of muscle groups. Based on isokinetic tests of peak torque production at slow speeds (30–60°·sec^{-1}), the following muscle balance ratios are recommended for agonist and antagonistic muscle groups:

Muscle groups	Muscle balance ratio
Hip extensors and flexors	1:1
Elbow extensors and flexors	1:1
Trunk extensors and flexors	1:1
Ankle inverters and evertors	1:1
Shoulder flexors and extensors	2:3
Knee extensors and flexors	3:2
Shoulder internal and external rotators	3:2
Ankle plantar flexors and dorsiflexors	3:1

Muscle balance between other pairs of muscle groups is also important. The difference in strength between contralateral (right vs. left sides) muscle groups should be no more than 15%, and the strength-to-body-mass (BM) ratio of the upper body (bench press 1-RM/BM) should be at least 40% of the lower body relative strength (leg press 1-RM/BM). If you detect imbalances, prescribe additional exercises for the weaker muscle groups.

Can strength or muscular endurance be assessed by a single test?

Strength and endurance are specific to the muscle group, the type of muscular contraction (static or dynamic), the speed of muscular contraction (slow or fast), and the joint angle being tested (static contraction). There is no single test to evaluate total body muscle strength or endurance. Minimally, the strength test battery should include a measure of abdominal, lower extremity, and upper extremity strength. In addition, if the individual trains dynamically, select a dynamic, not static, test to assess strength or endurance levels before and after training.

You should also use caution in selecting test items to measure muscle strength. The maximum number of sit-ups, pull-ups, or push-ups that an individual can perform measures muscular endurance, yet maximum-repetition tests have been included in some strength test batteries. This may lead to misinterpretation of the test results.

Should absolute or relative measures be used to classify a client's muscle strength?

A direct relationship exists between body size and muscle strength. Generally, larger individuals have more muscle mass, and therefore greater strength, than smaller individuals with less muscle mass.

Because strength directly relates to the body mass and lean body mass of the individual, you should express the test results in relative terms (e.g., 1-RM/BM). This is especially true in comparing your client's score to group norms and in comparing groups or individuals differing in body size and composition (e.g., men vs. women or older vs. younger adults).

Use relative strength scores for assessing individual improvement from training. As a result of resistance training, some individuals may gain body weight while others may lose weight, especially if they are using resistance training as part of a program for weight gain or loss. If you compare the client's relative strength scores (from pre- and posttest training), you will be able to evaluate the change in strength that is independent of a change in body weight.

How can the influence of strength on muscular endurance be controlled?

Performance on some endurance tests (e.g., pull-ups and push-ups) is highly dependent on the strength of the individual. It is recommended that you use relative endurance tests that are proportional to the body mass or maximum strength of the individual to assess muscle endurance. You cannot use a pull-up test to assess muscular endurance if the individual is not strong enough to lift the body weight for one repetition of that exercise. Therefore, select a modified or submaximal (percentage of body weight) endurance test.

Are there comprehensive norms that can be used to classify muscular fitness levels of diverse population subgroups?

Strength norms for women (20–82 yr) were developed for the bench press (1-RM), leg press (1-RM), static grip strength, and push-up tests (Brown and Miller 1998). These norms are based on data obtained from 304 independent-living women attending wellness classes at a university medical center. However, there is a lack of up-to-date endurance norms for men and strength and endurance norms for older men. New norms need to be established for this population in particular.

MUSCULAR FITNESS TESTING OF OLDER ADULTS

It is important to accurately assess the muscular fitness of older individuals. Adequate strength in the upper and lower body lessens risk of falls and of injuries associated with falling, reduces age-related loss of bone mineral, maintains lean body tissue, improves glucose utilization, and prevents obesity. Moderate-to-high levels of muscular strength enable older adults to maintain their functional independence and to perform activities of daily living as well as fitness and recreational activities. The following sections address tests that you can use to assess the muscular strength and physical performance of older clients.

STRENGTH TESTING OF OLDER ADULTS

Experts agree that it is safe to administer 1-RM tests to older adults if proper procedures (see "Steps for 1-RM Maximum Testing") are followed (Shaw, McCully, and Posner 1995). The risk of injury is low, with only 2.4% of older adults (55–80 yr) experiencing an injury during 1-RM assessment (Salem, Wang, and Sigward 2002; Shaw et al. 1995). Salem and colleagues (2002) suggested that at least one pretesting session (i.e., a practice 1-RM test session) is necessary to establish stable baseline 1-RM values for older adults.

Alternatively, you can estimate the 1-RM of older clients from submaximal muscular endurance tests. Kuramoto and Payne (1995) developed prediction equations to estimate 1-RM from a submaximal endurance test in middle-aged and older women. For this endurance protocol, the client completes as many repetitions as possible using a weight equivalent to 45% of her body mass. To estimate 1-RM, use the following equations:

Middle-Aged Women (40–50 yr)

$$1\text{-RM} = (1.06 \times \text{weight lifted in kg}) + (0.58 \times \text{reps}) - (0.20 \times \text{age}) - 3.41$$

$r = 0.94$ and $SEE = 1.85$ kg.

Older Women (60–70 yr)

$$1\text{-RM} = (0.92 \times \text{weight lifted in kg}) + (0.79 \times \text{reps}) - 3.73$$

$r = 0.90$ and $SEE = 2.04$ kg.

Knutzen, Brilla, and Caine (1999) tested the validity of selected 1-RM prediction equations for older women (mean age = 69 yr) and men (mean age = 73 yr). On average, these prediction equations underestimated the actual 1-RM for 11 different constant-resistance machine exercises. For exercises such as the biceps curl, the lateral row, the bench press, and ankle plantar and dorsiflexion, the predicted values were on average 0.5 to 3.0 kg less than the actual 1-RM values. However, larger differences (as much as a 10 kg underestimation) were noted for the triceps press-down, the supine leg press, and the hip flexion, extension, abduction, and adduction exercises. The Brzycki (1993) equation gave a closer estimate of actual 1-RMs for hip exercises (extension, flexion, adduction, and abduction) compared to the other equations evaluated; the Wathen (1994a) equation, $1\text{-RM} = 100 \times \text{weight lifted} / [48.8 + 53.8^{-0.075\,(\text{reps})}]$, most closely estimates 1-RM for all upper body exercises, the leg press, and dorsiflexion exercises. The authors concluded that the actual and predicted 1-RM are close enough to warrant using these prediction equations to determine resistance training intensities (i.e., %1-RMs) for older adults. In addition, given that the predicted 1-RM values were consistently less than the actual 1-RM values, the resistance training intensity will not likely exceed the prescribed value.

FUNCTIONAL FITNESS TESTING OF OLDER ADULTS

Functional fitness is the ability to perform everyday activities safely and independently without undue fatigue (Rikli and Jones 2013). Functional fitness is multidimensional, requiring aerobic endurance, flexibility, balance, agility, and muscular strength. Older individuals with moderate-to-high functional fitness have the ability to perform normal **activities of daily living (ADLs)** such as getting out of a chair or car, climbing stairs, shopping, dressing, and bathing; these individuals are able to stay strong, active, and independent as they age.

The Senior Fitness Test (Rikli and Jones 2013) assesses the physical capacity and functional fitness of older adults (60–94 yr). This test battery includes two measures of muscular strength: (*a*) an arm (biceps) curl for upper body strength (figure 6.6) and (*b*) a 30 sec chair stand for lower body strength (figure 6.7). The ACSM (2014) recommends using these two test items to safely assess the muscular fitness of most older adults.

ARM CURL TEST

Purpose: Assess upper body strength.

Application: Measure ability to perform ADLs such as lifting and carrying groceries, grandchildren, and pets.

Equipment: You will need a folding or straight-back chair, a stopwatch, and a 5 lb (2.27 kg) dumbbell for women or an 8 lb (3.63 kg) dumbbell for men.

Test procedures: The client sits in the chair with the back straight and the feet flat on the floor. The client holds the dumbbell in the dominant hand using a neutral (handshake) grip and lets this arm hang down at the side (see figure 6.6). For each repetition, the client curls the weight by fully flexing the elbow while supinating the forearm and returns the weight to the starting position by fully extending the elbow and pronating the forearm. Instruct your client to keep the upper arm in contact with the trunk during the test. Have your client perform as many repetitions as possible in 30 sec. Administer one trial.

Scoring: Count the number of repetitions executed in 30 sec. If the forearm is more than halfway up when the time expires, count the move as a complete repetition. Use table 6.15 to determine your client's percentile ranking.

Safety tips: Before testing, demonstrate the exercise for your client. Have your client perform one or two repetitions of the exercise without a dumbbell to check body position and lifting technique. Stop the test if the client complains of pain.

Validity and reliability: Arm curl test scores were moderately related ($r_{x,y}$ = 0.84 for men and 0.79 for women) to combined 1-RM values for the chest, upper back, and biceps (criterion-related validity). Average arm curl test scores of physically active older adults were significantly greater than those of sedentary older adults (construct validity). Test-retest reliability was r = 0.81.

FIGURE 6.6 Arm curl test for older adults.

Table 6.15 Arm Curl Test Norms for Older Adults*

	60-64 YR		65-69 YR		70-74 YR		75-79 YR		80-84 YR		85-89 YR		90-94 YR	
Percentile rank	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**
95	24	27	22	27	22	26	21	24	20	23	18	21	17	18
90	22	25	21	25	20	24	20	22	18	22	17	19	16	16
85	21	24	20	24	19	23	19	21	17	20	16	18	15	16
80	20	23	19	23	18	22	18	20	16	20	15	17	14	15
75	19	22	18	21	17	21	17	19	16	19	15	17	13	14
70	18	21	17	21	17	20	16	19	15	18	14	16	13	14
65	18	21	17	20	16	19	16	18	15	18	14	15	12	13
60	17	20	16	20	16	19	15	17	14	17	13	15	12	13
55	17	20	16	19	15	18	15	17	14	17	13	14	11	12
50	16	19	15	18	14	17	14	16	13	16	12	14	11	12
45	16	18	15	18	14	17	13	16	12	15	12	13	10	12
40	15	18	14	17	13	16	13	15	12	15	11	13	10	11
35	14	17	14	16	13	15	12	14	11	14	11	12	9	11
30	14	17	13	16	12	15	12	14	11	14	10	11	9	10
25	13	16	12	15	12	14	11	13	10	13	10	11	8	10
20	12	15	12	14	11	13	10	12	10	12	9	10	8	9
15	11	14	11	13	10	12	9	11	9	12	8	9	7	8
10	10	13	10	12	9	11	8	10	8	10	7	8	6	8
5	9	11	8	10	8	9	7	9	6	9	6	7	5	6

F = females; M = males.

*Values represent number of repetitions in 30 sec.

Adapted, by permission, from R. Rikli and C. Jones, 2013, *Senior fitness test manual,* 2nd ed. (Champaign, IL: Human Kinetics), 155.

30 SEC CHAIR STAND TEST

Purpose: Assess lower body strength.

Application: Measure ability to perform ADLs such as climbing stairs, walking, and getting out of a chair, bathtub, or car.

Equipment: You will need a folding or straight-back chair (seat height = 17 in. or 43 cm) and a stopwatch.

Test procedures: Place the chair against a wall to prevent slipping. Instruct your client to sit erect in the chair with the feet flat on the floor and the arms crossed at the wrists and held against the chest (see figure 6.7). For each repetition, the client rises to a full stand and then returns to the fully seated starting position. Have your client perform as many repetitions as possible in 30 sec. Administer one trial.

Scoring: Count the number of repetitions executed in 30 sec. If the client is more than halfway up when the time expires, count the move as a full stand. Use table 6.16 to determine your client's percentile ranking.

Safety tips: Brace the chair against a wall, watch for balance problems, and stop the test if the client complains of pain. Before testing, demonstrate the movement slowly to show proper form. Have your client perform one or two repetitions to check body position (fully standing and fully seated) for the test.

Validity and reliability: Scores for the chair stand test were moderately related to the 1-RM leg press (criterion-related validity) in older men ($r_{x,y}$ = 0.78) and women ($r_{x,y}$ = 0.71). Average scores were lower for older adults (80+ yr) than for relatively younger adults (60–69 yr) and higher for physically active older adults compared to sedentary older adults (construct validity). Test-retest reliability was r = 0.86 and r = 0.92 for older men and women, respectively.

FIGURE 6.7 30 sec chair stand test for older adults.

Table 6.16 30 Sec Chair Stand Test Norms for Older Adults*

	60-64 YR		65-69 YR		70-74 YR		75-79 YR		80-84 YR		85-89 YR		90-94 YR	
Percentile rank	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**
95	21	23	19	23	19	21	19	21	18	19	17	19	16	16
90	20	22	18	21	18	20	17	20	17	17	15	17	15	15
85	19	21	17	20	17	19	16	18	16	16	14	16	13	14
80	18	20	16	19	16	18	16	18	15	16	14	15	12	13
75	17	19	16	18	15	17	15	17	14	15	13	14	11	12
70	17	19	15	18	15	17	14	16	13	14	12	13	11	12
65	16	18	15	17	14	16	14	16	13	14	12	13	10	11
60	16	17	14	16	14	16	13	15	12	13	11	12	9	11
55	15	17	14	16	13	15	13	15	12	13	11	12	9	10
50	15	16	14	15	13	14	12	14	11	12	10	11	8	10
45	14	16	13	15	12	14	12	13	11	12	10	11	7	9
40	14	15	13	14	12	13	12	13	10	11	9	10	7	9
35	13	15	12	13	11	13	11	12	10	11	9	9	6	8
30	12	14	12	13	11	12	11	12	9	10	8	9	5	8
25	12	14	11	12	10	11	10	11	9	10	8	8	4	7
20	11	13	11	11	10	11	9	10	8	9	7	7	4	7
15	10	12	10	11	9	10	9	10	7	8	6	6	3	6
10	9	11	9	9	8	9	8	8	6	7	5	5	1	5
5	8	9	8	8	7	8	6	7	4	6	4	4	0	3

F = females; M = males.

*Values represent number of repetitions.

Adapted, by permission, from R. Rikli and C. Jones, 2012, *Senior fitness test manual,* 2nd ed. (Champaign, IL: Human Kinetics), 154.

MUSCULAR FITNESS TESTING OF CHILDREN

In the past, experts questioned whether or not it was safe to use 1-RM tests to evaluate children. A major concern was the risk of growth plate fractures when the children attempted to lift heavy weights. Experts now agree that it is safe to administer 1-RM tests to children (6–12 yr) if appropriate procedures are followed (Faigenbaum, Milliken, and Westcott 2003).

Results from 1-RM tests may be used to establish baselines for evaluating the progress of children in resistance training programs. You can also use these values to plan a personalized resistance training program for each child, to identify muscle imbalances, and to provide motivation. One shortcoming of 1-RM testing is that it must be closely supervised (one on one) to ensure safety, which limits its usefulness in physical education classes and youth sport programs. Also, child-sized exercise machines must be used; the safety of 1-RM testing using other modes (e.g., dumbbells or barbells) has not been adequately established.

1-RM TESTING GUIDELINES FOR CHILDREN

The following steps are recommended for 1-RM testing of children (Faigenbaum, Milliken, and Westcott 2003):

1. Have a certified, experienced exercise professional administer and closely supervise (one on one) all tests.
2. Before testing, familiarize the children with proper lifting techniques (i.e., proper breathing and controlled movements), allow them to practice these techniques, and answer any questions they may have.
3. Have the child warm up by performing 10 min of low-to-moderate intensity aerobic exercise and stretching.
4. Use dynamic, constant-resistance exercise machines designed specifically for children or individuals with small body frames.
5. Before the 1-RM lift, instruct the child to perform six repetitions with a relatively light load followed by three repetitions with a heavier load. Then gradually increase the weight and have the child attempt the 1-RM lift. Allow at least 2 min of rest between the series of single repetitions with increasing loads. Follow this procedure until the child fails to complete the full ROM of the exercise for at least two attempts. The 1-RM is typically achieved within 7 to 11 trials.
6. Record the 1-RM as the maximum weight lifted for the last successful trial.
7. After testing, have the child stretch the exercised muscle groups for 5 min.

SOURCES FOR EQUIPMENT

Product	Supplier's contact information
Aquatic exercise equipment	Hydro-Fit, Inc. (800) 346-7295 www.hydrofit.com
Body Masters (constant and variable resistance)	Body Masters Sports Industries, Inc. (800) 325-8964 www.usafitnessdirect.com
Cable tensiometer (static)	Pacific Scientific Co., Inc. (815) 226-3100 www.pacsci.com
CAM II (variable resistance)	Keiser Corp. (800) 888-7009 www.keiser.com
Cybex II, Orthotron (isokinetic)	Cybex International (888) 462-9239 www.cybexintl.com

Product	Supplier's contact information
Exercise and stability balls	Ball Dynamics International, LLC (800) 752-2255 www.fitball.com
Free-motion machines (constant and variable resistance)	FreeMotion Fitness (877) 363-8449 www.freemotionfitness.com
Free weights (constant resistance)	York Barbell Co. (800) 358-9675 www.yorkbarbell.com
Handgrip dynamometer (static)	Creative Health Products (800) 742-4478 www.chponline.com
Handheld digital dynamometer (static)	Hoggan Health Industries (800) 678-7888 www.hogganhealth.net
Leg/back dynamometer (static)	Best Priced Products (800) 824-2939 www.best-priced-products.com
Myotest accelerometer	Myotest Inc. +41 27.456.18.20 www.myotest.com
Nautilus (variable resistance)	Nautilus, Inc. (800) 864-1270 www.nautilus.com
Resistance bands and tubing	Creative Health Products (800) 742-4478 www.chponline.com
Total gym machines (variable resistance)	Total Gym/EFI (800) 541-4900 www.totalgym.com
Universal gym machines (constant and variable resistance)	Universal Gym Equipment (800) 843-3906 www.universalgymequipment.com

Key Points

- Strength is the ability of a muscle group to exert maximal contractile force against a resistance in a single contraction.
- Muscular endurance is the ability of a muscle group to exert submaximal force for an extended duration.
- Both strength and muscular endurance are specific to the muscle group and to the type of muscle contraction—static, concentric, eccentric, or isokinetic.
- The greatest resistance that can be used during dynamic, concentric muscular contraction with a constant-resistance exercise mode is equal to the maximum weight that can be moved at the weakest point in the ROM.
- Dynamometers, cable tensiometers, strain gauges, and load cells are used to measure static strength and endurance.
- Constant-resistance modes of exercise (free weights and exercise machines) are used to assess dynamic (i.e., concentric and eccentric) strength and endurance.
- The accommodating-resistance mode of exercise is used to assess isokinetic and omnikinetic strength, endurance, and power.
- Free-motion machines allow muscle groups to be exercised in multiple planes.
- Calisthenic-type exercise tests provide a crude index of strength and endurance but can be used when other equipment is not available.

- Strength should be expressed relative to the body mass or lean body mass of the individual.
- Muscular endurance tests should take into account the body mass or maximal strength of the individual.
- Test batteries should include a minimum of three to four items that measure upper body, lower body, and abdominal strength or endurance.
- It is important to follow standardized testing procedures and to control extraneous variables (e.g., motivation level, time of testing, isolation of body parts, and joint angles) when assessing strength and muscular endurance.
- It is safe to give 1-RM strength tests to children and older adults if appropriate testing procedures are followed.
- Although strength can be predicted from submaximal endurance tests, 1-RM assessments are preferable.
- Use the arm curl test and the 30 sec chair stand test to assess the functional strength of older clients.

Key Terms

Learn the definition of each of the following key terms. Definitions of terms can be found in the glossary.

accommodating resistance
activities of daily living (ADLs)
concentric contraction
constant-resistance exercise
dynamic contraction
eccentric contraction
free-motion machines
functional fitness
isokinetic contraction
isometric contraction
isotonic contraction
maximum voluntary isometric contraction (MVIC)
muscular endurance
muscular strength
omnikinetic exercise
one-repetition maximum (1-RM)
relative strength
static contraction
variable-resistance exercise

Review Questions

In addition to being able to define each of the key terms, test your knowledge and understanding of the material by answering the following review questions.

1. During dynamic movement, why does muscle force production fluctuate throughout the ROM?
2. Name two methods for assessing static strength and muscular endurance.
3. How do constant-resistance, variable-resistance, accommodating-resistance, and free-motion exercise machines differ?
4. Why are strength test scores typically expressed relative to the client's body mass?
5. Describe the recommended procedures for administering 1-RM strength tests.
6. Identify three sources of measurement error for muscular fitness testing. What can you do to control these potential errors?
7. Is it safe to give 1-RM tests to children and older adults?
8. Describe two tests that can be used to assess the functional strength of older adults.
9. Why is it important to assess muscle balance?
10. In terms of the specificity principle, explain why a single test cannot be used to adequately assess your client's overall strength. Minimally, what muscle groups should be tested to evaluate overall strength?
11. Identify the test items recommended by ACSM for assessing your client's upper and lower body strength.
12. For certain clients, you may choose not to administer 1-RM strength tests. Describe how you could obtain an estimate of their strength instead.

CHAPTER 7

Designing Resistance Training Programs

KEY QUESTIONS

- How do training principles specifically apply to the design of resistance training programs?
- How are resistance training programs modified to optimize the development of strength, muscular endurance, muscle power, or muscle size?
- What factors do I need to consider when designing individualized exercise prescriptions?
- Is resistance training recommended for children, adolescents, and older adults?
- What methods can be used to design advanced resistance training programs?
- What are the outcomes and health benefits derived from resistance training?
- What is the cause of delayed-onset muscle soreness, and can it be prevented?

Muscular strength and endurance are important to the overall health and physical fitness of your clients, enabling them to engage in physically active leisure-time pursuits, to perform activities of daily living more easily, and to maintain functional independence later in life. Resistance training is a systematic program of exercise for development of the muscular system. Although the primary outcome of resistance training is improved strength and muscular endurance, a number of health benefits are also derived from this form of exercise. Resistance exercise builds bone mass, thereby counteracting the loss of bone mineral (osteoporosis) and risk of falls as one ages. This form of training also lowers blood pressure in hypertensive individuals, reduces body fat levels, and may prevent the development of low back syndrome.

While resistance training has long been widely used by bodybuilders, powerlifters, and competitive athletes to develop strength and muscle size, participation in weightlifting by individuals of all ages and levels of athletic interest has increased dramatically over the past 30 yr. The popularity and widespread appeal of weightlifting exercise for general muscle conditioning challenge exercise specialists and personal trainers to develop resistance training programs that can meet the diverse needs of their clients.

This chapter shows you how to apply basic training principles (see chapter 3) to the design of resistance training programs for novice, intermediate, and advanced weightlifters. The chapter also presents guidelines for developing muscle strength, muscle endurance, muscle size, and muscle power. The chapter addresses various models of periodization, functional training exercise progressions, and guidelines for youth resistance training.

TYPES OF RESISTANCE TRAINING

Muscular fitness can be improved using various types of resistance training—isometric (static), dynamic (concentric and eccentric), and isokinetic. Although there are general guidelines for designing isometric, dynamic, and isokinetic resistance training programs, each exercise prescription should be individualized to meet the specific needs and goals of your client.

ISOMETRIC TRAINING

In 1953, Hettinger and Muller reported that people produce significant gains in isometric strength (5% per week) by holding one 6 sec contraction at two-thirds of maximum intensity, 5 days/wk. This type of training became popular in the late 1950s and early 1960s because the exercises could be performed anywhere and at any time with little or no equipment. A major disadvantage is that strength gains are specific to the joint angle used during training. Thus, to increase strength throughout the range of motion, the exercise needs to be performed at a number of different joint angles (e.g., 30°, 60°, 90°, 120°, and 180° of knee flexion).

Isometric exercise is widely used in rehabilitation programs to counteract strength loss and muscle atrophy, especially in cases in which the limb is temporarily immobilized. This type of training, however, is contraindicated for coronary-prone and hypertensive individuals because the static contraction may produce large increases in intrathoracic pressure. This reduces the venous return to the heart, increases the work of the heart, and causes a substantial rise in blood pressure.

After further research, Hettinger and Muller modified their original exercise prescription. Table 7.1 presents the general guidelines for designing training programs for isometric strength and endurance development. For descriptions and illustrations of isometric exercises for various muscle groups, see appendix C.4.

DYNAMIC RESISTANCE TRAINING

Dynamic resistance training is suitable for developing muscular fitness of men and women of all ages, as well as children. This type of resistance training involves concentric and eccentric contractions of the muscle group performed against a constant or variable resistance. Typically free weights (barbells and dumbbells) and constant- or variable-resistance machines are used for resistance training.

Several important concepts used to prescribe dynamic resistance training programs are intensity, repetitions, sets, training volume, and order of exercises (Fleck and Kraemer 2004). Intensity is expressed either as a percentage of the individual's 1-repetition maximum (%1-RM) or as the **repetition maximum (RM)**, which is the maximum weight that the person can lift for a given number of repetitions of an exercise (e.g., 8-RM equals the maximum weight that the person can lift for 8 repetitions). For the number of repetitions (i.e., 1- to 10-RM) corresponding to various percentages of 1-RM (i.e., 75% to 100% 1-RM), see table 6.12. The %1-RM values and average number of repetitions for intensities less than 75% 1-RM are as follows:

60% 1-RM = 15- to 20-RM

65% 1-RM = 14-RM

70% 1-RM = 12-RM

Intensity is inversely related to repetitions. In other words, individuals are able to perform more **repetitions** using lighter resistance or weights and fewer repetitions using heavier resistance. A **set** consists of a given number of consecutive repetitions of the exercise. **Training volume** is the total amount of weight lifted during the workout and is calculated by summing the products of the weight lifted, repetitions, and sets for each exercise.

The optimal training stimulus for developing muscular strength or endurance is controversial. Some research supports the conventional prescription of **high-intensity–low-repetition** resistance exercise for strength development and **low-intensity–high-repetition** exercise for muscular endurance (Kraemer et al. 2002; Kraemer and Ratamess 2004).

Table 7.1 Guidelines for Designing Isometric Training Programs

Type	Intensity	Duration	Repetitions	Frequency (days/wk)	Length of program
Isometric strength	100% MVC*	5 sec per contraction	5-10	5	4 wk or more
Isometric endurance	60% MVC or less	Until fatigued	1 per session	5	4 wk or more

*Maximal voluntary contraction.

To develop muscle strength and muscle mass, the American College of Sports Medicine (ACSM 2013) recommends selecting a resistance that allows the individual to complete 8 to 12 repetitions per set. To improve muscular endurance, a lower resistance (≤50% 1-RM) and higher number of repetitions (15-25 reps) are recommended (ACSM 2014). Table 7.2 summarizes the ACSM (2014) guidelines for the resistance training of healthy populations.

Although this training stimulus may be sufficient for beginner and novice lifters, experts recommend that resistance training programs be tailored to the specific goals of intermediate and advanced lifters (Kraemer et al. 2002; Kraemer and Ratamess 2004). You can design programs to optimize the development of muscle strength, size (hypertrophy), endurance, or power by varying the intensity, repetitions, sets, and frequency of training. Tables 7.3 through 7.5 present guidelines for designing programs for novice, intermediate, and advanced weightlifters. For descriptions of dynamic resistance training exercises, see appendix C.5. Also see the online video for additional information on grip and body position variations and common weightlifting errors and corrections.


Video 7.1-7.8

Intensity

As previously mentioned, the %1-RM and RM are widely used to estimate intensity for resistance training programs. The %1-RM, however, may not accurately estimate intensity because the number of repetitions performed at a given %1-RM varies among muscle groups and individuals. Still, many experts endorse the %1-RM to prescribe intensity (Kraemer et al. 2002). Alternatively, Naclerio and colleagues (2011) demonstrated that the intensity of bench press exercise can be controlled and monitored using the OMNI-resistance exercise RPE scale (see appendix B.4)

The mean optimal intensity for developing strength ranges between 60% and 100% 1-RM. At these intensities, most individuals are able to perform 1 to 12 repetitions (1-RM to 12-RM). The client's experience with resistance training dictates the optimal intensity for developing strength. Generally, you should prescribe intensities of 60% to 70% 1-RM for novice lifters, 70% to 80% 1-RM for intermediate lifters, and 80% to 100% 1-RM for advanced lifters (Kraemer et al. 2002; Kraemer and Ratamess 2004). Meta-analyses support these recommendations. Rhea and colleagues (2003a)

Table 7.2 ACSM Guidelines for Resistance Training of Healthy Populations

Goal	Intensity[a]	Repetitions	Sets[b]	Frequency	Number of exercises[c]
Muscle strength and muscle mass	60–80% 1-RM	8-12	2-4	2-3 nonconsecutive days/wk	8-10
Muscle endurance	≤50% 1-RM	15-25	≤2	2-3 nonconsecutive days/wk	8-10

[a]To point of momentary muscular fatigue or failure.

[b]Allow 2-3 min rest between sets.

[c]Perform a different exercise for a specific muscle group every two to three sessions.

Based on ACSM 2014.

Table 7.3 Guidelines for Resistance Training Programs for Novice Lifters

Goal	Intensity	Volume	Velocity	Frequency	Rest interval
Strength	60–70% 1-RM	2-4 sets of 8-12 reps	Slow to moderate	2-3 days/wk	2-3 min MJ; 1-2 min SJ
Hypertrophy	70–85% 1-RM	1-3 sets of 8-12 reps	Slow to moderate	2-3 days/wk	1-2 min
Endurance	≤50% 1-RM	≤2 sets of 15-20 reps	Slow	2-3 days/wk	<1 min
Power	85–100% 1-RM for force, 30–60% 1-RM for upper body, and 0–60% 1-RM for lower body exercises for velocity	2-4 sets of 8-12 reps	Moderate	2-3 days/wk	2-3 min for core exercises (MJ); 1-2 min for SJ

MJ = multijoint exercise; SJ = single-joint exercise.

Kraemer et al. 2002; Ratamess et al. 2009.

Table 7.4 Guidelines for Resistance Training Programs for Intermediate Lifters

Goal	Intensity	Volume	Velocity	Frequency	Rest interval
Strength	70–80% 1-RM	1-3 sets of 6-12 reps	Moderate	3 days/wk for whole-body workouts; 4 days/wk for split workouts	2-3 min MJ; 1-2 min SJ
Hypertrophy	70–85% 1-RM	1-3 sets of 8-12 reps	Slow to moderate	3-4 days/wk	1-2 min
Endurance	50–70% 1-RM	1-3 sets of 10-15 reps	Slow to moderate	3-4 days/wk	<1 min
Power	85–100% 1-RM for force, 30–60% 1-RM for upper body, and 0–60% 1-RM for lower body exercises for velocity	1-3 sets of 3-6 reps	Moderate	2-4 days/wk	2-3 min for core exercises (MJ); 1-2 min for SJ

MJ = multijoint exercise; SJ = single-joint exercise.

Kraemer et al. 2002; Ratamess et al. 2009.

Table 7.5 Guidelines for Resistance Training Programs for Advanced Lifters

Goal	Intensity	Volume	Velocity	Frequency	Rest interval
Strength	80–100% 1-RM, periodized	Multiple sets of 1-12 reps, periodized	Slow to fast	4-6 days/wk	2-3 min MJ; 1-2 min SJ
Hypertrophy	70–100% 1-RM	3-6 sets of 1-12 reps[a], periodized	Slow to moderate	4-6 days/wk	2-3 min MJ; 1-2 min SJ
Endurance	30–80% 1-RM	Multiple sets of 10-25 reps, periodized	Slow for 10-15 reps; moderate to fast for 15-25 reps	4-6 days/wk	<1 min for 10-15 reps; 1-2 min for 15-25 reps
Power	85–100% 1-RM for force; 30–60% 1-RM for velocity	3-6 sets of 1-6 reps, periodized	Fast	4-6 days/wk	2-3 min MJ; 1-2 min SJ

MJ = multijoint exercise; SJ = single-joint exercise.

[a]Greater emphasis on 6-RM to 12-RM.

For power, emphasize MJ exercises. For strength, hypertrophy, and endurance, use both MJ and SJ exercises; perform MJ before SJ exercises. Exercise larger muscle groups before smaller muscle groups.

Kraemer et al. 2002; Ratamess et al. 2009.

reported that the optimal intensity for strength gains in untrained (<1 yr of resistance training) and trained (>1 yr) lifters differs (60% 1-RM and 80% 1-RM, respectively). For competitive athletes (college and professional), the optimal training intensity is 85% 1-RM (Peterson, Rhea, and Alvar 2004). Keep in mind that these intensities are averages. Throughout the strength training program, intensity needs to be varied for continued improvement.

To develop muscular endurance, prescribe an intensity of ≤50% 1-RM (ACSM 2014). Although low-to-moderate intensity best suits muscle endurance and toning, it also brings some strength gains. The degree and rate of strength gain, however, will be less than that experienced with a program that optimizes strength development (specificity principle).

Sets

The optimal number of sets for improving muscular strength is controversial and depends on your client's goal; one or two sets for children and older adults and two to four sets for novice and intermediate lifters are recommended (Kraemer et al. 2002). A major advantage of single-set programs is that they require much less time for a training session than do multiple-set programs (20 vs. 50 min), potentially increasing your client's compliance. Some studies suggest that single sets (one set per exercise) are just as effective as multiple sets (two or three sets per exercise) for increasing the strength of untrained and recreational lifters during the first 3 to 4 mo of resistance training (Feigenbaum and Pollock 1999; Frohlich, Emrich, and Schmidtbleicher 2010; Hass et al. 2000).

However, the results from analyses of resistance training studies do not support prescribing single-set programs to develop the strength (Rhea et al. 2003a) or hypertrophy (Krieger 2010) of untrained and trained recreational lifters. Traditionally, a set refers to the number of consecutive repetitions performed for a specific exercise; however, Rhea and colleagues (2003a) noted that the total number of sets performed for a specific muscle group is a better indicator of training stress than sets per exercise. Using this definition of sets, they reported that an average of four sets during each training session optimizes strength development in untrained and trained lifters. For single-set programs, the authors suggest prescribing multiple exercises for a specific muscle group in order to reach the goal of four sets. The ACSM (2014) stated that each set should be performed to the point of volitional fatigue for each exercise (see table 7.2).

Multiple sets using periodization are recommended for serious athletes, powerlifters, and bodybuilders engaging in advanced strength training and hypertrophy programs (Frohlich et al. 2010; Kraemer et al. 2002). To optimize the strength gains of collegiate and professional athletes, an average of eight sets per muscle group is recommended (Peterson et al. 2004).

Frequency

Muscular fitness may improve from exercising just 1 day/wk, especially in clients with below-average muscular fitness. Recent research, however, suggests that the optimal frequency of strength training for untrained individuals is 3 days/wk. For healthy populations, the ACSM (2014) recommends 2 or 3 nonconsecutive days per week. For advanced lifters, four to six training sessions per week and split routines are recommended (Kraemer et al. 2002). To optimize the strength gains of trained recreational lifters and competitive athletes, each muscle group should be exercised twice a week (Rhea et al. 2003a; Peterson et al. 2004). Advanced lifters and competitive athletes who train 4 to 6 days/wk can accomplish this goal by using split routines (see “Variations for Frequency”). You should prescribe 48 hr of rest between workouts to allow the muscles to recuperate and to prevent injury from overtraining.

Volume

Training volume is the sum of the repetitions performed during each training session multiplied by the resistance used (Kraemer et al. 2002). Throughout the resistance training program, volume and intensity must be systematically increased (progression principle) to avoid plateaus and to ensure continued strength improvements. You can alter training volume by changing the number of exercises performed for each session, the number of repetitions performed for each set, or the number of sets performed for each exercise. Several models of periodized training can be used to systematically vary volume and intensity (see “Periodization”).

Order of Exercises

A well-rounded resistance training program should include at least one exercise for each of the major muscle groups in the body. In this way, **muscle balance**—that is, the ratio of strength between opposing muscle groups (agonists vs. antagonists), contralateral muscle groups (right vs. left side), and upper and lower body muscle groups can be maintained. Order the exercises so that your client first executes multijoint exercises—such as the seated leg press, bench press, and lat pull-down—that involve larger muscles (e.g., gluteus maximus, pectoralis major, and latissimus dorsi) and more muscle groups. Then have your client progress to single-joint exercises for smaller muscle groups (see table 7.6). To avoid muscle fatigue in novice weightlifters, arrange the exercises so that successive exercises do not involve the same muscle group. This allows time for the muscle to recover.

Dynamic Resistance Training Methods

You can use a variety of methods to design dynamic resistance training programs. The majority of these methods are best suited for advanced programs. Each uses a different approach for prescribing sets, order of exercises, or frequency of workouts.

Table 7.6 Example of Exercise Order for a Basic Resistance Training Program

Body Segment	Type of exercise*	Joint actions	Exercise
1. Hips and thighs	Multijoint	Hip extension and knee extension	Seated leg press
2. Chest	Multijoint	Shoulder horizontal flexion and elbow extension	Flat bench press
3. Upper back and mid back	Multijoint	Shoulder extension/adduction and elbow flexion	Lat pull-down
4. Legs	Single joint	Knee extension	Leg extension
5. Shoulders and upper arms	Multijoint	Shoulder abduction and elbow flexion	Upright row
6. Lower back	Multijoint	Trunk extension and hip extension	Back extension
7. Upper arms	Single joint	Elbow extension	Triceps push-down
8. Legs	Single joint	Knee flexion	Leg curl
9. Upper arms	Single joint	Elbow flexion	Arm curl
10. Calves	Single joint	Ankle plantar flexion	Toe raise
11. Forearms	Single joint	Wrist flexion and extension	Wrist curl
12. Abdomen	Single joint	Trunk flexion	Curl-up

*Multijoint exercises involving larger muscle groups are followed by single-joint exercises for smaller muscle groups.

Variations for Sets

You can use either a single set or multiple sets of exercise. For multiple sets, you may choose to have your client consecutively perform a designated number of sets (usually three or more) at a constant intensity (e.g., 10-RM) for each exercise. Alternatively, you may have your client perform one set of three different exercises for the same muscle group. For example, instead of three consecutive sets of barbell curls for the elbow flexors, you may prescribe one set of incline dumbbell curls, one set of hammer curls, and one set of barbell curls. This adds variety to the program and changes the training stimulus because different muscles or parts of a muscle are used to perform each of these exercises.

A client performing multiple sets of a given exercise may choose to lift the same weight for each set or to vary the intensity of each set by lifting progressively heavier (light-to-heavy sets) or lighter (heavy-to-light sets) weights. **Pyramiding** is a light-to-heavy system in which the client performs as many as six sets of each exercise. In the first set, the client lifts a relatively lighter weight for 10 to 12 repetitions (10- to 12-RM). In subsequent sets the individual lifts progressively heavier weights (i.e., 8-RM, 6-RM, and 4-RM). Because this involves such a large volume of work, you should prescribe the pyramid system for experienced weightlifters only. Bodybuilders commonly use this system to develop muscle size.

Variations for Order and Number of Exercises

Exercise scientists generally recommend ordering the exercises so that large muscle groups are exercised at the beginning of the workout with progression to smaller muscle groups later in the workout. To maximize the overload of muscle groups, however, some clients may choose to pre-exhaust muscle groups by reversing this order. To do this, the individual fatigues smaller muscles by using single-joint exercises prior to performing multijoint exercises.

When you prescribe two or more exercises for a specific muscle group, instruct the average individual to alternate muscle groups so that the muscle can rest and recover between exercises. For example, your client should not perform leg press and leg extension exercises consecutively because the quadriceps femoris is used in both of these exercises. Instead, intersperse one or more exercises using different muscle groups between these two exercises.

In contrast, many advanced weightlifters prefer to do **compound sets** or **tri-sets** in order to completely fatigue a targeted muscle group. To use this training system, the client performs two (compound sets) or three (tri-sets) exercises consecutively for the same muscle group, with little or no rest between the exercises. Many bodybuilders also use a training system called **supersetting**. For supersets, the client exercises agonistic and antagonistic muscle groups consecutively without resting. For example, to superset the hamstrings and quadriceps femoris, follow a leg curl set immediately with a leg extension set. Recently, Balsamo and colleagues (2012) compared the effects of different superset exercise sequences for the quadriceps femoris (leg extensions) and hamstrings (leg curls) on total training volume and perceived exertion. They reported that total training volume is increased and the RPE is decreased when leg curls preceded leg extensions. Further research is warranted to identify optimal exercise sequences for other agonist-antagonist muscle groups.

Variations for Frequency

Traditionally for advanced resistance training programs, exercise scientists have recommended resistance training 3 days/wk on alternate days (e.g., M-W-F) to allow the muscles time to recover. For individuals who want to resistance train 4 to 6 days/wk, prescribe a split routine. With a **split routine**, you are targeting different muscle groups on consecutive days, thereby allowing at least 1 day of recovery for each muscle group. For example, a bodybuilder may exercise the chest and shoulders on Monday and Thursday, the hips and legs on Tuesday and Friday, and the back and arms on Wednesday and Saturday.

Periodization

Periodization systematically varies the intensity and volume of resistance training. The goal of periodization is twofold: (1) to maximize the response of the neuromuscular system (i.e., gains in strength, endurance, power, and hypertrophy) by systematically changing the training or exercise stimulus and (2) to minimize overtraining and injury by planning rest and recovery. The training stimulus may be varied by manipulations in one or more of the following program elements:

- Training volume (number of sets, repetitions, or exercises)
- Training intensity (amount of resistance)
- Type of contraction (concentric, eccentric, or isometric)
- Training frequency

Given the number of program variables, there are numerous possibilities for designing periodized programs. Researchers have identified combinations that optimize the training stimulus for developing strength and muscular endurance (Rhea et al. 2002, 2003b).

The recommended amounts of rest between sets and exercises depend on exercise intensity; a lower intensity requires shorter rests and a higher intensity, longer rests (see "Exercise Intensity and Recommended Rest Periods"). In strength or power training, rests should last at least 3 to 5 min to allow resynthesis of adenosine triphosphate (ATP) and creatine phosphate (CP) and to prevent excessive accumulation of muscle and blood lactate (Kraemer 2003).

Three common periodization models are linear periodization (LP), reverse linear periodization (RLP), and undulating periodization (UP). All periodized training programs are divided into periods, or cycles; however, the duration and the training stimulus differ depending on the model used.

Classic Linear Periodization Model

The classic **linear periodization (LP)** model is divided into three types of cycles. The **macrocycle** (usually 9–12 mo) is divided into mesocycles that last 3 to 4 mo. **Mesocycles** are subdivided into **microcycles** lasting 1 to 4 wk. Within and between cycles, training intensity increases as training volume decreases. For example, a 3 mo (12 wk) mesocycle can be divided into three 4 wk microcycles as follows: during weeks 1 through 4, three sets are performed at 12-RM or 70% 1-RM; during weeks 5 through 8, three sets are performed at 10-RM or 75% 1-RM; and during weeks 9 through 12, three sets are performed at 8-RM or 80% 1-RM (see "Sample Linear Periodized (LP) Resistance Training Program for Intermediate Lifter"). The training intensity increases from 70% 1-RM (12-RM) to 80% 1-RM (8-RM) while the training volume systematically decreases due to the progressive reduction in the number of repetitions (from 12 to 8) performed during each microcycle.

EXERCISE INTENSITY AND RECOMMENDED REST PERIODS (KRAEMER 2003)

Intensity	%1-RM	Length of rest
>13-RM	<65%	<1 min
11-RM–13-RM	65-74%	1-2 min
8-RM–10-RM	75-80%	2-3 min
5-RM–7-RM	76-87%	3-5 min
<5-RM	≥87%	>5 min

Reverse Linear Periodization Model

The **reverse linear periodization (RLP)** model reverses the progression of the LP training stimulus. Between and within cycles, training intensity decreases as training volume increases. The RLP configuration of the mesocycles and microcycles is as follows: weeks 1 through 4, three sets at 80% 1-RM (8-RM); weeks 5 through 8, three sets at 75% 1-RM (10-RM); and weeks 9 through 12, three sets at 70% 1-RM (12-RM). As you can see, the training intensity decreases from 80% to 70% 1-RM (8-RM–12-RM) as the training volume increases (from 8–12 reps) during the three progressive microcycles.

Undulating Periodization Models

Compared to those in LP and RLP, the microcycles for **undulating periodization (UP)** are considerably shorter (biweekly, weekly, or even daily) so that they frequently change the training stimulus (intensity and volume). Your client may progress from high volume–low intensity to low volume–high intensity in the same week. For example, in a 3 days/wk UP program, the individual may perform three sets of 8-RM (high volume–low intensity) on day 1, three sets of 6-RM on day 2, and three sets of 4-RM on day 3 (low volume–high intensity). In subsequent microcycles (each week), this training stimulus could be repeated or could be varied to change the order of the training stimulus (e.g., day 1 = 4-RM, day 2 = 6-RM, and day 3 = 8-RM). One advantage of the UP program is that the training volume and intensity change frequently, subjecting the exercising muscles to a different training stimulus on a daily or weekly basis. As such, UP may avoid plateaus in training and maintain the client's interest and motivation for long-term resistance training.

Circuit Resistance Training

Circuit resistance training is a method of dynamic resistance training that increases strength, muscular endurance, and cardiorespiratory endurance (Gettman and Pollock 1981). Circuit resistance training compares favorably with the traditional resistance training programs for increasing muscle strength of untrained adults, especially if low-repetition, high-resistance exercises are used (Gettman et al. 1978; Wilmore et al. 1978). Additionally, Alcaraz and colleagues (2011) reported that high-resistance training (3- to 6-RM; 6 sets; 35 sec interset rest) was as effective as traditional resistance training for improving upper- and lower-body 1-RM strength and power in resistance-trained men.

A circuit resistance training program usually has 10 to 15 stations per circuit (see figure 7.1). The circuit is repeated two or three times so that the total time of continuous exercise is 20 to 30 min. At each exercise station, select a resistance that fatigues the muscle group in approximately 30 sec (as many repetitions as possible at approximately 40% to 55% of 1-RM). Include a 15 to 20 sec rest period between exercise stations. Circuit resistance training is usually performed 3 days/wk for at least 6 wk. This method of training is ideal for clients with a limited amount of time for exercise. As mentioned in chapter 5, you can add aerobic exercise stations to the circuit between each weightlifting station (i.e., super circuit resistance training) to obtain additional cardiorespiratory benefits.

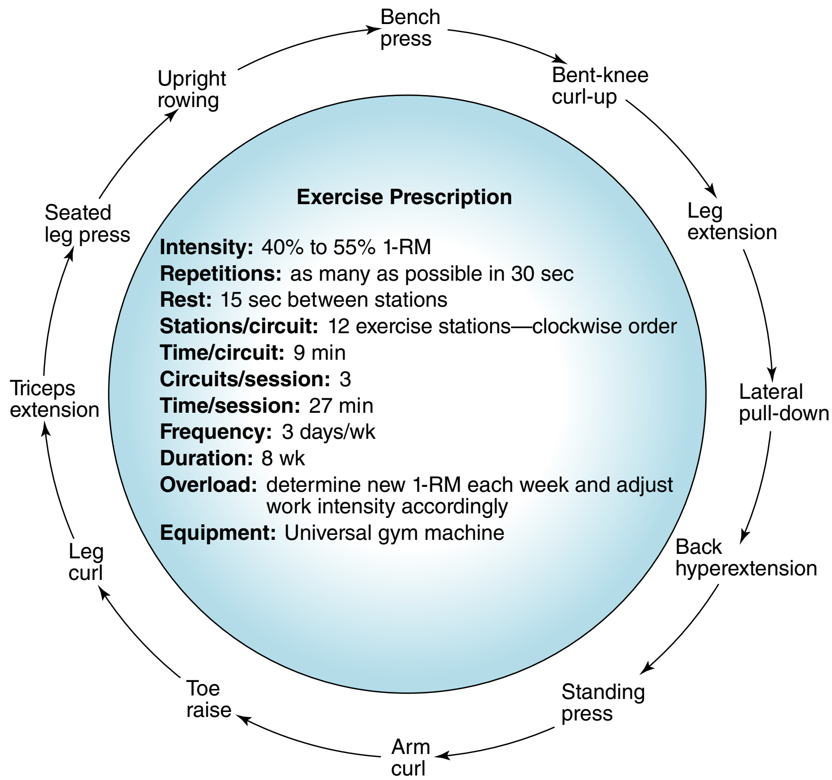


FIGURE 7.1 Sample circuit resistance training program. 1-RM = 1-repetition maximum.

CORE STABILITY AND FUNCTIONAL TRAINING

Core stability training is widely promoted in fitness settings to improve functional capacity (activities of daily living and occupational tasks) and sport skills performance of healthy individuals. **Core stability** is the ability to maintain the ideal alignment of the neck, spine, scapulae, and pelvis while performing an exercise or a sport skill. Abdominal bracing is more effective than abdominal hollowing in optimizing spinal stability. For core stability training, resistance exercises are performed on unstable surfaces (e.g., wobble board, balance disc, and Swiss ball). Compared to exercise on stable surfaces (e.g., ground-based free weights), exercising on unstable surfaces enhances the activation of the core and limb muscles but may decrease force, power, velocity, and range of motion during the resistance exercise. As such, core stability training may be better suited for developing muscular endurance than muscle strength and power (Willardson 2008). Instability resistance training, however, can play an important role in periodized training programs and rehabilitation programs. Also, nonathletes who prefer not to use ground-based free weights to achieve muscular fitness may receive health-related benefits from resistance training on instability devices (Behm et al. 2010). The muscles and their functional contribution to core stability are presented in "Core Stability Muscles and Function."

For years, functional training has been widely used in physical rehabilitation programs to improve joint stability, neuromuscular control, flexibility, and muscular fitness (strength and endurance) of injured clients. Functional training programs typically include four types of exercise:

- Spinal stabilization exercises to improve stability of the spine during movement
- Proprioception and balance exercises to enhance neuromuscular coordination
- Resistance exercises to develop muscular fitness
- Flexibility exercises to regain range of movement

CORE STABILITY MUSCLES AND FUNCTION

Muscles	Location	Function
Multifidus, rotators, intertransversales, interspinalis	Between adjacent vertebrae	Maintain core stability by contracting in response to sudden changes in posture
Transversus abdominis, internal abdominal obliques, quadratus lumborum	Transverse processes of lumbar vertebrae	Stabilize the spine by drawing in umbilicus and increasing compressive forces between bodies of lumbar vertebrae
Rectus abdominis, external abdominal obliques, erector spinae, latissimus dorsi	Pelvic girdle and rib cage	Maintain core stability during performance of heavy ground-based movements with free weights (e.g., squats)
Hip flexors, extensors, adductors, and abductors	Pelvis and lumbar vertebrae to femur	Produce pelvic tilt that results in movement of lumbar spine affecting core stability

Functional training has gained popularity and recognition, especially in health and fitness clubs. Usually the goal of functional training is to train and develop muscles so that performing everyday activities is easier, safer, and more efficient (Yoke and Kennedy 2004). However, some studies have examined the efficacy of functional training for improving sport performance (Thompson, Cobb, and Blackwell 2007).

Functional training is a system of exercise progressions for specific muscle groups that uses a six-step approach developed by Yoke and Kennedy (2004). The difficulty (strength) and skill (balance and coordination) levels of specific exercises are rated, with 1 representing the least difficult exercises (requiring less strength and skill) and 6 the most difficult exercises (requiring more strength and skill). As the difficulty of the exercises progresses, greater strength, balance, core stability, and coordination are required. The hardest exercises (6 rating) require the most core stability. To maintain proper postural alignment, the strength of the core muscle groups (erector spinae and abdominal prime movers and stabilizers) needs to be developed (**core strengthening**). Because core stability is dynamic, changing with body position during exercise, isolated core strengthening does not automatically increase core stability unless it is accompanied by motor skill training (Yessis 2003). Functional exercise progressions develop the strength and function of all muscle groups, not just core muscles. For an outline and example of functional exercise progressions, see "Functional Exercise Progressions: Six-Step Approach and Example."

It is not necessary for every client to progress to the most difficult levels (5 and 6) on the exercise continuum. Safety is of utmost importance. Be certain that your clients are able to perform exercises with proper form and postural alignment for the duration of the set before progressing to the next level. Your clients' ability to perform each level of exercise depends on their fitness and skill levels. Level 6 exercises should challenge competitive athletes or very fit individuals with excellent balance, strength, motor skill, and core stability. Although functional training potentially adds variety and challenge to workouts, research is needed to compare its effectiveness to that of conventional strength and muscular endurance training. Improvements in strength, endurance, balance, flexibility, and coordination as well as in functional performance of everyday tasks need to be evaluated. For more information, detailed descriptions, and illustrations of functional exercise progressions for all muscle groups, see Yoke and Kennedy (2004).

ISOKINETIC TRAINING

Isokinetic exercise combines the advantages of dynamic (full range of motion) and static (maximum force exerted) exercise. Since the resistance is accommodating, isokinetic training overcomes the problems associated with using either a constant- or variable-resistance exercise mode. You can use isokinetic training to increase strength, power, and muscular endurance. Isokinetic training involves dynamic, shortening contractions of the muscle group against an accommodating resistance that

FUNCTIONAL EXERCISE PROGRESSIONS: SIX-STEP APPROACH AND EXAMPLE

Step	Aim	Body position, resistance	Example for knee extensors
1. Isolate and educate	Teach client to focus on individual muscle action and to selectively contract or isolate the specific muscle group	Lying supine or prone on bench or floor	Lying supine with knees bent, hips flexed to 45°, and arms at sides, client extends the knee one leg at a time.
2. Add resistance	Increase resistance by using exercise machines, longer lever length, or elastic tubing	Sitting on bench or floor	Sitting upright on a bench with elastic tubing attached to the ankle, client extends the knee one leg at a time.
3. Add functional training positions	Decrease supporting base to require greater use of stabilizing muscles	Sitting or standing	Supported at low back level by a stability ball pressed against the wall, with pelvis and spine in neutral position, feet shoulder-width apart and far enough away from wall so that knees flex no more than 90° during exercise, client squats, not allowing hips to drop below the knees.
4. Combine increased function with resistance	Overload core stabilizers in functional positions	Using exercise machines, free weights, or elastic exercise bands to increase resistance	With exercise band attached to ankles, client stands in upright, neutral spine position, balancing on support leg with exercise leg flexed at hip and knee slightly flexed. Client flexes the hip while extending the knee of the exercise leg.
5. Exercise multiple muscle groups with increased resistance and core challenge	Increase demand on strength, balance, coordination, and core stability	Using multijoint exercise machines to increase resistance	Using seated, lying, or standing leg press machine, client extends hips and knees simultaneously.
6. Add balance, increased function, speed, or rotation	Increase demand on balance, speed, and joint rotation	Using smaller or moving base of support such as stability balls and balance boards or discs; using free weights (barbells or dumbbells) to increase resistance	Standing in upright position with one hand on wall or support bar and holding dumbbell in other hand, client extends hip and places one leg on stability ball. Client rolls the back leg backward on the ball, flexing the knee (no more than 90°) of the opposite leg while keeping the pelvis and spine in a neutral position and the shoulders and hips squared. Client returns to starting position by extending the knee of exercising leg and rolling opposite leg forward on top of the ball.

matches the force produced by the muscle group throughout the entire range of motion. The speed of the movement is controlled mechanically by the isokinetic exercise device. Isokinetic dynamometers are used for isokinetic training. If this equipment is not available, exercises can be done with a partner who offers accommodating resistance to the movement. The speed of the movement, however, is not precisely controlled.

Isokinetic training is done at speeds that vary between 24 and 300°·sec^{-1}, depending on the needs of the individual. The carryover effect appears to be greater when a person trains at faster speeds (180–300°·sec^{-1}) as compared to slower speeds (30–60°·sec^{-1}). In some studies, strength gains have been limited to velocities at or below the training velocity (Lesmes et al. 1978; Moffroid and Whipple 1970). Other researchers have reported significant strength gains at all testing velocities (30–300°·sec^{-1}) for high-velocity training groups (240–300°·sec^{-1}) (Coyle et al. 1981; Jenkins, Thackaberry, and Killian 1984). Additional research is needed to settle this issue. Table 7.7 presents general guidelines for designing isokinetic training programs for the development of strength and endurance.

A major advantage of isokinetic training over traditional forms of training is that little or no muscle soreness results because the muscles do not contract eccentrically. Isokinetic training is not the best choice, however, when the goal of training is an increase in muscle size. Eccentric contractions are apparently essential for muscle hypertrophy (Cote et al. 1988; Hather et al. 1991). Cote and colleagues (1988) reported no change in muscle fiber cross-sectional area during isokinetic training even though the strength of the quadriceps femoris increased 54%.

DEVELOPING RESISTANCE TRAINING PROGRAMS

Before designing a resistance training program for your client, review training principles and determine how each of these principles can be incorporated into your client's program. The training program needs to be individualized. By varying the combination of intensity, duration, and frequency of exercise, you can develop programs that meet the unique goals and needs of each client. Be sure to follow guidelines and recommendations for resistance training programs (see tables 7.2–7.5), as well as specific recommendations and precautions, when developing resistance training programs for children and older adults.

APPLICATION OF TRAINING PRINCIPLES TO RESISTANCE EXERCISE

To develop effective resistance training programs, you must apply each of the training principles presented in chapter 3 (see "Basic Principles for Exercise Program Design"). This section reviews some of the more pertinent training principles and outlines how these principles are applied to the design of resistance training programs.

Specificity Principle

The development of muscular fitness is specific to the muscle group that is exercised, the type of contraction, and training intensity. To increase the dynamic strength of the elbow flexors, for example, you must select exercises that involve the concentric and eccentric contraction of that particular muscle group. For strength, the person performs exercises at a high intensity with low repetitions; exercising at a low intensity with high repetitions stimulates the development of muscular endurance.

Strength and endurance gains are also specific to the speed and range of motion used during the training. With isometric training, strength gains at angles other than the training angle are typically 50% less than those at the exercised angle. Similarly, as previously noted, strength gains in isokinetic training may be limited to velocities at or below the training velocity (Lesmes et al. 1978; Moffroid and Whipple 1970).

Overload Principle

To promote strength and endurance gains, it is necessary to exercise the muscle group at workloads that are greater than normal for the client. The exercise

Table 7.7 Guidelines for Designing Isokinetic Training Programs

Type	Intensity	Repetitions	Sets	Speed	Frequency	Length of program
Isokinetic strength	Maximum contraction	2-15	3	24–180°·sec^{-1}	3-5 days/wk	6 wk or more
Isokinetic endurance	Maximum contraction	Until fatigued	1	≥180°·sec^{-1}	3-5 days/wk	6 wk or more

Steps for Developing a Resistance Training Program

The following steps, used to design the sample dynamic resistance training programs, provide an outline of how you should proceed.

1. In consultation with your clients, identify the primary goal of the program (i.e., strength, muscular endurance, muscle size, or muscle toning) and ask clients how much time they are willing to commit to this program.
2. Based on your client's goal, time commitment, and access to equipment, determine the type of resistance training program (i.e., dynamic, static, or isokinetic).
3. Using results from your client's muscular fitness assessment, identify specific muscle groups that need to be targeted in the exercise prescription.
4. In addition to core exercises for the major muscle groups, select exercises for those muscle groups targeted in step 3.
5. For novice weightlifters, order the exercises so the same muscle group is not exercised consecutively.
6. Based on your client's goals, determine appropriate starting loads, repetitions, and sets for each exercise.
7. Set guidelines for progressively overloading each muscle group.

intensity should be at least 60% of maximum to stimulate the development of strength. Clients may achieve more rapid strength gains, however, by exercising the muscle at or near maximum (80–100%) resistance. To stimulate endurance gains, intensities as low as 30% of maximum may be used; however, at low intensities the muscle group should be exercised to the point of fatigue.

Progression Principle

Generally, throughout the resistance training program, you must periodically increase the training volume, or total amount of work performed, to continue overloading the muscle so that the person can make further improvements in strength and muscular endurance. The progression needs to be gradual because doing too much too soon may cause musculoskeletal injuries and excessive muscle soreness. Typically you progressively overload muscle groups by increasing the resistance or amount of weight lifted. As clients adapt to the training stimulus, they will be able to perform more repetitions at the prescribed resistance. Thus, the number of repetitions a client is able to perform will indicate when it is necessary to increase the resistance throughout the training program. In addition to increasing resistance, you may progressively overload muscle groups by increasing the total number of repetitions performed at a selected intensity, altering the speed of movement (slow, moderate, fast pace), and varying the duration of rest periods between sets of exercises (Ratamess et al. 2009).

Additional Principles

Individuals with lower initial strength will show greater relative gains and a faster rate of improvement in response to resistance training than those starting out with higher strength levels (principles of initial values and interindividual variability). However, the rate of improvement slows, and eventually plateaus, as clients progress through the program and move closer to their genetic ceiling (principle of diminishing returns). Also, when the individual stops resistance training, the physiological adaptations and improvements in muscle structure and function are reversed (principle of reversibility). Using periodization techniques (see "Periodization"), you can lessen the effects of detraining on athletes and maintain strength gains during the competitive period by manipulating the intensity and volume of the resistance training exercise (see Wathen 1994b).

GENERAL PROCEDURES AND SAMPLE RESISTANCE TRAINING PROGRAMS

After assessing your client's muscular fitness, you can individualize the resistance training exercise prescription to meet the client's individual needs and interests by using the steps outlined in this section.

The first example (see "Sample Resistance Training Program for Older Adult") describes a beginning resistance training program developed for a 70 yr old man with no previous weightlifting experience. The primary goal for this program is to develop adequate muscular fitness so that the client can retain functional independence. This program follows the guidelines suggested by ACSM (2014) for designing resistance training programs for older adults. During the first 4 wk of training, low-intensity (30–40% 1-RM), high-repetition (15–20 reps) exercises familiarize the client with weightlifting exercise and reduce the chance of injury and excessive muscle soreness. The client gradually increases the resistance so that by the end of this phase, the exercise intensity is 50% 1-RM. After 8 wk, the intensity starts at 50% 1-RM and gradually increases to 75% 1-RM. The client does one or two sets of 10 to 15 repetitions for each exercise. To overload the muscles during this phase, he increases the resistance gradually, but only after he is able to complete 15 or more repetitions at the prescribed relative intensity. This program includes multijoint exercises using exercise machines only (no free weights). The client exercises two times a week, allowing at least 2 days of rest between each workout.

The second program (see "Sample Linear Periodized (LP) Resistance Training Program for Intermediate Lifter") is for a 25 yr old woman whose primary goal is to improve muscle strength. This client is an experienced weightlifter. Results from her 1-RM tests indicated that her upper body strength (particularly the shoulder flexor and forearm flexor muscle groups) is below average. Therefore, two exercises are prescribed for each of the weaker muscle groups. The strength of all other muscle groups is average or above average; therefore, only one exercise is prescribed for each of these muscle groups. Given her initial strength levels and weightlifting experience, the prescription is for three sets of each exercise; and the exercise intensity is set at 70% to 80% 1-RM to maximize the development of strength. The client completes about eight repetitions at the prescribed intensity for each microcycle. She devotes 50 to 60 min, 3 days/wk, to her workouts.

The third example (see "Sample Undulating Periodized (UP) Resistance Training Program for Bodybuilder") illustrates an advanced resistance training program developed for an experienced weightlifter (28 yr old male with superior strength) whose long-term goal is competitive bodybuilding. He engages in a high-volume undulating periodized training program. The intensity (70–85% 1-RM) and moderate repetitions (6–12 reps) vary systematically throughout each macro- and microcycle to maximize the development of muscle size. To achieve a high training volume, he performs three exercises for each muscle group and three or four sets of each exercise. To effectively overload the muscles, he performs three exercises for each muscle group consecutively (tri-sets) with little or no rest between the sets. He lifts weights 6 days/wk, splitting the routine so that he is not exercising the same muscle groups on consecutive days. With this routine, each muscle group is exercised two times a week.

Several excellent references deal with the design of advanced resistance training programs (Fleck and Kraemer 2004; Kraemer and Fleck 2007; National Strength and Conditioning Association 2008; Stone, Stone, and Sands 2007).

SAMPLE RESISTANCE TRAINING PROGRAM FOR OLDER ADULT

Client data

Age	70 yr
Gender	Male
Body weight	160 lb. (72.7 kg)
Program goal	Muscle fitness and functional independence
Time commitment	20-30 min per workout
Equipment	Exercise machines
Intensity	30–50% 1-RM for first 8 wk; 50–75% 1-RM thereafter
Frequency	2 days/wk; at least 48 hr between workouts
Duration	16 wk or longer
Overload	Increase reps first; increase resistance only when able to complete > 15 reps
Rest	2-3 min between exercises

Exercise[a]	1-RM (lb)*	Weeks[b]	Intensity[c] (% 1-RM)	Weight (lb)	Repetitions	Sets	Muscle groups
Leg press (seated)	180	1-4	30-40	55-70	15-20	1	Hip extensors
		5-8	40-50	72-90	15-20	1	Knee extensors
		9-12	50-60	90-110	10-15	1	
		13-16	60-75	110-135	10-15	1	
Chest flys (seated)	90	1-4	30-40	30-36	15-20	1	Shoulder horizontal flexors
		5-8	40-50	36-45	15-20	1	Elbow extensors
		9-12	50-60	45-54	10-15	1	
		13-16	60-75	54-68	10-15	1	
Leg curl (seated)	45	1-4	30-40	13-18	15-20	1	Knee flexors
		5-8	40-50	18-22	15-20	1	
		9-12	50-60	22-27	10-15	1	
		13-16	60-75	27-34	10-15	1	
Lat pull-down	100	1-4	30-40	30-40	15-20	1	Shoulder extensors
		5-8	40-50	40-50	15-20	1	Elbow flexors
		9-12	50-60	50-60	10-15	1	
		13-16	60-75	60-75	10-15	1	
Shoulder press (seated)	50	1-4	30-40	15-20	15-20	1	Shoulder flexors and adductors
		5-8	40-50	20-25	15-20	1	
		9-12	50-60	25-30	10-15	1	
		13-16	60-75	30-38	10-15	1	
Heel (calf) raises (seated)	90	1-4	30-40	27-36	15-20	1	Ankle plantar flexors
		5-8	40-50	36-45	15-20	1	
		9-12	50-60	45-54	10-15	1	
		13-16	60-75	54-68	10-15	1	
Abdominal curl	–	1-4	–	Body weight	5-10	1-2	Trunk flexors
		5-8			10-15	1-2	
		9-12			15-20	1-2	
		13-16			20-25	1-2	

[a]Multijoint exercise machines are used for most exercises. Seated and lying (instead of standing) positions are recommended to stabilize the body while lifting. Do exercises in the order listed.

[b]During first 2 wk, closely monitor and supervise workouts. Initial training phase lasts 8 wk.

[c]Intensity is gradually increased every 2 wk, only after client is able to do more than the prescribed number of repetitions at each target intensity.

*1 lb = 0.45 kg

SAMPLE LINEAR PERIODIZED (LP) RESISTANCE TRAINING PROGRAM FOR INTERMEDIATE LIFTER

Client data

Age	24 yr
Gender	Female
Body weight	155 lb. (70.4 kg)
Program goal	Muscle strength
Time commitment	50-60 min per workout
Equipment	Variable resistance machines and free weights
Cycles	3; each microcycle = 4 wk
Intensity	70-80% 1-RM
Repetition	8-12
Sets	3
Rest	1-2 min for 70% 1-RM; 2-3 min for 75-80% 1-RM
Frequency	3 days/wk, alternate days
Duration	12 wk or longer

Exercise[a]	1-RM (lb)[b]	Cycle 1 wk 1-4			Cycle 2 wk 5-8			Cycle 3 wk 9-12				
		Int	*Wt*[b]	*Rep*	*Int*	*Wt*[b]	*Rep*	*Int*	*Wt*[b]	*Rep*	*Sets*	*Muscle groups*
Leg press	200	70	140	12	75	150	10	80	160	8	3	Hip extensors, knee extensors
Bench press*	100	70	70	12	75	75	10	80	80	8	3	Shoulder flexors and adductors, elbow extensors
Leg curl (lying)	80	70	55	12	75	60	10	80	65	8	3	Knee flexors
Lat pull-down	140	70	100	12	75	105	10	80	110	8	3	Shoulder extensors and adductors, elbow flexors
Dumbbell fly* (flat bench)	40	70	25	12	75	30	10	80	35	8	3	Shoulder flexors and adductors
Heel (calf) raise (standing)	160	70	110	12	75	120	10	80	130	8	3	Ankle plantar flexors
Abdominal curl	—									25	3	Trunk flexors
Arm curl* (incline bench)	40	70	25	12	75	30	10	80	35	8	3	Elbow flexors
Lateral raise (dumbbell)	25	70	15	12	75	15-20	10	80	20	8	3	Shoulder abductors
Triceps press-down	60	70	40	12	75	45	10	80	50	8	3	Elbow extensors
Hammer curl* (dumbbells)	40	70	25	12	75	30	10	80	35	8	3	Elbow flexors

Int = %1-RM; Wt = weight lifted; Rep = number of repetitions.

[a]Do exercises in order listed, using larger muscle groups first. Perform multijoint exercises before single-joint exercises. Other exercises that work the same muscle groups may be substituted to add variety to the program (see appendix C.5, "Dynamic Resistance Training Exercises").

[b]1 lb = 0.45 kg; weight is to nearest 5 lb increment for most exercises.

*Two exercises are prescribed for each of the weaker muscle groups (shoulder flexors and elbow flexors) identified from client's strength assessment.

SAMPLE UNDULATING PERIODIZED (UP) RESISTANCE TRAINING PROGRAM FOR BODYBUILDER

Client data

Age	28 yr	*Mesocycles*	4; each mesocycle = 1 mo
Gender	Male	*Microcycles*	4; each microcycle = 1 wk
Body weight	190 lb. (86.2 kg)	*Intensity*	70–85% 1-RM
Program goal	Hypertrophy	*Repetition*	6-12
Time commitment	90 min per workout	*Sets*	3 or 4
Equipment	Free weights and exercise machines	*Rest*	1 min rest between tri-sets
		Frequency	6 days/wk, split routine
		Duration	24 wk or longer

UP mesocycles and microcycles

	Intensity	Volume
MONTH 1		
Week 1	70% 1-RM	3 or 4 sets; 12 reps
Week 2	75% 1-RM	3 or 4 sets; 10 reps
Week 3	80% 1-RM	3 or 4 sets; 8 reps
Week 4	85% 1-RM	3 or 4 sets; 6 reps
MONTH 2		
Week 1	75% 1-RM	3 or 4 sets; 10 reps
Week 2	80% 1-RM	3 or 4 sets; 8 reps
Week 3	85% 1-RM	3 or 4 sets; 6 reps
Week 4	70% 1-RM	3 or 4 sets; 12 reps
MONTH 3		
Week 1	80% 1-RM	3 or 4 sets; 8 reps
Week 2	85% 1-RM	3 or 4 sets; 6 reps
Week 3	70% 1-RM	3 or 4 sets; 12 reps
Week 4	75% 1-RM	3 or 4 sets; 10 reps
MONTH 4		
Week 1	85% 1-RM	3 or 4 sets; 6 reps
Week 2	80% 1-RM	3 or 4 sets; 8 reps
Week 3	75% 1-RM	3 or 4 sets; 10 reps
Week 4	70% 1-RM	3 or 4 sets; 12 reps

(continued)

Sample Undulating Periodized (UP) Resistance Training Program for Bodybuilder *(continued)*

Split Routine Using Tri-Sets

Exercises	1-RM (lb)[c]	Muscles
Monday and Thursday[a]		
Chest[b]		
Flat bench press (barbell)	250	Pectoralis major (midsternal portion); triceps brachii
Incline dumbbell fly	80	Pectoralis major (clavicular portion); anterior deltoid
Decline bench press (barbell)	180	Pectoralis major (lower sternal portion)
Shoulders[b]		
Upright row (barbell)	140	Middle deltoid
Front dumbbell raises	80	Anterior deltoid
Posterior cable pull (horizontal plane)	100	Posterior deltoid
Tuesday and Friday[a]		
Hips and thighs[a]		
First tri-set		
Squats (Smith machine)	300	Gluteus maximus; quadriceps femoris; upper hamstrings
Leg extension (machine)	150	Quadriceps femoris
Leg curl (standing, unilateral, machine)	90	Hamstrings (mid-to-lower portions)
Second tri-set		
Leg press (seated)	400	Gluteus maximus; quadriceps femoris; upper hamstrings
Leg curl (lying)	130	Hamstrings (mid-to-lower portions)
Glute-ham raise	—	Gluteus maximus; hamstrings
Leg and calves[b]		
Standing calf (heel) raise	250	Gastrocnemius; soleus
Ankle flexion exercise (seated)	90	Tibialis anterior
Seated calf raise	180	Soleus; gastrocnemius
Wednesday and Saturday[a]		
Back[b]		
Lat pull-down (wide grip)	225	Latissimus dorsi (lateral portions); biceps brachii; brachialis
Seated row (narrow grip)	240	Latissimus dorsi (midportion); biceps brachii; brachialis
Dumbbell row	90	Latissimus dorsi (midportions); biceps brachii; brachialis
Elbow flexors[b]		
Standing barbell curl	130	Biceps brachii; brachialis; brachioradialis
Preacher curl (dumbbells)	100	Biceps brachii (midportion); brachialis
Hammer curl (dumbbells)	80	Brachioradialis; brachialis
Elbow extensors[b]		
Lying triceps extension (barbell)	120	Triceps brachii (long head)
Triceps push-down (cables)	150	Triceps brachii (short and lateral heads)
Triceps pull-down with lateral flair (cables)	130	Triceps brachii (lateral head)

[a]Other exercises that work same muscles may be substituted on the second day to add variety to the program (see appendix C.5, "Dynamic Resistance Training Exercises").

[b]For tri-sets, the three exercises listed are performed consecutively without rest, then the tri-set is repeated for the prescribed number of sets for that muscle group (1 min rest between sets).

[c]1 lb = 0.45 kg.

DESIGNING RESISTANCE TRAINING PROGRAMS FOR CHILDREN

Children and adolescents can safely participate in resistance training if special precautions and recommended guidelines are carefully followed. Because children are anatomically and physiologically immature, high-resistance training programs are not typically recommended for them. Most experts agree that to lessen the risk of injury (e.g., epiphyseal growth plate fractures) to developing bones and joints, exercise intensity should not exceed 80% 1-RM, which equates to 8 to 15 repetitions per set. Faigenbaum and colleagues (1999) reported that high-repetition–moderate-intensity training (one set, 13-RM to 15-RM) was more effective than low-repetition–high-intensity training (one set, 6-RM to 8-RM) for improving the strength and muscle endurance of children (5–12 yr) during the initial training phase (8 wk). Strength gains in resistance-trained children result from neural adaptations (e.g., increased activation of motor units and coordination) rather than from hypertrophy (Guy and Micheli 2001). In addition, resistance training positively affects the bone mineral density of the femoral neck in adolescent girls ages 14 to 17 yr (Nichols, Sanborn, and Love 2001). There is no evidence that children lose flexibility when they resistance train (Guy and Micheli 2001). Resistance training is safe and beneficial for youth, especially when the established training guidelines are followed (see "Youth Resistance Training Guidelines"). These guidelines are based primarily on recommendations outlined

Youth Resistance Training Guidelines

- Provide qualified instruction and supervision.
- Provide an exercise environment that is safe and free of hazards.
- Teach clients about the benefits and risks of strength training.
- Design a comprehensive program that focuses on developing muscular fitness and motor skills.
- Begin each workout with a 5 to 10 min warm-up.
- Select 8 to 12 multijoint exercises for major muscle groups; include exercises for the abdominal muscles and lower back.
- Use equipment that is appropriate for the size, strength, and maturity of the child.
- Start with one or two sets of 8 to 15 repetitions with light to moderate load (~60% 1-RM) for each exercise.
- Slowly progress to three or four sets at 60% to 80% 1-RM, or 8-RM to 15-RM, depending on the child's needs and goals; as strength improves, increase the number of repetitions before increasing resistance.
- Increase resistance gradually and only when the child can perform the specified number of repetitions with good form.
- Reduce the resistance for prepubescent children who cannot perform a minimum of 8 repetitions with good form.
- Prescribe low-repetition (fewer than 8 reps) exercises for mature adolescents only.
- Focus on correct exercise technique (slow and smooth movements and breathing) instead of amount of weight lifted.
- Train two or three times per week on nonconsecutive days.
- Closely supervise the child in the event of a failed repetition.
- Monitor progress (e.g., use workout logs), listen to the child's concerns, and answer questions.
- Systematically vary the training program to keep it fresh and challenging by adding new exercises, changing the number of sets and repetitions, and incorporating calisthenics as well as exercises using elastic tubing and fitness balls.
- Focus on participation and provide positive reinforcement.

Adapted from Behm et al., 2008.

in the Canadian Society for Exercise Physiology position paper on resistance training for children and adolescents (Behm et al. 2008) and the National Strength and Conditioning Association position paper on youth resistance training (Faigenbaum et al. 2009).

DESIGNING RESISTANCE TRAINING PROGRAMS FOR OLDER ADULTS

Resistance training provides many health benefits, especially for older adults. The primary goal of the resistance training program is to develop sufficient muscular fitness so that older adults may carry out activities of daily living (ADLs) without undue stress or fatigue and may retain their functional independence. In order to achieve these goals, age-related losses in muscle mass (**sarcopenia**) and muscle strength (**dynapenia**) must be counteracted. Experts agree that resistance training is the most effective mode of exercise to maintain and to improve strength and muscle mass in older adults (Garber et al. 2011; Peterson et al. 2010; Peterson and Gordon 2011; Romo-Perez, Schwingel, and Chodzko-Zajko 2011; Tremblay et al. 2011). Candow and associates (2011) reported that 22 wk of whole-body resistance training (3 days/wk) was sufficient not only in attenuating age-related deficits in lean body tissue and upper and lower body strength of older (60–71 yr) men, but in realizing strength levels comparable to those of untrained, younger men.

Vincent and colleagues (2002) noted long-term (6 mo) improvements in the strength and muscular endurance of older adults (60–83 yr) who participated in either a low-intensity (one set at 50% 1-RM) or a high-intensity (1 set at 80% 1-RM) resistance training program, 3 days/wk. Likewise, Hunter and colleagues (2001) reported that isometric and dynamic muscle strength gains are similar for older adults (>60 yr) engaging in either a nonperiodized, high-intensity program (2 sets at 80% 1-RM, 3 days/wk) or an undulating periodized (UP) program varying training volume each day (2 sets at 50%, 65%, or 80% 1-RM, 3 days/wk). Some evidence suggests that training 1, 2, or 3 days a week at 80% 1-RM produces similar strength gains in older (65–79 yr) adults (Taaffe et al. 1999). Based on results from meta-analyses of studies investigating resistance training and strength gains, Peterson and colleagues (2010, 2011) concluded that the higher the training volume, the greater the absolute and relative improvement in strength and lean body mass of older adults.

Muscle power (strength × speed of contraction) is a significant predictor of ability to perform ADLs. With aging, both strength and power decline due to atrophy of slow and fast muscle fibers. Muscle power declines at a relatively faster rate (3–4% per yr after age 60) than strength. Some experts suggest that resistance training of older persons should emphasize the development of power by using fast-velocity resistance exercise (Forbes, Little, and Candow 2012; Porter 2006). For fast-velocity exercise, the concentric phase of the exercise is performed as quickly as possible, and the eccentric phase should take about 2 sec.

In addition to increasing strength, power, and muscular endurance, resistance training may improve the performance of functional tasks such as lifting and reaching, rising from the floor or a chair to a standing position, stair climbing, and walking (Henwood and Taaffe 2003; Messier et al. 2000; Schot et al. 2003; Vincent et al. 2002). Also, the postural sway and balance of older, osteoarthritic adults were improved by participation in either long-term resistance training or aerobic walking (Messier et al. 2000). Improved strength and balance may help prevent falls and injuries in older adults.

For older adults, the ACSM (Garber et al. 2011) recommends resistance training 2 days/wk at moderate intensity (40–50% 1-RM; 10-15 reps) to improve strength and at a lower intensity (20–50% 1-RM) to improve power. Although resistance training guidelines for older adults vary among organizations, the consensus is that older adults should exercise the major muscle groups of the body at least 2 days/wk on nonconsecutive days. Most suggest prescribing 2 or 3 sets of 8 to 10 different exercises at intensities ranging between 8- and 15-RM (Peterson and Gordon 2011; Romo-Perez et al. 2011; Tremblay et al. 2011). As with your younger clients, the training volume needs to be varied and gradually increased over time (progression principle). For a detailed example of a 6 mo progressive resistance training program for healthy, older adults, see Peterson (2010) or Peterson and Gordon (2011).

The ACSM (2014) recommends moderate-intensity (rating of perceived exertion [RPE] = 5-6) to vigorous-intensity (RPE = 7-8) exercise at least 2 days/wk to improve the muscular fitness of older adults; prescribe at least one set of 10 to 15 repetitions for 8 to 10 different exercises each workout.

In addition to these general guidelines for designing resistance training programs for healthy adults (see table 7.2), the following guidelines and precautions are recommended for older adults:

- During the first few weeks of training, use minimal resistance for all exercises.
- Instruct older adults about proper weightlifting and breathing techniques.
- Trained exercise leaders who have experience working with older adults should closely supervise and monitor the client's weightlifting techniques and resistance training program during the first few exercise sessions.
- Prescribe multijoint, rather than single-joint, exercises.
- Use exercise machines to stabilize body position and control the range of joint motion. Avoid using free weights with older adults.
- Each exercise session should last approximately 20 to 30 min and should not exceed 60 min.
- Older adults should rate their perceived exertion during exercise. Ratings of perceived exertion should be 5 or 6 (moderate) or 7 or 8 (vigorous).
- Prescribe at least two sets of 8 to 15 repetitions for 8 to 10 different exercises for the major muscle groups.
- Train at least 2 days/wk, allowing at least 48 hr of rest between the exercise workouts.
- Discourage clients with arthritis from lifting weights when they are actively experiencing joint pain or inflammation.
- When clients are returning to resistance training following a layoff of more than 3 wk, they should start with a low resistance that is less than 50% of the weight they were lifting prior to the layoff.

COMMON QUESTIONS ABOUT RESISTANCE TRAINING

Because of the popularity of resistance training, there is an overwhelming amount of information about the subject in professional journals as well as in popular magazines and newspapers. This section presents common questions that exercise professionals may have about designing resistance training programs and addresses questions and concerns that your clients may pose.

PROGRAM DESIGN

Which resistance training method, nonperiodized or periodized, is better?

The answer depends on your client's initial training status and goals. During the first stage (4 wk) of resistance training, both nonperiodized and periodized multiple-set programs increase the muscular fitness of untrained and novice lifters (Baker, Wilson, and Carlyon 1994); however, a varied training stimulus is needed for continued improvements in muscle strength and endurance during long-term (>4 wk) training (Fleck 1999; Marx et al. 2001). Recently, Kell (2011) reported that periodized training (12 wk; 3 or 4 days/wk) significantly improved the strength of men and women who had nonperiodized training experience. Periodized training is highly recommended for intermediate and advanced lifters; nonperiodized training may be more appropriate for clients just starting a weightlifting program or who are primarily interested in maintaining strength and muscle tone. Varying workouts daily (undulating periodized training) helps prevent boredom and maintain exercise compliance.

Which periodization model is best?

The answer depends on your client's training goal. One research team conducted two studies to assess the effectiveness of different types of periodized programs (LP, RLP, and daily UP) for increasing the strength and local muscular endurance of young, resistance-trained women and men (Rhea et al. 2002, 2003b). The researchers reported that daily UP was superior to LP for developing the strength of young men who trained 3 days/wk for 12 wk. For endurance gains, there were no statistically significant differences in LP, RLP, and daily UP training. Analysis of effect sizes, however, indicated that RLP was more effective than either LP or daily UP for increasing the muscular endurance of women and men who trained 2 days/wk for 15 wk. Other researchers also noted that daily UP programs are more effective than LP programs for increasing strength, muscle endurance, and muscle thickness in untrained males (Miranda et al. 2011; Simao et al. 2012).

Another research team (Painter et al. 2012) compared the efficiency of LP and daily UP programs for male and female track and field athletes. Program efficiency was estimated by dividing performance gains (e.g. in 1-RM squat) by the volume of work. They reported that the LP training model produces greater strength gains relative to the work invested (i.e., more efficient) than the daily UP model.

Is single-set training as effective as multiple-set training?

Some research suggests that single-set training is as effective as multiple-set training for increasing the strength of untrained individuals during the initial stage of resistance training. For long-term training, however, multiple sets elicit greater strength gains for trained men and women (Marx et al. 2001; Wolfe, LeMura, and Cole 2004). For a comprehensive quantitative meta-analysis of studies comparing single- and multiple-set programs, see Wolfe and colleagues (2004). Paulsen, Myklested, and Reestad (2003) noted that the best method depends on the muscle groups exercised. They reported that multiple sets were superior to single sets for increasing leg strength, whereas the two types of programs were equally effective for increasing the upper body strength of untrained men during the initial phase (6 wk) of training.

Is it better to train using fixed-form or free-form exercise machines?

Both fixed-form and free-form resistance exercise machines may be used to improve muscular fitness. Fixed-form devices limit the range of motion and plane of motion during the resistance exercise (e.g., a leg extension machine that allows flexion/extension in sagittal plane only). In contrast, free-form exercise machines allow movement in multiple planes (e.g., chest fly machine that allows press or fly movements in horizontal and oblique planes). One study compared the effects of 16 wk of fixed-form training and free-form training on strength and balance of sedentary men and women (Spennewyn 2008). The improvement in overall strength of the free-form training group (116%) was significantly greater than that of the fixed-form training group (58%). Also, overall balance performance improved 245% and 49%, respectively, for the free-form and fixed-form training groups. Additional research is needed to substantiate these preliminary findings.

Are abdominal training devices more effective than traditional calisthenic exercises for strengthening abdominal muscles?

Currently, there is little scientific evidence justifying manufacturers' claims that abdominal training devices improve strength more effectively than simply performing calisthenic exercises without these devices (e.g., curl-ups). These devices purportedly overload the abdominal muscles by adding resistance (e.g., abdominal belts) and isolate the abdominal musculature by supporting the head, neck, or back. However, studies using electromyography (EMG) show that exercising with these devices does not increase the muscle activity of the abdominal prime movers (rectus abdominis and external abdominal oblique muscles) more than exercising without the devices (American Council on Exercise 1997; Demont et al. 1999; Francis et al. 2001). Although research does not support the use of abdominal trainers, they can add variety to conventional abdominal exercises and may even improve some clients' adherence to the abdominal exercise regimen.

To progressively overload (increase the training stimulus of) the abdominal muscles, you can have your client modify body position (e.g., perform abdominal curls on a decline bench rather than on a flat bench), hold a weight across the chest, or change arm positions. Abdominal exercises become more difficult as the arms move from along the sides to behind the head to overhead.

How can stability balls, medicine balls, and resistance bands be used to improve a client's fitness?

Stability balls, medicine balls, and resistance bands can be used in a variety of ways to improve muscular strength, power, core stability, flexibility, and static and dynamic balance. Calisthenic exercises such as abdominal crunches and back extensions can be performed while clients are lying on the ball; dumbbell exercises can be performed while they are lying supine or prone or sitting on the ball. Stability and medicine ball exercises are used to train the body as a linked system, starting with the core muscle groups. Use of resistance bands and tubing allows the individual to train the muscles with exercises that simulate the movement patterns of a specific sport. For more information about stability ball, medicine ball, and resistance band training, see Goldenberg and Twist (2007) and Page and Ellenbecker (2005).

Does performing the curl-up on a labile (movable) surface increase the challenge for the abdominal muscles?

Another way to increase the training stimulus for developing abdominal muscular fitness is to perform curl-up exercises on a labile surface. Vera-Garcia, Grenier, and McGill (2000) studied the EMG activity of the abdominal muscles (upper and lower rectus abdominis and internal and external abdominal oblique muscles) during four types of curl-ups: curl-ups on a stable bench, curl-ups on a gym ball with feet flat on the floor, curl-ups on a gym ball with feet on a bench, and curl-ups on a wobble board. Curl-ups performed on labile surfaces (gym ball and wobble board) doubled the EMG activity of the rectus abdominis and quadrupled the activity of the external oblique muscles. In terms of maintaining whole-body stability, the curl-up on the gym ball with the feet flat on the floor was the most demanding, as evidenced by increased EMG activity in all the abdominal muscles. Curl-ups with the upper body supported on the wobble board produced the most EMG activity in the upper rectus abdominis. Although exercising on a labile surface increases abdominal muscle activity and coactivation, it also increases loads on the spine. In rehabilitation programs, curl-ups on movable surfaces should be used only with clients who can tolerate higher spinal loads (Vera-Garcia, Grenier, and McGill 2000).

What is whole-body vibration training and how does it work?

Over 50 yr ago, scientists explored the idea of using vibration loading to prevent bone mineral loss and muscle atrophy in astronauts during space travel. Today **whole-body vibration (WBV)** exercise devices can be found in fitness and rehabilitation centers throughout the world. WBV exercise involves positioning the body on a motorized platform that produces vibratory signals at a set frequency and amplitude. Frequency is measured in hertz (Hz) and usually ranges from 20 to 60 Hz. At 35 Hz, for example, the targeted muscles will contract and relax 35 times per second. Amplitude, or the vertical displacement of the platform during vibrations, is measured in millimeters. Intensity is a direct function of the frequency and amplitude. These oscillating vibrations are transmitted to the weight-bearing muscles and bones. The body parts in direct contact with the surface of the platform will receive the greatest amount of vibration. Typically, the client stands on the platform holding the handles and performs lower body exercises such as squats, lunges, calf raises, or light jumping. Alternatively, the arms or feet may be placed on the platform for upper body and abdominal exercises such as push-ups, triceps dips, side support, abdominal planks, and static stretches.

Vibration devices vary in the way in which the oscillating signals are delivered to the body. For synchronous WBV devices, the vibration is applied to the right and left foot simultaneously, whereas side-alternating models apply the vibration sequentially to the right and left foot. In the fitness setting, low-magnitude vibratory platforms are usually used. For these devices, the magnitude of acceleration due to gravity (1 g = 9.81 $m \cdot sec^2$) is less than 1 g. High-magnitude devices provide an acceleration greater than 1 g and may cause musculoskeletal and neural damage, posing a health risk (Abercromby et al. 2007; Judex and Rubin 2010). These high-intensity WBV devices are not regulated by the Food and Drug Administration and are more commonly used in clinical rehabilitation settings. WBV exercise, even at low intensities, is contraindicated for pregnant women or individuals with thrombosis, seizures, pacemakers, or other electronic implants (Albasini, Krause, and Rembitzki 2010).

The frequency, intensity, and duration of WBV sessions used in training studies vary greatly. Frequency of training sessions varies between 1 and 7 per wk and their duration can last from 6 wk to 18 mo. The peak acceleration of the vibration platform is usually less than 1 g, with intensity of the oscillating signals varying from 10 to 60 Hz (frequency) and 0.05 to 8 mm (amplitude). The vibration signal is delivered in bouts, lasting anywhere from 30 sec to 10 min (Lau et al. 2011). The disparity in training protocols and lack of standardization of methods complicates the synthesis, application, and ability to generalize research findings. To address this issue, the International Society of Musculoskeletal and Neuronal Interactions developed a set of recommendations for describing methods used in WBV training intervention studies (Rauch et al. 2010).

Vibration loading produces small changes in muscle length that stimulate a **tonic vibration reflex**. This reflex activates muscle spindles and alpha motor neurons, causing the muscles to contract (Torvinen et al. 2002). Torvinen and colleagues examined the long-term (4 mo) effects of vibration training combined with unloaded static and dynamic exercises on strength, power, and balance. They noted that the greatest relative gains in isometric leg extension strength and in leg power (measured by the vertical jump) occurred after the first 2 mo of training. Gains in strength and power during the last 2 mo of training were minimal. Thus, it appears that vibration training elicits a neural response and adaptation (recruitment of motor units through the activation of muscle spindles) similar to that observed during the early stages of conventional resistance training. When compared to a standard fitness program (combined aerobic and resistance training) and to conventional resistance training (exercise machines) in women, vibration training during unloaded static and dynamic exercises produced similar gains in isometric, isokinetic, and dynamic strength over 3 to 4 mo (Delecluse, Roelants, and Verschueren 2003; Roelants et al. 2004). However, Abercromby and colleagues (2007) reported that more than 10 min a day of whole-body vibration training may have adverse health effects. Vibration training warrants further study, especially to determine its applicability in improving strength, flexibility, and possibly even balance in elderly individuals in order to prevent falls, as well as to identify any long-term potential health hazards for this form of training.

Is whole-body vibration training as effective as traditional resistance training for improving musculoskeletal fitness of my clients?

Over the past decade, research has examined the potential of using whole-body vibration as a method for improving muscular strength, explosive power, bone density, body composition, balance, mobility, and postural control (McBride et al. 2010). Additionally, the usefulness of WBV for attenuating muscle soreness due to eccentric exercise and for reducing low back pain has been addressed. Only studies dealing with effects of WBV on musculoskeletal parameters are summarized in this section. Findings relative to body composition, balance, mobility, postural control, and low back pain will be addressed in later chapters. Much of the research focuses on older adults, in light of age-related declines in muscle strength (dynapenia), muscle mass (sarcopenia), and bone mineral (osteoporosis). For specific guidelines for using WBV in the treatment of low back pain, osteoporosis and osteopenia, balance disorders, sarcopenia, and dynapenia, see Albasini and colleagues (2010).

For older clients, the addition of WBV to resistance training augments the positive effects of resistance training on muscle strength (Bemben et al. 2010; Bogaerts et al. 2009) and muscle hypertrophy (Machado et al. 2010). In some cases, WBV training is even more effective than resistance training alone for increasing muscle strength and power of older women (Lau et al. 2011; von Stengel et al. 2012).

For younger, well-trained adults, supplementing the resistance training with WBV does not augment strength gains or corticospinal excitability induced by resistance training alone (Artero et al. 2012; Weier and Kidgell 2012). WBV, however, does have an additive effect on muscular power in well-trained athletes (Fort et al. 2012; Ronnestad et al. 2012).

The effects of WBV training on bone mineral density (BMD) vary. In a study of older, postmenopausal women, von Stengel, Kemmler, Bebenek, and colleagues (2011) reported that the BMD of the lumbar spine increases significantly following 12 mo of WBV training. In contrast, others have shown little or no change in BMD of the femur, spine, and hip with WBV training. In fact, a number of review articles and meta-analyses of published literature over the last decade concluded that WBV training does not lead to a clinically important increase in BMD of postmenopausal women (Cheung and Giangregorio 2012; Lau et al. 2011; von Stengel, Kemmler, Engelke, et al. 2011; Wysocki et al. 2011). At this time, WBV should not replace usual treatments for osteoporosis; however, further research should examine the efficacy of using WBV as an adjunct therapy for osteoporosis, sarcopenia, and dynapenia.

Is kettlebell training a safe and effective method to enhance my client's muscular fitness?

In the United States, kettlebell exercise has emerged as a popular mode of exercise training with purported claims of improved muscular strength and endurance, as well as cardiorespiratory fitness and body composition. Recently, Otto and colleagues (2012) reported that 6 wk of **kettlebell training** significantly improves the muscular strength (1-RM back squat) and power (1-RM power clean) of healthy, young men; however, traditional resistance training (weightlifting) produces greater improvements in strength compared to kettlebell training. Likewise, Lake and Lauder (2012) noted that 6 wk of kettlebell training [12 min bouts; 30 sec exercise, 30 sec rest using 12 kg (BW < 70 kg) and 16 kg (BW > 70 kg) kettlebells] produces a 9.8% increase in maximum strength (1-RM half-squat) and a 19.8% increase in explosive strength (ht of vertical jump) in young men.

Due to the unique shape of kettlebells, the client needs to learn how to control and stabilize the weight of the kettlebell during exercise. Thus, some kettlebell exercises are well suited for functional training of strength and stability for carrying a suitcase or grocery bag (Liebenson 2011).

Given that kettlebell exercises involve a lot of swinging and bending movements, is kettlebell exercise contraindicated for clients with neck and low back pain?

Jay and colleagues (2011) investigated the efficacy of using kettlebell training to improve trunk extensor strength and to lessen low back and neck pain of adults engaging in occupations with a high prevalence of musculoskeletal pain symptoms. The training group performed full-body, ballistic kettlebell exercises, 3 days/wk for 8 wk. Compared to a control group, kettlebell training reduced pain in the neck and shoulders (–2.1 pt) and low back (–1.4 pt). The training group also showed a significant increase in trunk extensor strength. Recently, McGill and Marshall (2012) measured spinal compression and shear loads during kettlebell swings. This exercise creates a hip-hinge squat pattern with cycles of rapid muscle activation and relaxation for the low back extensors (50% MVC [maximum voluntary contraction]) and gluteal muscles (80% MVC) when using a 16 kg kettlebell. Unlike the anterior shear produced during traditional lower body weightlifting exercises, kettlebell swings create a posterior shear of the L4 vertebrae on the L5 vertebrae. This observation lends support to anecdotal reports that kettlebell exercise may be useful in restoring and improving low back health and function (McGill and Marshall 2012).

CLIENT CONCERNS

Is it OK to lift weights every day?

During weightlifting, you are exercising your muscles at greater than normal workloads, producing microscopic tears in the muscle cells and connective tissues. Your body responds by producing new muscle proteins, which causes muscle growth and increased strength. For these changes to occur, you need to rest the exercised muscles between workouts. Most people show substantial improvements in strength when they lift weights every other day, just two or three times a week. If you lift weights every day, you run the risk of overtraining your muscles. Overtraining may cause muscle strains, tendinitis, bursitis, and other muscle and joint injuries. Experienced weightlifters who work out every day split their exercise routine so that they do not exercise the same muscle groups on consecutive days. A split routine reduces the risk of excessive muscle soreness and overuse injuries if you lift weights every day.

Can I use calisthenic exercises like push-ups and pull-ups to improve my strength?

You can use calisthenic exercises to increase your strength. Exercise professionals often prescribe push-ups and pull-ups in addition to free-weight and machine exercises to strengthen the chest, arm, and back muscles. When you do calisthenics, your body weight provides the resistance. If you are unable to lift your body weight, you will need to modify the calisthenic exercise. For example, doing push-ups with your body weight supported by your knees and hands is easier than doing standard push-ups with your body fully extended and your weight supported by your hands and feet. As your strength improves, you may increase the difficulty of the push-up by placing your hands wider than shoulder-width apart.

If you are unable to lift your body weight, you can modify pull-ups by using a spotter. As you pull up, assist your movement by extending your knees as the spotter supports your lower legs or ankles. To increase the difficulty of a pull-up, place your hands wider than shoulder-width apart and use an overhand (pronated) grip instead of an underhand (supinated) grip.

I have followed my exercise prescription closely, but over the last several weeks I haven't seen any change in my strength. What should I do?

At the beginning of your program, your strength gains were dramatic and rapid because your initial strength level was less than it is now. As your muscles adapt to the training stimulus, you may reach a plateau, or a point where you can't seem to improve further. It may be helpful if you periodically alter the training stimulus more frequently (weekly or even daily) by changing your combination of intensity, repetitions, and sets (ask your personal trainer about a periodized program). For example, if you are presently doing high-intensity–low-repetition exercises during each workout, you may want to decrease your intensity (from 80% to 70% 1-RM) and increase your repetitions (from 6-8 to 10-12) for several days. Selecting different exercises for the muscle groups may also help.

Will I become muscle bound and lose flexibility if I lift weights?

It is a common misconception that resistance training decreases joint flexibility. Studies of elite bodybuilders and powerlifters indicate that these athletes have excellent flexibility. Also, one study showed that resistance training actually increased the flexibility of elderly women. The key to remaining flexible during resistance training is to perform each exercise throughout the entire range of motion. Also, statically stretching the muscle groups after each workout may help you maintain flexibility.

Will resistance training help me lose weight and fat?

Resistance training positively alters your body composition and preserves your lean body tissues. Although your body weight may not change, your lean body mass (muscle and bone) increases and your body fat decreases. Given that muscle tissue is more metabolically active (burns more calories) than fat tissue, the increase in muscle size and lean body mass helps maintain your resting metabolic rate when you are on a weight loss diet. Exercise science and nutrition professionals recommend using resistance training combined with aerobic exercise to maximize the loss of body fat and to maintain lean body tissues.

Will my strength improve if I train aerobically at the same time that I am resistance training?

If you concurrently participate in aerobic and resistance training, your muscle growth and strength improvement may be lessened because of the increased energy demands and protein requirements of endurance training. In a recent meta-analysis of studies addressing this question, Wilson, Marin, and associates (2012) reported that doing resistance training concurrently with running significantly lessens strength gains and hypertrophy. The frequency and duration of endurance training were negatively related to hypertrophy, strength, and power. Although this interference is an important consideration for competitive bodybuilders and power athletes, your decision to participate in both forms of training depends on your overall exercise program goal. If your goal is improved health or weight loss, experts recommend including both aerobic and resistance training in your program.

Are protein and amino acid supplements necessary to maximize muscle growth and strength during resistance training?

Although the protein needs of resistance-trained individuals (1.6–1.8 $g \cdot kg^{-1}$ each day) are higher than the recommended dietary allowance for inactive individuals (0.8 $g \cdot kg^{-1}$ each day), for most individuals, a well-balanced diet containing 12% to 25% protein will meet increased protein needs during resistance training. In 2009, Verdijk and colleagues studied the effects of timed protein supplementation immediately before and after exercise on muscle mass and strength gains of healthy, older men after 12 wk of resistance training. Results showed that in older men who regularly consume adequate amounts of dietary protein, timed protein supplementation does not further augment gains in muscle mass or strength produced by resistance training alone.

However, if your goal is to augment muscle hypertrophy and strength gains beyond those produced from resistance training alone, whole protein or amino acid supplementation, consumed close to the time you engage in resistance exercise, may dramatically enhance the acute anabolic response to the exercise (Hayes and Cribb 2008). Protein supplementation promotes muscle hypertrophy in the following ways:

- Supplementing protein close to the time of resistance exercise ensures a greater stimulation of anabolic activity in the muscles.
- Supplementing between meals may promote additional stimulation of protein synthesis and net gain in muscle protein.
- The acute anabolic response to meals diminishes with aging; however, strategic supplementation with proteins rich in essential amino acids, especially leucine, may help to restore the anabolic response to meals.

Amino acid supplementation is especially popular among strength-trained athletes. Studies show that ingesting amino acids or a protein-carbohydrate supplement (e.g., 6 g of essential amino acids and 35 g sucrose) immediately before and after exercise stimulates protein synthesis and maximizes the anabolic (protein building) response of skeletal muscle tissue to resistance training (Ratamess et al. 2003). Tipton and colleagues (2001) noted that ingesting an amino acid–carbohydrate supplement immediately before resistance exercise is more effective than ingesting the supplement immediately after exercise in terms of increasing the net protein balance in skeletal muscle. In a study of elderly men who resistance trained over 12 wk, it was noted that those who took a protein-carbohydrate supplement immediately after exercise (within 5 min) had greater gains in muscle hypertrophy, lean body mass, and muscular strength than those who ingested the supplement 2 hr after the training session (Esmarck et al. 2001). These studies show that the timing of amino acid supplementation is critical in optimizing muscle growth in response to resistance training.

What types of protein and amino supplements are most effective for augmenting muscle and strength development in response to resistance training?

The type of protein consumed may influence the anabolic response to resistance training. Whey protein supplements (i.e., >80% protein concentrates or >90% protein isolates) are widely used among athletes to increase muscle mass. Whey protein supplements are the richest source of branched-chain amino acids, particularly leucine, which is a regulator of muscle protein synthesis (Hayes and Cribb 2008). In a study comparing the effects of whey protein and casein supplements in athletic individuals engaging in a 10 wk resistance training program, the group taking whey protein isolates ($1.5\ g \cdot kg^{-1} \cdot day^{-1}$) had a fivefold better gain in fat-free mass and better gains in strength compared to the group taking an equivalent daily dose of casein supplements (Cribb et al. 2006). To enhance muscle hypertrophy and strength gains during resistance training, whey protein isolates should be consumed immediately before and after exercise (Hayes and Cribb 2008).

Will creatine supplements enhance strength and muscle size during resistance training?

According to the International Society for Sports Nutrition, creatine monohydrate is an effective ergogenic supplement for increasing lean body mass and high-intensity exercise capacity in athletes (Kreider et al. 2010). Over 300 studies have tested the effects of creatine supplementation on performance. Overall, the data suggest that creatine supplementation can improve the performance of high-intensity exercise lasting less than 30 sec (Branch 2003; Rawson and Clarkson 2003). Studies demonstrate that creatine supplementation combined with resistance training increases muscular strength, body mass, fat-free mass, muscle fiber size, and training volume in healthy young adults as well as in older women and men (Brose, Parise, and Tarnopolsky 2003; Cribb et al. 2007; Nissen and Sharp 2003). However, differences in skeletal muscle morphology may affect hypertrophy responses (i.e., changes in lean body mass, fiber-specific hypertrophy, and contractile protein content) to resistance training (Cribb et al. 2007). Creatine supplements increase muscle creatine, but there is much interindividual variability in the response (Rawson and Clarkson 2003). Theoretically, an increase in muscle creatine enhances training volume and decreases the amount of recovery time needed between sets and exercises. The increased training stimulus improves the physiological adaptation to resistance training for some individuals (i.e., they experience a greater gain in muscle mass and strength).

In addition, researchers have compared the separate and combined effects of creatine monohydrate (CrM) and whey protein supplementation on strength and muscle hypertrophy improvements with resistance training. After 10 or 11 wk of resistance training, both CrM and whey protein supplements resulted in significant improvements in strength compared to values in a control group. However, the addition of creatine monohydrate (0.1–0.3 $g \cdot kg^{-1} \cdot day^{-1}$) to the whey protein supplement (1.5 $g \cdot kg^{-1} \cdot day^{-1}$) produced much greater gains in body weight, lean body mass, and muscle hypertrophy than whey protein alone (Cribb, Williams, and Hayes 2007; Cribb et al. 2007). Thus, if the goal of the resistance training program is to maximize gains in muscle mass and body weight along with strength improvement, the addition of CrM to a whey protein supplement is recommended (Hayes and Cribb 2008).

Is it safe to take creatine supplements?

Although anecdotal reports associate creatine supplementation with muscle cramping, gastrointestinal distress, and soft tissue injuries (Poortmans and Francaux 2000), there is no compelling evidence that short-term or long-term use of creatine monohydrate adversely affects kidney, liver, or cardiovascular function or markers of health status such as muscle and liver enzymes, lipid profiles, and electrolytes of healthy adults (Kreider et al. 2003; 2010).

One reported side effect of creatine supplementation is increased stiffness in the musculotendinous unit, which theoretically predisposes individuals to muscle strains and tears. To address this concern, Watsford and colleagues (2003) studied changes in stiffness following 28 days of creatine supplementation and reported that creatine ingestion does not increase the stiffness of the series elastic components in the musculotendinous unit of the triceps surae (the gastrocnemius and soleus). These findings suggest that the muscle strains and tears reportedly associated with creatine supplementation are not caused by a change in the elasticity (stiffness) of the musculotendinous system. Also, when compared to a placebo group, subjects taking creatine supplements showed no differences in markers of exercise-induced muscle damage following eccentric exercise (Rawson, Gunn, and Clarkson 2001).

Do β-hydroxy-β-methylbutyrate (HMB) supplements increase lean body mass and muscle strength?

β-hydroxy-β-methylbutyrate (HMB) is a metabolite of the amino acid, leucine. HMB has a potent anticatabolic effect on skeletal muscle by inhibiting muscle protein breakdown and enhancing protein synthesis (Zanchi et al. 2011). HMB also reduces muscle damage associated with resistance training. In a meta-analysis of dietary supplements, Nissen and Sharp (2003) reported that HMB is one of only two supplements (the other being creatine) that significantly increases the lean body mass and muscular strength of individuals engaging in resistance training. Analysis of nine studies that used control groups to assess HMB supplementation (3 $g \cdot day^{-1}$) indicated that, on average, lean body mass and muscular strength increased 0.28% and 1.40% per week, respectively, for the treatment groups. The effect sizes for net gains in lean body mass (ES = 0.15) and strength (ES = 0.19) were significant. HMB supplementation during 3 to 8 wk of resistance training did not adversely affect hematology or liver and kidney function but positively affected cardiovascular risk factors (decreased total cholesterol, low-density lipoprotein cholesterol, and systolic blood pressure) (Nissen and Sharp 2003).

One study (Jowko, Ostaszewski, and Jank 2001) examined the effect of combining HMB with creatine supplementation on strength and lean body mass. Over a 3 wk strength training program, the group taking this combination of supplements showed greater gains in strength and lean body mass compared to those taking only creatine or only HMB. Using HMB in combination with creatine is promising for enhancing strength and lean body mass, especially in athletes and patients with catabolic diseases or disorders.

Although HMB supplementation (1.5–3 $g \cdot day^{-1}$) enhances training adaptations in untrained and older individuals, most studies report insignificant gains in muscle mass and strength of athletes using HMB supplements. Additional research is needed to determine the effects of HMB on training adaptations of athletes (Kreider et al. 2010).

EFFECTS OF RESISTANCE TRAINING PROGRAMS

Resistance training improves muscular fitness by increasing both strength and muscular endurance. This section addresses the morphological, neurological, and biochemical effects of resistance training.

MORPHOLOGICAL EFFECTS OF RESISTANCE TRAINING ON THE MUSCULOSKELETAL SYSTEM

Resistance training leads to morphological adaptations in skeletal muscles and bone. Structural changes in muscle fibers account for a large portion of the strength gains resulting from resistance training. Increases in bone mineral content and bone density improve bone health. The following questions deal with these adaptations.

What is exercise-induced muscle hypertrophy?

One effect of strength training is an increase in the size of the muscle tissue. This adaptation, known as **exercise-induced hypertrophy**, results from an increase in the total amount of contractile protein, the number and size of myofibrils per fiber, and the amount of connective tissue surrounding the muscle fibers (Goldberg et al. 1975). With heavy resistance training, fast (Type II) muscle fibers show a twofold greater increase in size than slow (Type I) fibers (Kosek et al. 2006). An increase in protein synthesis and myogenic satellite cell proliferation are two major processes leading to hypertrophy. Although these two processes are initiated immediately following your client's first bout of resistance training exercise, it typically takes 4 to 6 wk of intensive training to observe a measurable amount of hypertrophy in untrained adults (Seynnes, de Boer, and Narici 2007).

Is it possible to increase the number of muscle fibers by resistance training?

Heavy resistance training has been reported to produce an increase in the number of muscle fibers (i.e., hyperplasia) in animals due to longitudinal splitting and satellite cell proliferation (Antonio and Gonyea 1993; Edgerton 1970; Gonyea, Ericson, and Bonde-Petersen 1977). Such processes, however, have not been clearly demonstrated in human skeletal muscle tissue (Taylor and Wilkinson 1986; Tesch 1988). Although some data suggest that human skeletal muscle has the potential to increase muscle fiber number (Alway et al. 1989; Sjostrom et al. 1992), hyperplasia probably contributes less than 5% to overall muscle growth in response to heavy resistance training (Kraemer, Fleck, and Evans 1996). The major factor contributing to exercise-induced hypertrophy for humans, apparently, is an increase in the size of existing muscle fibers.

Does resistance training alter muscle fiber type from slow-twitch to fast-twitch?

One way that muscle fibers are classified is by identifying the myosin heavy chain isoforms present in individual muscle fibers. Three different isoforms of myosin heavy chain (MHC) proteins are MHC I, MHC IIA, and MHC IIX (formerly called Type IIB). Pure muscle fibers contain only one type of isoform. Hybrid muscle fibers contain a mix of MHC I and MHC IIA or MHC IIA and MHC IIX. MHC I fibers are the slowest contracting fibers and MHC IIX are the fastest contracting fibers; the contractile speed of hybrid fibers is somewhere between these two (Andersen and Aagaard 2010; Harridge 2007). Heavy resistance training decreases the expression of MHC IIX and simultaneously increases the expression of MHC IIA fibers, but MHC I fibers are relatively unaffected (Fry 2004; Andersen and Aagaard 2000). Thus, strength training appears to affect only the relative amount and size of MHC IIA and IIX fast fibers, with no change in the contractile characteristics of MHC I slow fibers (Andersen and Aagaard 2010).

Is the relationship between muscle size and strength the same for men and women?

Muscle strength is directly related to the cross-sectional area of the muscle tissue. Ikai and Fukunaga (1968) noted that the static strength per unit of cross-sectional area of the elbow flexors was similar for young men and women. These values ranged between 4.5 and 8.9 $kg \cdot cm^2$; average values were 6.2 and 6.7 $kg \cdot cm^2$ for women and men, respectively. Cureton and colleagues (1988) also reported that the dynamic strength per unit of cross-sectional area (CSA) was similar for men and women. Posttraining ratios of elbow flexor or extensor strength to upper arm CSA were 1.65 $kg \cdot cm^2$ and 1.85 $kg \cdot cm^2$, respectively, for men and women. Likewise, the posttraining ratios for leg strength to thigh CSA were 1.10 $kg \cdot cm^2$ for men and 0.90 $kg \cdot cm^2$ for women.

Is there a limit to the degree of hypertrophy in response to resistance training?

A ceiling or plateau effect appears to exist in the degree of hypertrophy attainable. As mentioned previously, the two major processes responsible for muscle hypertrophy are protein synthesis and satellite cell proliferation. This ceiling effect may be related to the client's ability to activate the pool of satellite cells and to add new nuclei to the muscle cells. The amount of cellular hypertrophy for moderate and extreme responders following a 16 wk resistance training program typically ranges between 25% to 75% of the cross-sectional area of the muscle tissue (Petrella et al. 2008). In light of the amount of interindividual variation in the degree of hypertrophy in response to resistance training, it is important to closely examine the client's training background and to modify the resistance training exercise prescription accordingly (Andersen and Aagaard 2010).

How much do women's muscles hypertrophy in response to resistance training?

In the past, it was believed that resistance training produced less muscle hypertrophy in women than in men even though their relative strength gains were similar, but muscle hypertrophy was assessed indirectly using anthropometric and body composition measures. Cureton and colleagues (1988), however, using computerized tomography to directly assess muscle hypertrophy in a heavy resistance training program (70–90% 1-RM, 3 days/wk for 16 wk), found significant increases in CSA of the upper arms of women (5 cm^2 or 23%) as well as men (7 cm^2 or 15%). Although absolute change in muscle volume was greater in men, the relative degree of hypertrophy (% change) was similar for men and women (Cureton et al. 1988). Research confirms this observation. Walts and colleagues (2008) reported that 10 wk of strength training resulted in similar relative gains in muscle volume of the knee extensors of Caucasian and African-American men (9%) and women (7.5%).

Today experts agree that the relative increases in fiber size are similar for women and men when the training stimulus is the same (Deschenes and Kraemer 2002). In addition, periodized resistance training is particularly effective for increasing muscle size in women. Kraemer and colleagues (2004) compared the effects of total and upper body periodized training programs on muscle hypertrophy in young women. Over 6 mo of training, the total body periodized program produced greater and more consistent gains in overall (upper and lower body) muscle size compared to upper body periodized training. An intensity range of 3-RM to 8-RM produced greater muscle hypertrophy than did a range of 8-RM to 12-RM.

Is it possible for older adults to increase the size of their muscles by resistance training?

Electromyographic evidence led Moritani and deVries (1979) to conclude that increased strength in older men who engaged in resistance training was highly dependent on neural changes, such as increased frequency of motor neuron discharge and recruitment of motor units. Because of studies such as this, it was long believed that strength gains from resistance training in older individuals were due primarily to neural adaptation rather than muscle hypertrophy.

However, Frontera and colleagues (1988) reported that resistance training produces muscle hypertrophy in men ages 60 to 72 yr. The men trained in a high-intensity program for the knee extensors and flexors (3 sets at 80% 1-RM) for 12 wk. Computerized tomography revealed significant increases in total thigh area (4.8%), total muscle area (11.4%), and quadriceps area (9.3%). The relative increase in total muscle area was similar to values reported for young men (Luthi et al. 1986). Research also shows significant increases in muscle size in older women, as well as in very old (87–96 yr) men and women, due to high-intensity (80% 1-RM) resistance training (Charette et al. 1991; Fiatarone et al. 1991).

Exercise-induced hypertrophy appears to be an important mechanism underlying strength gains in older women and men. This implies that older adults can effectively counter age-related loss in muscle mass by participating in a vigorous resistance training program.

Recently, Raue and colleagues (2012) identified and compared gene sets responsible for eliciting a growth response to resistance training in young (24 yr) and old (84 yr) adults. Approximately 660 genes are affected by resistance training during the 1st and 36th training sessions. These genes are termed the **transcriptome signature of resistance exercise** (Raue et al. 2012) and are correlated with gains in muscle size and strength. The number of genes responding to acute resistance exercise in untrained and trained muscles decreased in young adults but stayed fairly constant in old adults, thereby suggesting a lack of training response in older adults. The skeletal muscle of young adults was more responsive to resistance exercise at the gene level compared to that of older adults. After 12 wk of resistance training, however, a greater number of genes changed expression in old vs. young adults. This finding indicated that some cell types in old muscle are capable of adapting to resistance training. The resistance exercise gene response was more pronounced in MHC IIA fibers than in MHC I fibers. This study provides insight into understanding the molecular basis for increases in muscle size in response to resistance exercise (hypertrophy), as well as decreases in muscle size (atrophy) due to aging and lack of physical exercise.

Does resistance training improve bone health and joint integrity?

Resistance training has beneficial effects on bone health that may decrease the risk of osteoporosis and bone fractures, particularly in women. This form of training may help to achieve the highest possible peak bone mass in premenopausal women and may aid in maintaining and increasing bone in postmenopausal women and older adults (Layne and Nelson 1999). Bone mineral density of the lumbar spine and femur in premenopausal women significantly increased after 12 to 18 mo of strength training (Lohman et al. 1995). Also, lumbar bone mineral density of early-postmenopausal women was improved following 9 mo of strength training (Pruitt et al. 1992). In a long-term study of postmenopausal women (45–65 yr), the muscle strength and bone mineral density improved significantly (25–75%) after 1 yr of resistance training (2 sets; 6- to 8-RM; 70–80% 1-RM; 2 days/wk). Women who lifted weights consistently for over 4 yr had significant changes in bone mineral density at the femur and lumbar spine sites. The researchers concluded that women who maintained bone density lifted weights two or more times per week (Metcalfe 2010). Evidence suggests that resistance training and higher-intensity weight-bearing activities (not walking) may slow the decline in bone loss even if there is no significant increase in bone mineral density. Improvements in bone mineral density appear to be site specific; the greater changes occur in bones to which the exercising muscles attach. Experts agree that resistance training has a more potent effect on bone health than do weight-bearing aerobic exercises such as walking and jogging (Layne and Nelson 1999).

Resistance training also improves the size and strength of ligaments and tendons (Edgerton 1973; Fleck and Falkel 1986; Tipton et al. 1975). These changes may increase joint stability, thereby reducing the risk of sprains and dislocations.

SUMMARY OF EFFECTS OF RESISTANCE TRAINING

Morphological Factors

- Muscle hypertrophy due to increase in contractile proteins, number and size of myofibrils, connective tissues, and size of MHC II muscle fibers
- No change in relative amounts of MHC I and MHC II muscle fibers
- Conversion of MHC IIX to MHC IIA fast fibers
- Little or no change in the number of muscle fibers (<5%)
- Increase in size and strength of ligaments and tendons
- Increase in bone density and bone strength
- Increase in muscle capillary density

Neural Factors

- Increase in motor unit activation and recruitment
- Increase in discharge frequency of motor neurons
- Decrease in neural inhibition
- Increase in corticospinal excitability

Biochemical Factors

- Minor increase in ATP and CP stores
- Minor increase in creatine phosphokinase (CPK), myosin adenosine triphosphatase (ATPase), and myokinase activity
- Decrease in mitochondrial volume density
- Increase in testosterone, growth hormone, insulin-like growth factor (IGF-I), and catecholamines during resistance training exercises
- Enhanced fat oxidation and fat availability during submaximal cycle ergometer exercise following resistance exercise

Additional Factors

- Little or no change in body mass
- Increase in fat-free mass
- Decrease in fat mass and relative body fat
- Improved bone health increases with exercise intensity
- Changes in the transcriptome signature of genes

BIOCHEMICAL EFFECTS OF RESISTANCE TRAINING

The morphological changes in skeletal muscles due to resistance training are caused by hormones. This section addresses questions regarding hormonal responses to resistance exercise, as well as changes in the metabolic profile of skeletal muscles.

What causes the increase in muscle size with resistance training?

Exercise-induced hypertrophy occurs through hormonal mechanisms. Anabolic (protein building) hormones such as testosterone, growth hormone, and insulin-like growth hormone increase in response to heavy resistance exercise and interact to promote protein synthesis. The magnitude of testosterone and growth hormone release, however, appears to be related to the size of the muscle groups used, the exercise intensity (%1-RM), and the length of rest between sets, with larger increases observed for high-intensity (5- to 10-RM) exercise and short (1 min) rest periods involving large muscle groups (Kraemer et al. 1991). In men, high-intensity resistance training produces significant increases in testosterone and growth hormone, but testosterone appears to be the principal muscle-building hormone (Deschenes and Kraemer 2002). Levels of catecholamines (norepinephrine, epinephrine, and dopamine), which augment the release of testosterone and insulin-like growth factor, also increase in men in response to heavy resistance exercise (Kraemer et al. 1987). In women, growth hormone is likely the most potent muscle-building hormone (Deschenes and Kraemer 2002).

Does resistance training alter the metabolic profile of skeletal muscles?

Although high-intensity resistance training results in substantial increases in muscle proteins, it appears to have little or no effect on muscle substrate stores and enzymes involved with the generation of adenosine triphosphate (ATP). Although stores of ATP and creatine phosphate (CP) may increase significantly in response to strength training (MacDougall et al. 1979), the changes are not large enough to have practical significance. Strength training produces only minor alterations in myosin adenosine triphosphatase (ATPase) activity (Tesch 1992) and other ATP turnover enzymes, such as creatine phosphokinase (CPK), in response to strength training (Costill et al. 1979; Komi et al. 1978; Thorstensson et al. 1976). Strength training using heavy resistance and explosive exercises results in decreased activities for hexokinase, myofibrillar ATPase, and citrate synthase (Tesch 1988).

Does resistance training decrease aerobic capacity and endurance performance?

The mitochondrial volume density following heavy resistance training has been reported to decrease as a consequence of a disproportionate increase of contractile protein in comparison with mitochondria. In theory, this could be detrimental to aerobic capacity and endurance performance. A review of studies of this phenomenon, however, concluded that participation in heavy resistance training does not negatively affect aerobic power (Dudley and Fleck 1987; Sale et al. 1987). Also, capillary density has been shown to increase, which in turn enhances the potential to remove lactate produced by the muscles during moderate-intensity, high-volume resistance exercise (Kraemer et al. 1996).

In fact, Goto and colleagues (2007) reported that resistance exercise performed 20 min before a submaximal (50% $\dot{V}O_2max$) exercise bout significantly improved fat availability and fat oxidation during a 60 min aerobic exercise bout on a cycle ergometer. Resistance exercise also increased norepinephrine, growth hormone, glycerol concentrations, and blood lactate levels prior to the aerobic exercise bout.

However, Nader (2006) concluded that endurance training may potentially interfere with strength improvements due to resistance training when individuals engage in both forms of training concurrently. The interference may be caused by changes in protein synthesis induced by endurance exercise or by too-frequent training sessions. Endurance exercise activates adenosine monophosphate kinase (AMPK), which in turn may inhibit muscle protein synthesis. Nader presents a working model of how molecular mechanisms may inhibit strength gains with concurrent strength and endurance training.

NEUROLOGICAL EFFECTS OF RESISTANCE TRAINING

In addition to muscle hypertrophy, neural adaptations significantly contribute to strength gains, especially during the initial stages of resistance training. This section addresses questions regarding neural adaptations to short- and long-term resistance training.

What changes in neural function occur in response to resistance training?

The nervous system responds to resistance training by increasing the activation and recruitment of motor units (the alpha motor neuron and all of the muscle fibers it innervates) and by decreasing the cocontraction of antagonistic muscle groups (Sale 1988). Recruiting additional motor units as well as increasing the frequency of firing results in greater muscular force production. Some evidence suggests that the central drive from higher neural centers (e.g., motor cortex of brain) changes and that the amounts of neurotransmitters and postsynaptic receptors at the neuromuscular junction increase (Deschenes and Kraemer 2002). These changes facilitate the activation and recruitment of additional motor units, thereby increasing force production.

Recently, **transcranial magnetic stimulation (TMS)** has been used to assess the strength of neural signals between the motor cortex and skeletal muscles (Kidgell and Pearce 2011). With this technique, adaptations in the central nervous system in response to strength training can be studied. In one study using TMS, strength improved after 4 wk of isometric strength training because of decreased cortical inhibition, thereby improving the corticospinal drive to the motor unit pool (Carroll et al. 2009). Kidgell and colleagues (2010) reported that strength gains (28% in trained arm and 19% in untrained contralateral arm) in response to resistance training (4 sets; 6-8 repetitions at 80% 1-RM) are related to increased corticospinal excitability (53% and 33% increase, respectively, in trained and untrained arms). Findings from TMS studies suggest that neural adaptations in response to strength training occur at the cortical, spinal, and motor unit levels. Manipulation of the load, timing of repetitions, and precision of movement (ballistic vs. controlled) modulate central nervous system adaptations (Kidgell and Pearce 2011).

At what stage during resistance training does neural adaptation occur?

In the past, it was believed that neural adaptations are primarily responsible for strength gains only during the initial stage (first 2–8 wk) of resistance training. At about 8 to 10 wk of resistance training, muscle hypertrophy contributes more than neural adaptation to strength gains, but hypertrophy eventually levels off (Sale 1988). Evidence suggests that muscle hypertrophy is finite and may be limited to no more than 12 mo (Deschenes and Kraemer 2002). Given that long-term resistance training (>6 mo) continues to increase strength without hypertrophy, experts now believe that a secondary phase of neural adaptation is most likely responsible for strength gains occurring between 6 and 12 mo of training (Deschenes and Kraemer 2002).

What role do neural factors play in age-related loss of muscle strength?

Over the past decade, the term *sarcopenia*, or an age-related loss in muscle mass, has also been used to define age-related loss in muscle strength. This implies that changes in muscle mass are fully responsible for changes in strength. According to Clark and Manini (2008), longitudinal studies indicate that age-related changes in muscle mass account for less than 5% of the change in strength with aging. Changes in muscle mass and strength do not follow the same time course, suggesting that neural factors, along with changes in muscle factors (e.g., muscle architecture, fiber type transformations, and electrocontractile coupling), may modulate age-related loss of strength. They recommend using the term *dynapenia* to refer to age-related loss in strength. Although it is difficult to identify specific neural mechanisms associated with dynapenia, changes in supraspinal drive, coactivation of antagonist muscles, muscle synergism, and maximal spinal cord output may mediate strength loss with aging (Clark and Manini 2008).

MUSCULAR SORENESS

Muscular soreness may develop as a result of resistance training because isolated muscle groups are being overloaded beyond normal use. **Acute-onset muscle soreness** occurs during or immediately following the exercise and is usually caused by ischemia and the accumulation of metabolic waste products in the muscle tissue. The pain and discomfort may persist up to 1 hr after the cessation of the exercise.

In **delayed-onset muscle soreness (DOMS)**, the pain occurs 24 to 48 hr after exercise. Although the causes of DOMS are not known (Armstrong 1984; Smith 1991), it appears to be related to the type of muscle contraction. Eccentric exercise produces a greater degree of delayed muscular soreness than either concentric or isometric exercise (Byrnes, Clarkson, and Katch 1985; Schwane et al. 1983; Talag 1973). Little or no muscular soreness occurs with isokinetic exercise (Byrnes, Clarkson, and Katch 1985). This most likely reflects the fact that isokinetic exercise devices offer no resistance to the recovery phase of the movement and therefore the muscle does not contract eccentrically.

THEORIES OF DELAYED-ONSET MUSCLE SORENESS

Although the precise causes of DOMS remain unclear, several theories have been proposed. The more widely recognized theories suggest that exercise, particularly eccentric exercise, causes damage to skeletal muscle cells and connective tissues, producing an acute inflammation.

Connective Tissue Damage

Abraham (1977) extensively studied the factors related to DOMS produced by resistance training. He suggested that DOMS most likely results from disruption in the connective tissue of the muscle and its tendinous attachments. Abraham noted that urinary excretion of hydroxyproline, a specific by-product of connective tissue breakdown, was higher in subjects who experienced muscular soreness than in those who did not. Because a significant rise in urinary hydroxyproline levels indicates an increase in both collagen degradation and synthesis, he concluded that more strenuous exercise damages the connective tissue, which increases the degradation of collagen and creates an imbalance in collagen metabolism. To compensate for this imbalance, the rate of collagen synthesis increases.

Skeletal Muscle Damage

Researchers have assessed skeletal muscle damage induced through exercise. **Exercise-induced muscle damage (EIMD)** may occur when individuals engage in novel exercise, eccentric exercise, or exercise to which they are unaccustomed. The muscle damage results in decreased force production and increased passive tension, as well as increased muscle soreness, swelling, and intramuscular proteins in the blood (Howatson and van Someren 2008). Much of the research on EIMD has focused on the effects of eccentric exercise on muscle damage and soreness. Regardless of the speed or intensity of contraction, eccentric exercise injures both the contractile and cytoskeletal components of myofibrils as well as the excitation coupling system; this is especially true for novel exercise (Howatson and van Someren 2008). Friden, Sjostrom, and Ekblom (1983) observed structural damage to myofibrillar Z bands resulting from eccentric exercise. Proske and Morgan (2001) pointed out that disruption of the sarcomere organization within the skeletal muscle is most likely the cause of the decreased active tension and force production that follows a series of intense eccentric contractions. Mackey and colleagues (2008) reported that electrically stimulated isometric contractions may also produce muscle damage at the sarcomere level. Z-line disruption and microphage infiltration provided direct evidence of damage to myofibers and sarcomeres. More research is needed to assess the effects of various types of muscle contraction, as well as high- and low-impact eccentric exercise (e.g., downhill running and eccentric cycle exercise), on muscle damage (Friden 2002).

Researchers have also examined markers of muscle damage such as serum CPK, lactate dehydrogenase, and myoglobin. Schwane and colleagues (1983) noted a significant increase in plasma CPK levels produced by downhill running. They suggested that the mechanical stress from eccentric exercise causes cellular damage, resulting in an enzyme efflux. Clarkson and colleagues (1986) reported similar increases in serum CPK levels following concentric (37.6%), eccentric (35.8%), and isometric (34%) arm curl exercises. They concluded that muscle damage occurred with all three types of contraction; however, the subjects perceived greater muscle soreness with eccentric and isometric exercises. Likewise, Byrnes and colleagues (1985) observed that both concentric and eccentric resistance training elevated serum CPK levels, but that individuals who trained concentrically did not develop DOMS.

Armstrong's Model of Delayed-Onset Muscle Soreness

On the basis of an extensive literature review, Armstrong (1984) proposed the following model of the development of DOMS:

1. The structural proteins in muscle cells and connective tissue are disrupted by high mechanical forces produced during exercise, especially eccentric exercise.
2. Structural damage to the sarcolemma alters the permeability of the cell membrane, allowing a net influx of calcium from the interstitial space. Abnormally high levels of calcium inhibit cellular respiration, thereby lessening the cell's ability to produce ATP for active removal of calcium from the cell.
3. High calcium levels within the cell activate a calcium-dependent proteolytic enzyme that degrades Z discs, troponin, and tropomyosin.
4. This progressive destruction of the sarcolemma (postexercise) allows intracellular components to diffuse into the interstitial space and plasma. These substances attract monocytes and activate mast cells and histocytes in the injured area.
5. Histamine, kinins, and potassium accumulate in the interstitial space because of the active phagocytosis and cellular necrosis. These substances, as well as increased tissue edema and temperature, may stimulate pain receptors, resulting in the sensation of DOMS.

Acute Inflammation Theory

Smith (1991) suggested that acute inflammation, in response to muscle cell and connective damage caused by eccentric exercise, is the primary mechanism underlying DOMS. Many of the signs and symptoms of acute inflammation, such as pain, swelling, and loss of function, are also present with

DOMS. On the basis of research about acute inflammation and DOMS, Smith proposed the following sequence of events:

1. Connective tissue and muscle tissue disruption occurs during eccentric exercise, especially when the individual is not accustomed to eccentric exercise.
2. Within a few hours, neutrophils in the blood are elevated and migrate to the site of injury for several hours post injury.
3. Monocytes also migrate to the injured tissues for 6 to 12 hr post injury.
4. Macrophages synthesize prostaglandins (series E).
5. The prostaglandins sensitize type III and IV pain afferents, resulting in the sensation of pain in response to intramuscular pressure caused by movement or palpation.
6. The combination of increased pressure and hypersensitization produces the sensation of DOMS.

In summary, it appears that there is no single mechanism or theory to explain DOMS. In a recent review article, Lewis, Ruby, and Bush-Joseph (2012) concluded that the culmination of six different mechanisms underlie muscle soreness. DOMS starts with microtrauma to the muscles and connective tissues. This trauma is followed by inflammation and shifts of fluids and electrolytes, causing the pain and discomfort associated with DOMS.

PREVENTION OF EXERCISE-INDUCED MUSCLE DAMAGE AND MUSCULAR SORENESS

Given that eccentric muscle contraction is an integral part of human locomotion, physical activities, and sport, researchers have explored myriad intervention strategies to lessen the negative effects of eccentric muscle actions and to treat EIMD. These approaches include nutrition (e.g., antioxidants, carbohydrate-protein supplements, and β-hydroxy-β-methylbutyrate) and pharmacological strategies (e.g., aspirin, ibuprofen, and naproxen); manual (e.g., massage and cryotherapy), neuromuscular (e.g., transcutaneous electrical nerve stimulation [TENS] and ultrasound) and whole-body vibration therapies; and exercise (e.g., prior bouts of eccentric exercise and stretching). Some evidence suggests that cold water immersion (cryotherapy) may reduce DOMS after exercise (Bleakley et al. 2012). Likewise, whole-body vibration therapy prior to eccentric exercise reduces muscle inflammation, strength loss, and DOMS symptoms (Aminian-Far et al. 2011; Broadbent et al. 2010). Additionally, a single bout of low-volume, high-intensity eccentric exercise has been consistently shown to have a positive effect on reducing EIMD. Howatson and van Someren (2008) provide an excellent review of research dealing with the prevention and treatment of EIMD.

For many years, slow static stretching exercises were recommended to warm up major muscle groups at the start of the resistance training workout. It was believed that this form of stretching prevented muscle injury and soreness (deVries 1961). However, evidence suggests that stretching prior to physical activity does not prevent injury (Pope et al. 2000). Also, stretching before, after, or before and after exercise does not produce clinically significant reductions in delayed-onset muscle soreness (Henschke and Lin 2011; Herbert and de Noronha 2007; Herbert, de Noronha, and Kamper 2011). In fact, stretching prior to resistance exercise may actually decrease strength and force production (Rubini, Costa, and Gomes 2007). Therefore, stretching immediately prior to resistance exercise is not recommended. Instead of performing static stretching, your client should warm up by completing 5 to 10 repetitions of the exercise at a low intensity (e.g., 40% 1-RM). Law and Herbert (2007) reported that low-intensity exercise (i.e., warm-up) prior to unaccustomed eccentric exercise (e.g., walking backward downhill on an inclined treadmill for 30 min) reduced muscle soreness up to 48 hr after exercise. In contrast, neither low-intensity, cool-down exercise nor stretching after exercise reduces muscle soreness (Herbert and de Noronha 2007; Herbert et al. 2011; Law and Herbert 2007).

Using a gradual progression of exercise intensity at the beginning of a resistance training program also may help to prevent muscular soreness. Some experts suggest using 12- to 15-RM during the beginning phases of strength training. Make sure that your clients gradually increase exercise intensity throughout the resistance training program. Avoiding eccentric contractions during dynamic resistance training also may lessen the chance of muscular soreness. An assistant or exercise partner should return the weight to the starting position.

Key Points

- The specificity principle states that muscular fitness development is specific to the muscle group, type of contraction, training intensity, speed, and range of movement.
- The overload principle states that the muscle group must be exercised at greater than normal workloads to promote muscular strength and endurance development.
- For nonperiodized resistance training programs, the training volume must be progressively increased to overload the muscle groups for continued gains in strength and muscular endurance.
- In most programs, resistance training exercises should be ordered so that successive exercises do not involve the same muscle group. For advanced programs, however, exercises for the same muscle group should be done consecutively.
- Dynamic resistance training can be used to develop muscular strength, power, size, or endurance by modifying the intensity, repetitions, sets, and frequency of the exercise.
- Periodization programs can result in greater changes in strength than nonperiodized resistance training programs.
- Strength and endurance gains resulting from resistance training are due to morphological, neurological, and biochemical changes in the muscle tissue.
- Eccentric exercise produces a greater degree of DOMS than either concentric, isometric, or isokinetic exercise.
- Little or no muscular soreness is produced by isokinetic training.
- The precise cause of DOMS is unknown; however, connective tissue and muscle damage, as well as acute inflammation, have been proposed as possible causes.

Key Terms

Learn the definition of each of the following key terms. Definitions of terms can be found in the glossary.

acute-onset muscle soreness
β-hydroxy-β-methylbutyrate (HMB)
compound sets
core stability
core strengthening
delayed-onset muscle soreness (DOMS)
dynapenia
exercise-induced hypertrophy
exercise-induced muscle damage (EIMD)
functional training
high intensity–low repetitions
kettlebell training
linear periodization (LP)
low intensity–high repetitions
macrocycle
mesocycle
microcycle
muscle balance
periodization
pyramiding
repetition maximum (RM)
repetitions
reverse linear periodization (RLP)
sarcopenia

set
split routine
supersetting
tonic vibration reflex
training volume
transcranial magnetic stimulation (TMS)
transcriptome signature of resistance exercise
tri-sets
undulating periodization (UP)
whole-body vibration (WBV)

Review Questions

In addition to being able to define each of the key terms, test your knowledge and understanding of the material by answering the following review questions.

1. What are the health benefits of resistance training?
2. Name three general types of resistance training. Which one is best suited for physical therapy rehabilitation programs?
3. What is the major advantage of isokinetic training compared to traditional forms of resistance training?
4. Describe the ACSM guidelines for designing resistance training programs for healthy adults. What modifications are necessary when you are planning resistance training programs for children and older adults?
5. Describe how the basic exercise prescriptions for strength training and muscular endurance training programs differ.
6. Describe how you can increase training volume for advanced strength training and hypertrophy programs.
7. Describe two methods of varying sets for advanced strength training programs.
8. Explain two methods that an advanced weightlifter can use to completely fatigue a targeted muscle group.
9. Describe three periodization models. How do they differ?
10. Explain how the specificity, overload, and progression principles are applied in the design of resistance training programs.
11. Explain what causes the exercise-induced hypertrophy resulting from resistance training. In the time course of a resistance training program, when is this morphological adaptation most likely to occur?
12. Define sarcopenia and dynapenia. Identify muscle morphological and neurological mechanisms responsible for dynapenia.
13. What neural adaptations account for initial strength gains during resistance training? When are these changes most likely to be observed during the time course of resistance training?
14. Describe the potential effects of resistance training on bone health.
15. Describe one theory of DOMS. What can you instruct your clients to do to help prevent and relieve muscle soreness caused by resistance training?
16. What will you tell your clients if they ask about supplementing their resistance training with creatine?

APPENDIX C

Muscular Fitness Exercises and Norms

Appendix C.1 describes standardized testing protocols for 11 muscle groups using digital, handheld dynamometry.

Appendix C.2 includes norms for isokinetic (Omni-Tron) muscular fitness tests. Average strength, endurance, and power values are presented for young adults, older adults, and resistance-trained individuals.

Appendix C.3 provides age-gender squat and bench press norms for untrained to elite lifters.

Appendix C.4 describes and illustrates some sample basic isometric exercises for a variety of muscle groups.

Appendix C.5 provides an extensive list of dynamic resistance training exercises. Exercises for the upper and lower extremities are organized by body region (e.g., chest, upper arm, thigh). For each exercise, equipment, body positions, joint actions, prime movers, and exercise variations are presented.

Appendix C.1: Standardized Testing Protocols for Digital, Handheld Dynamometry

Muscle group	Position	Limb/joint position	Dynamometer placement
1. Elbow flexors	Supine	Shoulder 30° abducted, elbow 90° flexed, forearm supinated	Proximal to wrist on flexor surface of forearm
2. Elbow extensors	Supine	Same as for elbow flexors	Proximal to wrist on extensor surface of forearm
3. Shoulder extensors	Supine	Shoulder 90° anteflexed, elbow extended	Proximal to elbow on extensor surface of arm
4. Shoulder abductors	Supine	Shoulder 45° abducted, elbow extended	Proximal to lateral epicondyle of humerus
5. Wrist extensors	Sitting	Elbow 90° flexed, forearm supported and pronated, wrist in neutral position, finger flexed	Proximal to 3rd metacarpal head
6. Hip flexors	Supine	Hip 90° flexed, knee relaxed, ankle supported by tester	Proximal to knee on anterior surface of thigh
7. Hip extensors	Supine	Hip 90° flexed, knee relaxed	Proximal to knee on posterior surface of thigh
8. Hip abductors	Supine	Hips 45° flexed, knees 90° flexed, contralateral knee supported by chest of tester	Lateral epicondyle of knee
9. Knee flexors	Sitting	Knee 90° flexed	Proximal to ankle on posterior surface of leg
10. Knee extensors	Sitting	Knee 90° flexed	Proximal to ankle on anterior surface of leg
11. Ankle dorsiflexors	Sitting	Knee 90° flexed, foot in neutral position	Proximal to metatarsophalangeal joints on dorsal surface of foot

Data from van den Beld et al. 2006.

Appendix C.2: Average Strength, Endurance, and Power Values for Isokinetic (Omni-Tron) Tests

Strength[a]	Young adult[b]	Older adult[c]	Weight trained[d]
Females			
Chest press	88.1	76.7	131.8
Lateral row	82.6	77.4	111.4
Shoulder press	32.9	30.4	60.1
Lateral pull-down	70.8	66.3	101.2
Knee extension	67.7	59.3	82.7
Knee flexion	51.5	43.3	64.3
Males			
Chest press	173.8	154.9	218.6
Lateral row	153.5	143.2	178.6
Shoulder press	69.2	62.4	102.6
Lateral pull-down	134.8	115.3	176.0
Knee extension	110.9	95.5	127.2
Knee flexion	75.9	67.3	89.9

[a]Values of strength measured in foot-pounds at dial setting 10.
[b]Average age for females = 15.1 ± 2.6 years; for males = 15.8 ± 2.7 years.
[c]Average age for females = 38.2 ± 9.7 years; for males = 37.6 ± 9.6 years.
[d]Average age for females = 21.2 ± 2.0 years; for males = 20.6 ± 2.1 years.
Data courtesy of Hydra-Fitness, Belton, TX, 1988.

Endurance[a]	Young adult[b]	Older adult[c]	Weight trained[d]
Females			
Chest press	64.3	53.4	125.7
Lateral row	102.4	85.7	143.7
Shoulder press	28.1	25.1	56.3
Lateral pull-down	109.1	91.5	216.3
Knee extension	88.7	86.6	111.6
Knee flexion	114.3	89.2	148.2
Males			
Chest press	211.8	167.3	321.1
Lateral row	266.9	221.2	312.5
Shoulder press	112.4	94.2	170.9
Lateral pull-down	352.2	296.3	501.5
Knee extension	72.9	80.8	98.9
Knee flexion	83.5	84.2	130.9

[a]Values of endurance measured in foot-pounds at dial setting 3.
[b]Average age for females = 15.1 ± 2.6 years; for males = 15.8 ± 2.7 years.
[c]Average age for females = 38.2 ± 9.7 years; for males = 37.6 ± 9.6 years.
[d]Average age for females = 21.2 ± 2.0 years; for males = 20.6 ± 2.1 years.
Data courtesy of Hydra-Fitness, Belton, TX, 1988.

(continued)

Appendix C.2 (*continued*)

Power[a]	Young adult[b]	Older adult[c]	Weight trained[d]
Females			
Chest press	86.3	73.7	163.0
Lateral row	121.3	113.6	156.3
Shoulder press	39.5	32.9	81.9
Lateral pull-down	165.4	128.4	254.1
Knee extension	101.9	73.4	122.5
Knee flexion	103.5	74.6	142.1
Males			
Chest press	264.9	228.4	392.3
Lateral row	302.4	268.4	345.0
Shoulder press	130.7	122.0	224.5
Lateral pull-down	430.9	354.7	550.9
Knee extension	198.4	159.4	233.5
Knee flexion	182.0	155.5	259.5

[a]Values of power measured in foot-pounds at dial setting 6.
[b]Average age for females = 15.1 ± 2.6 years; for males = 15.8 ± 2.7 years.
[c]Average age for females = 38.2 ± 9.7 years; for males = 37.6 ± 9.6 years.
[d]Average age for females = 21.2 ± 2.0 years; for males = 20.6 ± 2.1 years.
Data courtesy of Hydra-Fitness, Belton, TX, 1988.

Appendix C.3: 1-RM Squat and Bench Press Norms for Adults

1-RM Squat Test Norms for Adult Men[a]

Body weight	Untrained	Novice	Intermediate	Advanced	Elite
114	80	145	175	240	320
123	85	155	190	260	345
132	90	170	205	280	370
148	100	190	230	315	410
165	110	205	250	340	445
181	120	220	270	370	480
198	125	230	285	390	505
220	130	245	300	410	530
242	135	255	310	425	550
275	140	260	320	435	570
319	145	270	325	445	580
320+	150	275	330	455	595

[a] Measured in lb.

In order for these standards to apply, squat must be performed with thighs traveling below parallel to floor.

1-RM Squat Test Norms for Adult Women[a]

Body weight	Untrained	Novice	Intermediate	Advanced	Elite
97	45	85	100	130	165
105	50	90	105	140	175
114	55	100	115	150	190
123	55	105	120	160	200
132	60	110	130	170	210
148	65	120	140	185	230
165	70	130	150	200	255
181	75	140	165	215	270
198	80	150	175	230	290
199+	85	160	185	240	305

[a] Measured in lb.

In order for these standards to apply, squat must be performed with thighs traveling below parallel to floor.

Courtesy of Lon Kilgore, University of the West of Scotland.

(continued)

Appendix C.3 (*continued*)

1-RM Bench Press Norms for Adult Men[a]

Body weight	Untrained	Novice	Intermediate	Advanced	Elite
114	85	110	130	180	220
123	90	115	140	195	240
132	100	125	155	210	260
148	110	140	170	235	290
165	120	150	185	255	320
181	130	165	200	275	345
198	135	175	215	290	360
220	140	185	225	305	380
242	145	190	230	315	395
275	150	195	240	325	405
319	155	200	245	335	415
320+	160	205	250	340	425

[a] Measured in lb.

In order for these standards to apply, the bar must make contact with the chest above the bottom of the sternum with a momentary pause and be pressed to full elbow extension.

1-RM Bench Press Norms for Adult Women[a]

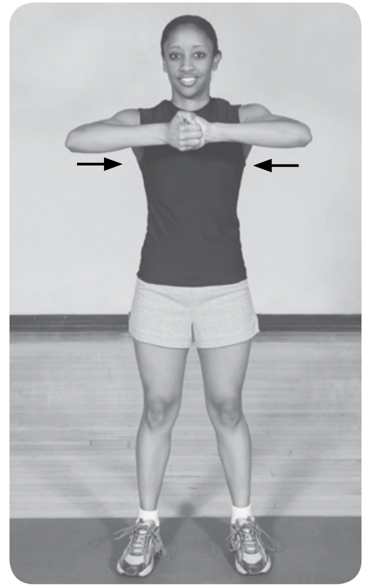
Body weight	Untrained	Novice	Intermediate	Advanced	Elite
97	50	65	75	95	115
105	55	70	80	100	125
114	60	75	85	110	135
123	65	80	90	115	140
132	70	85	95	125	150
148	75	90	105	135	165
165	80	95	115	145	185
181	85	110	120	160	195
198	90	115	130	165	205
199+	95	120	140	175	220

[a] Measured in lb.

In order for these standards to apply, the bar must make contact with the chest above the bottom of the sternum with a momentary pause and be pressed to full elbow extension.

Courtesy of Lon Kilgore, University of the West of Scotland.

Appendix C.4: Isometric Exercises



Video C4.1

Exercise 1: Chest Push

Muscle groups: Shoulder and elbow flexors

Equipment: None

Description:

1. Lock hands together.
2. Keep forearms parallel to ground and hands close to chest.
3. Push hands together.

Exercise 2: Shoulder Pull

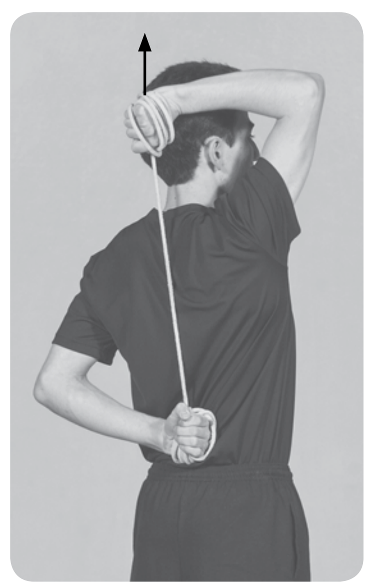
Video C4.2

Muscle groups: Shoulder and elbow extensors

Equipment: None

Description:

1. Using same position as in chest push, attempt to pull hands apart.



Video C4.3

Exercise 3: Triceps Extension

Muscle groups: Elbow extensors

Equipment: Towel or rope

Description:

1. Placing right hand over shoulder and left hand at small of back, grasp rope or towel behind back.
2. Attempt to pull towel or rope upward with right hand.
3. Change position of hands.

(continued)

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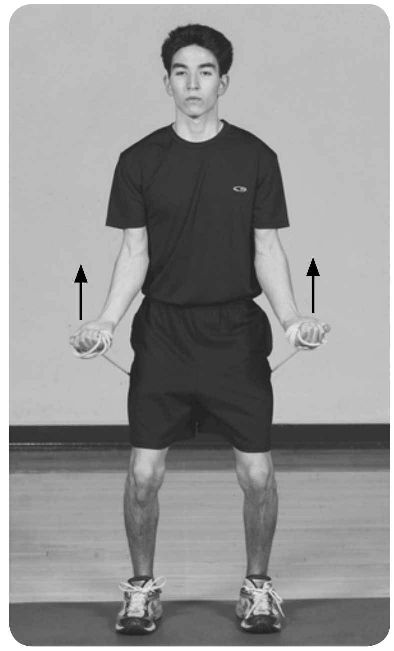

Exercise 4: Arm Curls

Muscle groups: Elbow flexors

Equipment: Towel or rope

Description:

1. Stand with knees flexed about 45°.
2. Place rope or towel behind thighs and grasp each end with hands shoulder-width apart.
3. Attempt to flex elbows.

Exercise 5: Ball Squeeze

Muscle groups: Wrist and finger flexors

Equipment: Tennis ball

Description:

1. Hold tennis ball firmly in hand and squeeze maximally.

Exercise 6: Leg and Thigh Extensions

Muscle groups: Hip and knee extensors

Equipment: Rope

Description:

1. Stand on rope with knees flexed.
2. Grasp rope firmly with hands at sides, elbows fully extended.
3. Keeping trunk erect, attempt to extend legs by lifting upward.

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Exercise 7: Leg Press

Muscle groups: Hip and knee extensors

Equipment: Doorway

Description:

1. Sit in doorway facing side of door frame.
2. Grasp door frame behind head.
3. Attempt to extend legs by pushing feet against door frame.

Exercise 8: Leg Curl

Muscle groups: Knee flexors

Equipment: Dresser or desk

Description:

1. Pull out lower dresser drawer slightly.
2. Lying prone, with knees flexed, hook heels under bottom of drawer.
3. Attempt to pull heels toward head.

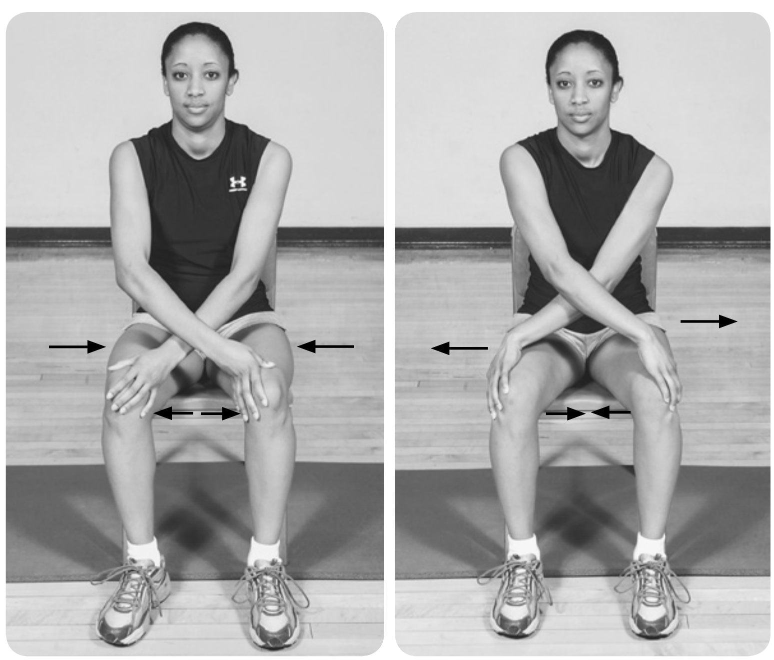
Exercise 9: Knee Squeeze or Pull

Muscle groups: Hip adductors or abductors

Equipment: Chair

Description:

1. Sitting on chair with forearms crossed and hands on inside of knees, attempt to squeeze knees together (adductors).
2. Same position but place hands on outside of knees; attempt to pull knees apart (abductors).



(continued)

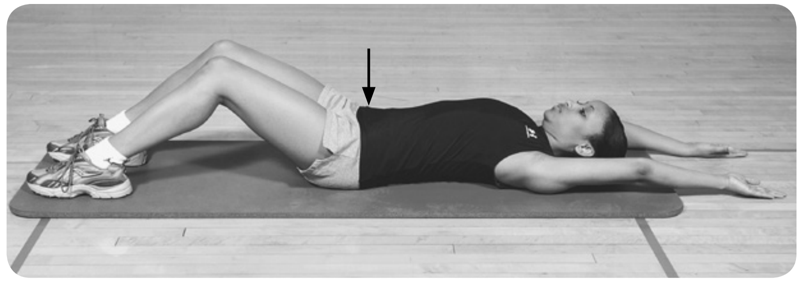
Exercise 10: Pelvic Tilt

Muscle groups: Abdominals

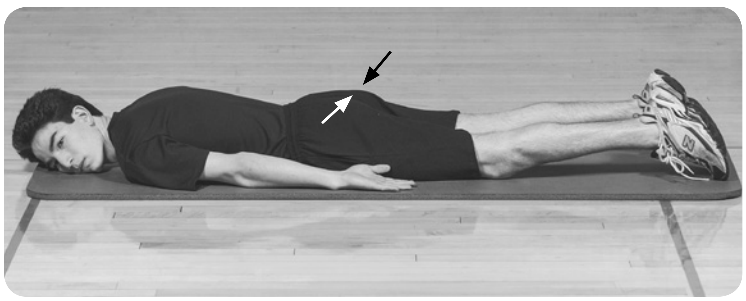
Equipment: None

Description:

1. Supine with knees flexed and arms overhead.
2. Tighten abdominal muscles while pressing lower back into floor.



Exercise 11: Gluteal Squeeze



Muscle groups: Hip extensors and abductors

Equipment: None

Description:

1. Lie prone with legs together and fully extended.
2. Tighten and squeeze the buttocks together.

Appendix C.5: Dynamic Resistance Training Exercises

Exercise	Type[a]	Variations	Equipment[b]	Body position	Joint actions	Prime movers
Upper extremity						
Chest						
Bench press	M-J	Flat	B, D, M	Supine lying on flat bench	Shoulder horizontal adduction, elbow extension	Pectoralis major (midsternal), triceps brachii
		Incline	B, D, M	Sitting on incline bench	Shoulder flexion, elbow extension	Pectoralis major (clavicular), triceps brachii
		Decline	B, D	Supine lying on decline bench	Shoulder flexion, elbow extension	Pectoralis major (lower sternal), triceps brachii
Push-up	M-J	Hands wider than shoulders	None	Prone; BW supported by hands and feet	Shoulder horizontal adduction, elbow extension	Pectoralis major (midsternal), triceps brachii
		Hands narrower than shoulders	None	Same as above	Shoulder flexion, elbow extension	Pectoralis major (clavicular), ant deltoid, triceps brachii
Bar dip	M-J	Neutral grip	Parallel bars	Vertically supported by bars	Shoulder flexion, elbow extension	Pectoralis major (clavicular), ant deltoid, triceps brachii
		Pronated grip		Same as above	Shoulder adduction, elbow extension	Pectoralis major (midsternal), triceps brachii
Fly	S	Flat	D	Supine lying on flat bench	Shoulder adduction	Pectoralis major (midsternal)
Pullover (bent arm)	S	Flat	B, D	Supine lying on flat bench	Shoulder extension	Pectoralis major (lower sternal), post deltoid, latissimus dorsi

(continued)

From Vivian H. Heyward and Ann L. Gibson, 2014, *Advanced Fitness Assessment and Exercise Prescription,* 7th ed. (Champaign, IL: Human Kinetics).

Appendix C.5: Dynamic Resistance Training Exercises *(continued)*

Exercise	Type[a]	Variations	Equipment[b]	Body position	Joint actions	Prime movers
Upper extremity (cont.)						
Shoulders						
Overhead press	M-J	Military	B, D, M	Sitting or standing	Shoulder flexion, elbow extension	Pectoralis major (clavicular), ant deltoid, triceps brachii
		Behind the head	B	Sitting	Shoulder abduction, elbow extension	Ant/mid deltoid, supraspinatus
Upright row	M-J		B, D	Standing	Shoulder abduction, scapula upward rotation, elbow flexion	Mid deltoid, supraspinatus, trapezius (upper), brachialis
Front arm raise	S		B, C, D	Standing	Shoulder flexion	Pectoralis major (clavicular), ant deltoid
Lateral arm raise	S		C, D, M	Sitting or standing	Shoulder abduction	Mid deltoid, supraspinatus, pectoralis major (clavicular)
Reverse fly	S		C, D	Standing	Shoulder horizontal extension	Post deltoid, infraspinatus, teres minor
Upper arm						
Arm curl	S	Supinated grip	B, D, M	Standing or sitting on incline bench or preacher bench	Elbow flexion	Biceps brachii, brachialis
	S	Neutral grip	Same as above		Elbow flexion	Brachioradialis, brachialis, biceps brachii
	S	Pronated grip	Same as above		Elbow flexion	Brachialis
Triceps press-down	M-J		M	Seated	Shoulder flexion, elbow extension	Ant deltoid, pectoralis major (clavicular), triceps brachii

From Vivian H. Heyward and Ann L. Gibson, 2014, *Advanced Fitness Assessment and Exercise Prescription,* 7th ed. (Champaign, IL: Human Kinetics).

Exercise	Type[a]	Variations	Equipment[b]	Body position	Joint actions	Prime movers
Upper extremity (cont.)						
Upper arm (cont.)						
Triceps extension	S		B	Supine lying on flat bench	Elbow extension	Triceps brachii
Triceps push-down	S	V-bar or strength bar	C	Standing	Elbow extension	Triceps brachii
French press	S		D	Standing or sitting	Elbow extension	Triceps brachii (medial head)
Overhead press	S		C, R	Standing with trunk flexed 45°	Elbow extension	Triceps brachii
Triceps kickback	S		D	Standing with one knee/hand on flat bench and trunk horizontal to floor	Elbow extension	Triceps brachii (long head)
Forearm						
Radioulnar rotation	S		D	Forearm/elbow supported on bench; hand free	Supination and pronation	Supinator, pronator teres, biceps brachii, brachioradialis
Wrist curl	S		D	Same as above	Wrist flexion	FCU, FCR
Reverse wrist curl	S		D	Same as above	Wrist extension	ECU, ECR (longus, brevis)
Radioulnar flexion	S		D	Standing with arm at side	Radial flexion, ulna flexion	FCR, ECR, FCU, ECU
Upper-mid back						
Lat pull-down	M-J	Pronated, wide grip	M	Sitting	Shoulder adduction, scapula adduction	Latissimus dorsi (upper), teres major, pectoralis major (upper), trapezius, rhomboids
	M-J	Narrow, neutral grip	M	Sitting	Shoulder extension, elbow flexion	Latissimus dorsi (lower), pectoralis major (lower sternal), biceps brachii

(continued)

From Vivian H. Heyward and Ann L. Gibson, 2014, *Advanced Fitness Assessment and Exercise Prescription*, 7th ed. (Champaign, IL: Human Kinetics).

Appendix C.5: Dynamic Resistance Training Exercises *(continued)*

Exercise	Type[a]	Variations	Equipment[b]	Body position	Joint actions	Prime movers
Upper mid-back (cont.)						
Seated row	M-J	Neutral grip	M	Sitting	Shoulder extension, elbow flexion	Latissimus dorsi (lower), biceps brachii
	M-J	Pronated grip	M	Sitting with elbows horizontal to floor	Shoulder horizontal extension, elbow flexion	Post deltoid, latissimus dorsi (upper), infraspinatus, brachialis
Bent-over row	M-J	Neutral grip	D	Standing with trunk flexed 90°	Shoulder extension, elbow flexion	Latissimus dorsi, biceps brachii
	M-J	Pronated grip	D	Standing with trunk flexed 90° and elbows out	Shoulder horizontal extension, elbow flexion	Post deltoid, infraspinatus, latissimus dorsi, brachialis
Pull-up	M-J	Pronated grip	Pull-up bar	Vertically hanging from bar	Shoulder adduction, elbow flexion	Latissimus dorsi (upper), pectoralis major (sternal), brachialis
Chin-up	M-J	Supinated or neutral grip	Pull-up bar	Vertically hanging from bar	Shoulder extension, elbow flexion	Latissimus dorsi (lower), pectoralis major (sternal), biceps brachii
Shoulder shrug	S	Regular	B, D, M	Standing	Shoulder girdle (scapula and clavicle) elevation	Trapezius (upper), levator scapulae, rhomboids
	S	Elevation with shoulder roll		Standing	Shoulder girdle elevation, scapula adduction	Trapezius (mid), rhomboids
Lower back						
Trunk extension	M-J		M	Sitting with pelvis/thighs stabilized	Spinal extension	Erector spinae
Back raise	M-J		Glut-ham developer	Prone with pelvis supported; trunk flexed	Spinal extension	Erector spinae
Side bends	M-J		D	Standing	Spinal lateral flexion	Quadratus lumborum

From Vivian H. Heyward and Ann L. Gibson, 2014, *Advanced Fitness Assessment and Exercise Prescription,* 7th ed. (Champaign, IL: Human Kinetics).

Exercise	Type[a]	Variations	Equipment[b]	Body position	Joint actions	Prime movers
Lower back (cont.)						
Isometric side support (side bridge)	M-J		None	Side-lying with BW supported by forearm and feet	None	Quadratus lumborum, abdominal obliques
Single-leg extension	M-J		None	Hands and knees	Spinal extension, hip extension	Erector spinae, gluteus maximus, hamstrings (upper)
Abdomen						
Curl-up	M-J	Bent knee	None	Supine lying with knees bent	Spinal flexion	Rectus abdominis
	M-J	With twist	None	Same as above	Spinal flexion	Abdominal obliques
Abdominal crunch	M-J		M	Sitting	Spinal flexion	Rectus abdominis
Reverse sit-up	M-J		None	Supine lying on floor on bench	Spinal flexion	Rectus abdominis (lower)
Lower extremity						
Hip						
Half squat	M-J		B, M	Standing	Hip extension, knee extension	Gluteus maximus, hamstrings (upper), quadriceps femoris
Leg press	M-J		M	Sitting	Hip extension, knee extension	Gluteus maximus, hamstrings (upper), quadriceps femoris
Lunge	M-J		B, D	Standing	Hip extension, knee extension	Gluteus maximus hamstrings (upper), quadriceps femoris
Glut-ham raise	M-J		Glut-ham developer	Prone with thighs supported and trunk flexed	Hip extension and knee flexion	Gluteus maximus, hamstrings

(continued)

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Appendix C.5: Dynamic Resistance Training Exercises *(continued)*

Exercise	Type[a]	Variations	Equipment[b]	Body position	Joint actions	Prime movers
Lower extremity (cont.)						
Hip (cont.)						
Hip flexion	S		C, M	Standing	Hip flexion	Iliopsoas, rectus femoris (upper)
Hip extension	S		C, M	Standing	Hip extension	Gluteus maximus, hamstrings (upper)
Hip adduction	S		M	Sitting or supine lying	Hip adduction	Adductor longus, brevis, and magnus; gracilis
Hip abduction	S		M	Sitting or supine lying	Hip abduction	Gluteus medius
Side leg raise	S		None	Lying on side	Hip abduction	Gluteus medius, hamstrings (upper)
Good morning exercise	S		B, D	Standing	Hip extension	Gluteus maximus, hamstrings (upper)
Thigh						
Leg extension	S		M	Seated	Knee extension	Quadriceps femoris
Leg curl	S	Straight	M	Prone lying, seated, or standing	Knee flexion	Hamstrings (lower)
	S	Knee externally rotated	M	Same as above	Knee flexion	Biceps femoris
	S	Knees internally rotated	M	Same as above	Knee flexion	Semitendinosus, semimembranosus
Lower leg						
Heel raise	S	Standing	D, M	Standing	Ankle plantar flexion	Gastrocnemius
	S	Seated	M	Sitting	Ankle plantar flexion	Soleus
Toe raise	S		Strength bar	Sitting	Ankle dorsiflexion	Tibialis anterior, peroneus tertius, extensor digitorum longus

Note: FCU = flexor carpi ulnaris; ECU = extensor carpi ulnaris; FCR = flexor carpi radialis; ECR = extensor carpi radialis.
[a]Type of exercise: M-J = multijoint exercise; S = single-joint exercise; [b]Equipment codes: B = barbell; C = cables; D = dumbbells; M = exercise machine; R = rope.

From Vivian H. Heyward and Ann L. Gibson, 2014, *Advanced Fitness Assessment and Exercise Prescription,* 7th ed. (Champaign, IL: Human Kinetics).

List of Abbreviations

Terms

%BF	Percent body fat
AAHPERD	American Alliance for Health, Physical Education, Recreation and Dance
ACSM	American College of Sports Medicine
ADL	Activities of daily living
ADP	Air displacement plethysmography
AI	Adequate intake
AIT	Aerobic interval training
ATP	Adenosine triphosphate
AV	Atrioventricular
BIA	Bioelectrical impedance analysis
BIS	Bioimpedance spectroscopy
BM	Body mass
BMI	Body mass index
BMR	Basal metabolic rate
BP	Blood pressure
BSA	Body surface area
BV	Body volume
BW	Body weight
C	Circumference
CDC	Centers for Disease Control and Prevention
CE	Constant error
CHD	Coronary heart disease
CP	Creatine phosphate
CR	Contract-relax
CRAC	Contract-relax with agonist contraction
CSA	Cross-sectional area
CSEP	Canadian Society for Exercise Physiology
CTT	Counting talk test
CV	Cardiovascular
CVD	Cardiovascular disease
D	Skeletal diameter
Db	Body density
DBP	Diastolic blood pressure
DOMS	Delayed-onset muscle soreness
DXA	Dual-energy X-ray absorptiometry
ECG	Electrocardiogram
EDD	Exercise deficit disorder
EIMD	Exercise-induced muscle damage
EMG	Electromyography

Terms

ESH-IP	European Society of Hypertension International Protocol
FFB	Fat-free body
FFM	Fat-free mass
FITT-VP	Frequency, intensity, time, type of exercise, volume, and progression
FM	Fat mass
FRC	Functional residual lung capacity
GH	Growth hormone
GI	Glycemic index
GIS	Geographical information system
GPS	Global positioning system
GV	Volume of air in gastrointestinal tract
GXT	Graded exercise test
HDL	High-density lipoprotein
HDL-C	High-density lipoprotein cholesterol
HIT	High-intensity interval training
HMB	β-hydroxy-β-methylbutyrate
HR	Heart rate
HRmax	Maximal heart rate
HRrest	Resting heart rate
HRR	Heart rate reserve
HT	Standing height
HT^2/R	Resistance index
HW	Hydrostatic weighing
LDL	Low-density lipoprotein
LDL-C	Low-density lipoprotein cholesterol
LP	Linear periodization
MET	Metabolic equivalent
MET·min	MET minutes
MRI	Magnetic resonance imaging
MVIC	Maximal voluntary isometric contraction
N	Sample size
NCEP	National Cholesterol Education Program
NHANES	National Health and Nutrition Examination Survey
NIDDM	Non-insulin-dependent diabetes mellitus
NIH	National Institutes of Health
NIR	Near-infrared interactance
P	Power output

Terms

PAL	Physical activity level
PAR-Q	Physical Activity Readiness Questionnaire
PARmed-X	Physical Activity Readiness Medical Examination Questionnaire
PEI	Physical efficiency index
PNF	Proprioceptive neuromuscular facilitation
$\dot{Q}$	Cardiac output
ρ	Specific resistivity
R	Resistance for bioimpedance analysis
r	Pearson product–moment correlation
RDA	Recommended dietary allowance
REE	Resting energy expenditure
rep	Repetition
RER	Respiratory exchange ratio
RLP	Reverse linear periodization
RM	Repetition maximum
Rmc	Multiple correlation coefficient
RMR	Resting metabolic rate
ROM	Range of motion
RPE	Rating of perceived exertion
RV	Residual (lung) volume
SAD	Sagittal abdominal diameter
SBP	Systolic blood pressure
SCENIHR	Scientific Committee on Emerging and Newly Identified Health
SEE	Standard error of estimate
SIT	Sprint interval training
SKF	Skinfold
ΣSKF	Sum of skinfolds
SRP	Steep ramp cycling protocol
SV	Stroke volume
TBW	Total body water
TC	Total cholesterol
TC/HDL-C	Ratio of total cholesterol to HDL-cholesterol
TE	Total error
TEE	Total energy expenditure
TGV	Thoracic gas volume
TLC	Total lung capacity
TLCNS	Total lung capacity, head not submerged
TMS	Transcranial magnetic stimulation
UWW	Underwater weight
UP	Undulating periodization
VLDL	Very low-density lipoprotein
$\dot{V}O_2$	Volume of oxygen consumed per minute
$\dot{V}O_2max$	Maximal oxygen uptake
$\dot{V}O_2R$	Oxygen uptake reserve
WBAN	Wireless body area network
WBV	Whole-body vibration
WHR	Waist-to-hip ratio
WHTR	Waist-to-height ratio
Xc	Reactance
YMCA	Young Men's Christian Association
YYIR1C	Modified Yo-Yo Intermittent Recovery Level 1 test for children
Z	Impedance

Units of Measure

bpm	beats per minute
C	Celsius
cc	cubic centimeter
cm	centimeter
dl	deciliter
F	Fahrenheit
ft-lb	foot-pound
g	gram
hr	hour
Hz	hertz
in.	inch
kcal	kilocalorie
kg	kilogram
kgm	kilogram-meter
kHz	kilohertz
km	kilometer
L	liter
lb	pound
m	meter
meq	milli-equivalent
mg	milligram
mi	mile
min	minute
ml	milliliter
mm	millimeter
mmHg	millimeters of mercury
mo	month
mph	miles per hour
N	newton
Nm	newton-meter
rpm	revolutions per minute
sec	second
W	watt
wk	week
yr	year
µg	microgram
µg RE	retinol equivalent
Ω	ohm

Glossary

absolute $\dot{V}O_2$—Measure of rate of oxygen consumption and energy cost of non-weight-bearing activities; measured in $L \cdot min^{-1}$ or $ml \cdot min^{-1}$.

accelerometer—Device used to record body acceleration minute to minute, providing detailed information about frequency, duration, intensity, and patterns of movement.

accommodating-resistance exercise—Type of exercise in which fluctuations in muscle force throughout the range of motion are matched by an equal counterforce as the speed of limb movement is kept at a constant velocity; isokinetic exercise.

acquired immune deficiency syndrome (AIDS)—Disease characterized as a deficiency in the body's immune system, caused by human immunodeficiency virus (HIV).

active-assisted stretching—Stretching technique that involves voluntarily moving a body part to the end of its active range of motion, followed by assistance in moving the body part beyond its active range of motion.

active stretching—Stretching technique that involves moving a body part without external assistance; voluntary muscle contraction.

activities of daily living (ADLs)—Normal everyday activities such as getting out of a chair or car, climbing stairs, shopping, dressing, and bathing.

acute-onset muscle soreness—Soreness or pain occurring during or immediately after exercise; caused by ischemia and accumulation of metabolic waste products in the muscle.

aerobic interval training (AIT)—Subclass of high-intensity interval training; consists of repeated combinations of near maximal (80–95% $\dot{V}O_2R$) 4 min bouts of exercise and rest or recovery periods of similar duration.

air displacement plethysmography (ADP)—Densitometric method to estimate body volume using air displacement and pressure-volume relationships.

allele—One member of a pair or series of genes that occupy a specific position on a specific chromosome.

android obesity—Type of obesity in which excess body fat is localized in the upper body; upper body obesity; apple-shaped body.

aneurysm—Dilation of a blood vessel wall causing a weakness in the vessel's wall; usually caused by atherosclerosis and hypertension.

angina pectoris—Chest pain.

ankylosis—Limited range of motion at a joint.

anorexia nervosa—Eating disorder characterized by excessive weight loss.

anthropometry—Measurement of body size and proportions including skinfold thicknesses, circumferences, bony widths and lengths, stature, and body weight.

aortic stenosis—Narrowing of the aortic valve, obstructing blood flow from the left ventricle into the aorta.

Archimedes' principle—Principle stating that weight loss underwater is directly proportional to the volume of water displaced by the body's volume.

arrhythmia—Abnormal heart rhythm.

arteriosclerosis—Hardening of the arteries, or thickening and loss of elasticity in the artery walls that obstruct blood flow; caused by deposits of fat, cholesterol, and other substances.

asthma—Respiratory disorder characterized by difficulty in breathing and wheezing due to constricted bronchi.

at risk for overweight—Characterizing children with a body mass index between the 85th and 94th percentiles for age and sex.

ataxia—Impaired ability to coordinate movement characterized by staggering gait or postural imbalance.

atherosclerosis—Buildup and deposition of fat and fibrous plaque in the inner walls of the coronary arteries.

atrial fibrillation—Cardiac dysrhythmia in which the atria quiver instead of pumping in an organized fashion.

atrial flutter—Type of atrial tachycardia in which the atria contract at rates of 230 to 380 bpm.

atrophy—A wasting or decrease in size of a body part.

attenuation—Weakening of X-ray energy as it passes through fat, lean tissue, and bone.

augmented unipolar leads—Three ECG leads (aVF, aVL, aVR) that compare voltage across each limb lead to the average voltage across the two opposite electrodes.

auscultation—Method used to measure heart rate or blood pressure by listening to heart and blood sounds.

balance—Complex construct involving multiple biomechanical, neurological, and environmental systems.

ballistic stretching—Type of stretching exercise that uses a fast bouncing motion to produce stretch and increase range of motion.

basal metabolic rate (BMR)—Measure of minimal amount of energy needed to maintain basic and essential physiological functions.

behavior modification model—Psychological theory of change; clients become actively involved with the change process by setting short- and long-term goals.

β-hydroxy-β-methylbutyrate (HMB)—Dietary supplement known to increase lean body mass and strength of individuals engaging in resistance training.

bias—In regression analysis, a systematic over- or underestimation of actual scores caused by technical error or biological variability between validation and cross-validation samples; constant error.

biaxial joint—Joint allowing movement in two planes; condyloid and saddle joints.

bioelectrical impedance analysis (BIA)—Field method for estimating the total body water or fat-free mass using measures of impedance to current flowing through the body.

bioimpedance spectroscopy (BIS)—Type of bioimpedance analysis that combines upper body, lower body, and whole-body bioimpedance to estimate FFM and %BF; utilizes a range of electrical frequencies and allows for determination of extracellular water (low level frequencies) and intracellular water (high level frequencies).

Bland and Altman method—Statistical approach used to assess the degree of agreement between methods by calculating the 95% limits of agreement and confidence intervals; used to judge the accuracy of a prediction equation or method for estimating measured values of individuals in a group.

body composition—A component of physical fitness; absolute and relative amounts of muscle, bone, and fat tissues composing body mass.

body density (Db)—Overall density of fat, water, mineral, and protein components of the human body; total body mass expressed relative to total body volume.

body mass (BM)—Measure of the size of the body; body weight.

body mass index (BMI)—Crude index of obesity; body mass (kg) divided by height squared (m^2).

body surface area—Amount of surface area of the body estimated from the client's height and body weight.

body volume (BV)—Measure of body size estimated by water or air displacement.

body weight (BW)—Mass or size of the body; body mass.

bone strength—Function of mineral content and density of bone tissue; related to risk of bone fracture.

Boyle's law—Isothermal gas law stating that volume and pressure are inversely related.

bradycardia—Resting heart rate < 60 bpm.

bronchitis—Acute or chronic inflammation of the bronchi of the lungs.

caloric threshold—Method to estimate duration of exercise based on the caloric cost of the exercise and to estimate the total amount of exercise needed per week for health benefits.

cardiac arrest—Sudden loss of heart function usually caused by ventricular fibrillation.

cardiomyopathy—Any disease that affects the structure and function of the heart.

cardiorespiratory endurance—Ability of heart, lungs, and circulatory system to supply oxygen to working muscles efficiently.

cardiovascular disease (CVD)—Disease of the heart, blood vessels, or both; types of cardiovascular disease include atherosclerosis, hypertension, coronary heart disease, congestive heart failure, and stroke.

center of pressure—Vertical force applied to the supporting base or a force platform during sitting or standing.

chest leads—Six ECG leads (V_1 to V_6) used to measure voltage across specific areas of the chest.

cholesterol—Waxy, fatlike substance found in all animal products (e.g., meats, dairy products, and eggs).

chylomicron—Type of lipoprotein derived from intestinal absorption of triglycerides.

circumference (C)—Measure of the girth of body segments.

cirrhosis—Chronic, degenerative disease of the liver in which the lobes are covered with fibrous tissue; associated with chronic alcohol abuse.

claudication—Cramp-like pain in the calves due to poor circulation in leg muscle.

complex carbohydrates—Macronutrients found in plant-based foods, whole grains, and low-fat dairy products, for example, starch and cellulose.

compound sets—Advanced resistance training system in which two sets of exercises for the same muscle group are performed consecutively, with little or no rest between sets.

computerized dynamic posturography—Computer system designed to assess the individual and composite functioning of sensory, motor, and biomechanical components of balance.

concentric contraction—Type of dynamic muscle contraction in which muscle shortens as it exerts tension.

congestive heart failure—Impaired cardiac pumping caused by myocardial infarction, ischemic heart disease, or cardiomyopathy.

constant error (CE)—Average difference between measured and predicted values for cross-validation group; bias.

constant-resistance exercise—Type of exercise in which the external resistance remains the same throughout the range of motion (e.g., lifting free weights or dumbbells).

continuous exercise test—Type of graded exercise test that is performed with no rest between workload increments.

continuous training—One continuous, aerobic exercise bout performed at low-to-moderate intensity.

contract-relax agonist contract (CRAC) technique—Type of proprioceptive neuromuscular facilitation technique in which the target muscle is isometrically contracted and then stretched; stretching is assisted by a submaximal contraction of the agonistic muscle group.

contract-relax (CR) technique—Type of proprioceptive neuromuscular facilitation technique in which the target muscle is isometrically contracted and then stretched.

contracture—Shortening of resting muscle length caused by disuse or immobilization.

core stability—Ability to maintain ideal alignment of neck, spine, scapulae, and pelvis while exercising.

core strengthening—Strengthening core muscle groups (erector spinae and abdominal movers and stabilizers) used for core stability.

coronary heart disease (CHD)—Disease of the heart caused by a lack of blood flow to heart muscle, resulting from atherosclerosis.

counting talk test (CTT)—Method to monitor exercise intensity; measure of the client's ability to comfortably count out loud while exercising; based on the relationship between exercise intensity and pulmonary ventilation.

criterion method—Gold standard or reference method; typically a direct measure of a component used to validate other tests.

cross-training—Type of training in which the client participates in a variety of exercise modes to develop one or more components of physical fitness.

cuff hypertension—Overestimation of blood pressure caused by use of a bladder that is too small for the arm circumference.

cyanosis—Bluish discoloration of skin caused by lack of oxygenated hemoglobin in the blood.

damping technique—Technique used to reduce the motion of the underwater weighing scale arm during the total body submersion process.

decision-making theory—Theory stating that individuals decide whether or not to engage in a behavior by weighing the perceived benefits and costs of that behavior.

delayed-onset muscle soreness (DOMS)—Soreness in the muscle occurring 24 to 48 hr after exercise.

densitometry—Measurement of body volume leading to calculation of total body density; hydrodensitometry and air displacement plethysmography are densitometric methods.

diabetes—Complex disorder of carbohydrate, fat, and protein metabolism resulting from a lack of insulin secretion (type 1) or defective insulin receptors (type 2).

diastolic blood pressure (DBP)—Lowest pressure in the artery during the cardiac cycle.

dietary thermogenesis—Energy needed for digesting, absorbing, transporting, and metabolizing foods.

digital activity log—A handheld computer used to record the type and duration of physical activities performed during the day.

diminishing return principle—Training principle; as genetic ceiling is approached, rate of improvement slows or evens off.

discontinuous exercise test—Type of graded exercise test that is performed with 5 to 10 min of rest between increments in workload.

discontinuous training—Several intermittent, low- to high-intensity aerobic exercise bouts interspersed with rest or relief intervals.

dose-response relationship—The volume of physical activity is directly related to health benefits from that activity.

dual-energy X-ray absorptiometry (DXA)—Method used to measure total body bone mineral density, bone mineral content, as well as estimate fat and lean soft tissue mass.

dynamic balance—Ability to maintain an upright position while the center of gravity and base of support are moving.

dynamic contraction—Type of muscle contraction producing visible joint movement; concentric, eccentric, or isokinetic contraction.

dynamic flexibility—Measure of the rate of torque or resistance developed during stretching throughout the range of joint motion.

dynamic stretching—Type of stretching exercise that uses slow, controlled movements that are repeated several times to produce stretch and increase range of motion.

dynapenia—Age-related loss in muscle strength.

dyslipidemia—Abnormal blood lipid profile.

dyspnea—Shortness of breath or difficulty breathing caused by certain heart conditions, anxiety, or strenuous exercise.

eccentric contraction—Type of muscle contraction in which the muscle lengthens as it produces tension to resist gravity or decelerate a moving body segment.

edema—Accumulation of interstitial fluid in tissues such as pericardial sac and joint capsules.

elastic deformation—Deformation of the muscle-tendon unit that is proportional to the load or force applied during stretching.

electrocardiogram (ECG)—A composite record of the electrical events in the heart during the cardiac cycle.

embolism—Piece of tissue or thrombus that circulates in the blood until it lodges in a vessel.

emphysema—Pulmonary disease causing damage in alveoli and loss of lung elasticity.

exercise deficit disorder (EDD)—Term associated with children who do not engage in at least 60 min/day of moderate-to-vigorous intensity physical activity.

exercise-induced hypertrophy—Increase in size of muscle as a result of resistance training.

exercise-induced muscle damage (EIMD)—Skeletal muscle damage induced through exercise.

exergaming—Interactive digital games in which the player physically moves to score points.

factorial method—Method used to assess energy needs; the sum of the resting metabolic rate and the additional calories expended during work, household chores, personal daily activities, and exercise.

false negative—An error in which individuals are incorrectly identified as having no risk factors when in fact they do have risk factors.

false positive—An error in which individuals are incorrectly identified as having risk factors when they do not have risk factors.

fat-free body (FFB)—All residual, lipid-free chemicals and tissues in the body, including muscle, water, bone, connective tissue, and internal organs.

fat-free mass (FFM)—*See* fat-free body; weight or mass of the fat-free body.

fat mass (FM)—All extractable lipids from adipose and other tissues in the body.

FITT-VP principle (FITT-VP)—Describes six components of an exercise prescription: frequency, intensity, time, type, volume, and progression of activity.

flexibility—Ability to move joints fluidly through complete range of motion without injury.

flexibility training—Systematic program of stretching exercises that progressively increases the range of motion of joints over time.

flexometer—Device for measuring range of joint motion using a weighted 360° dial and pointer.

free-motion machines—Resistance exercise machines that have adjustable seats, lever arms, and cable pulleys for exercising muscle groups in multiple planes.

functional balance—Ability to perform daily activities requiring balance, for example, picking up an object from the floor.

functional fitness—Ability to perform everyday activities safely and independently without fatigue; requires aerobic endurance, flexibility, balance, agility, and muscular strength.

functional training—System of exercise progressions for specific muscle groups using a stepwise approach that increases the difficulty level (strength) and skill (balance and coordination) required for each exercise in the progression.

gait velocity—The speed of walking. Indirect measure of dynamic balance while walking used to detect mobility problems and risk of falling.

generalized prediction equations—Prediction equations that are applicable to a diverse, heterogeneous group of individuals.

geographical information system (GIS)—Computer system that stores latitude and longitude information about location and the surrounding environment.

global positioning system (GPS)—System that uses 24 satellites and ground stations to calculate geographic locations and accurately track a specific activity.

glucose intolerance—Inability of body to metabolize glucose.

glycemic index (GI)—Rating of the body's glycemic response to a food compared to the reference value (GI = 100 for white bread or glucose).

goniometer—Protractor-like device used to measure joint angle at the extremes of the range of motion.

graded exercise test (GXT)—A multistage submaximal or maximal exercise test requiring the client to exercise at gradually increasing workloads; may be continuous or discontinuous; used to estimate $\dot{V}O_2$max.

Graves' disease—Disease associated with an overactive thyroid gland that secretes greater than normal amounts of thyroid hormones; also known as hyperthyroidism or thyrotoxicosis.

gross $\dot{V}O_2$—Total rate of oxygen consumption, reflecting the caloric cost of both rest and exercise.

gynoid obesity—Type of obesity in which excess fat is localized in the lower body; lower body obesity; pear-shaped body.

HbA1c—An indicator of the average blood glucose over the past 2 to 3 months; glycolsylated hemoglobin.

HDL-cholesterol (HDL-C)—Cholesterol transported in the blood by high-density lipoproteins.

health belief model—Model suggesting that individuals will change a behavior because they perceive a threat of disease if they do not change.

healthy body weight—Body mass index from 18.5 to 25 kg/m^2.

heart block—Interference in the conduction of electrical impulses that control normal contraction of the heart muscle; may occur at sinoatrial node, atrioventricular node, bundle of HIS, or a combination of these sites.

heart rate monitor—Device used to assess heart rate and to monitor exercise intensity.

heart rate reserve (HRR)—Maximal heart rate minus the resting heart rate.

hemiscan procedure—Used for clients who are too wide for the DXA scan table; client is positioned off center on the DXA scan table so that one side of the body is completely within the scan field.

hepatitis—Inflammation of the liver characterized by jaundice and gastrointestinal discomfort.

high blood pressure—Hypertension; chronic elevation of blood pressure.

high CHD risk—One or more signs or symptoms of cardiovascular, pulmonary, renal, or metabolic disease; characterizing individuals with known cardiovascular, pulmonary, renal, or metabolic disease.

high-density lipoprotein (HDL)—Type of lipoprotein involved in the reverse transport of cholesterol to the liver.

high-intensity interval training—Style of cardiometabolic training based on repeated combinations of vigorous-intensity exertion followed by a rest or recovery period; commonly performed using an aerobic modality; combinations of exertion and rest can be manipulated so that training focuses on a specific metabolic pathway.

high intensity–low repetitions—Optimal training stimulus for strength development; 85% to 100% 1-RM or 1- to 6-RM.

high total cardiovascular risk—Category of CVD risk estimate along the risk continuum; identifies those in need of active risk factor management and those who have several CVD risk factors that, in combination, elevate the risk of a CV event.

hybrid sphygmomanometer—Device used to measure blood pressure that combines features of electronic and auscultatory devices.

hydrodensitometry—Method used to estimate body volume by measuring weight loss when the body is fully submerged; underwater weighing.

hydrostatic weighing (HW)—*See* hydrodensitometry.

hypercholesterolemia—Excess of total cholesterol, LDL-cholesterol, or both in blood.

hyperlipidemia—Excess lipids in blood.

hypermobility—Excessive range of motion at a joint.

hyperplasia—Increase in number of cells.

hypertension—High blood pressure; chronic elevation of blood pressure.

hyperthyroidism—Overactive thyroid gland that secretes greater than normal amounts of thyroid hormones; also known as thyrotoxicosis or Graves' disease.

hypertrophy—Increase in size of cells.

hypoglycemia—Low blood glucose level.

hypokalemia—Inadequate amount of potassium in the blood characterized by an abnormal ECG, weakness, and flaccid paralysis.

hypomagnesemia—Inadequate amount of magnesium in the blood resulting in nausea, vomiting, muscle weakness, and tremors.

hypothyroidism—Underactive thyroid gland that secretes lower than normal amounts of thyroid hormones; also known as myxedema.

hypoxia—Inadequate oxygen at the cellular level.

impedance (Z)—Measure of total amount of opposition to electrical current flowing through the body; function of resistance and reactance.

improvement stage—Stage of exercise program in which client improves most rapidly; frequency, intensity, duration are systematically increased; usually lasting 16 to 20 wk.

inclinometer—Gravity-dependent goniometer used to measure the angle between the long axis of the moving segment and the line of gravity.

initial conditioning stage—Stage of exercise program used as a primer to familiarize client with exercise training, usually lasting 4 wk.

initial values principle—Training principle; the lower the initial value of a component, the greater the relative gain and the faster the rate of improvement in that component; the higher the initial value, the slower the improvement rate.

insulin-dependent diabetes mellitus (IDDM)—Type 1 diabetes, caused by lack of insulin production by the pancreas.

interindividual variability principle—Training principle; individual responses to training stimulus are variable and depend on age, initial fitness level, and health status.

interval training—A repeated series of exercise work bouts interspersed with rest or relief periods.

ischemia—Decreased supply of oxygenated blood to body part or organ; due to occlusion or restriction of blood flow.

ischemic heart disease—Pathologic condition of the myocardium caused by lack of oxygen to the heart muscle.

isokinetic contraction—Maximal contraction of a muscle group at a constant velocity throughout entire range of motion.

isometric contraction—Type of muscle contraction in which there is no visible joint movement; static contraction.

isotonic contraction—Type of muscle contraction producing visible joint movement; dynamic contraction.

joint laxity—Looseness or instability of a joint, increasing risk of musculoskeletal injury.

Karvonen method—Method to prescribe exercise intensity as a percentage of the heart rate reserve added to the resting heart rate; percent heart rate reserve method.

kettlebell training—Type of resistance training that uses a cast-iron weight (resembling a cannonball with a handle) to perform ballistic exercises; improves strength, cardiovascular fitness, and flexibility.

kilocalorie (kcal)—Amount of heat needed to raise the temperature of 1 kg of water 1° C; measure of energy need and expenditure.

lactate threshold—Exercise intensity at which blood lactate production exceeds blood lactate removal; denoted by an increase of 1 $mmol \cdot L^{-1}$ between two consecutive stages; an indication of when the primary metabolic pathway switches from mitochondrial oxidation to glycolysis.

LDL-cholesterol (LDL-C)—Cholesterol transported in the blood by low-density lipoproteins.

limb leads—Three ECG leads (I, II, III) measuring the voltage differential between left and right arms (I) and between the left leg and right (II) and left (III) arms.

limits of agreement—Statistical method used to assess the extent of agreement between methods; also known as the Bland and Altman method.

limits of stability—Measure of the maximum excursion of the center of gravity during maintenance of balance over a fixed supporting base.

linear periodization (LP)—Strength training method that progressively increases training intensity as training volume decreases between microcycles.

line of best fit—Regression line depicting relationship between reference measure and predictor variables in an equation.

line of gravity—Vertical projection of the center of gravity of the body to the supporting base.

line of identity—Straight line with a slope equal to 1 and an intercept equal to 0; used in a scatter plot to illustrate the differences in the measured and predicted scores of a cross-validation sample.

lipoprotein—Molecule used to transport and exchange lipids among the liver, intestine, and peripheral tissues.

low back pain—Pain produced by muscular weakness or imbalance resulting from lack of physical activity.

low CHD risk—Characterizing young, asymptomatic individuals having no more than one net risk factor.

low-density lipoprotein (LDL)—Primary transporter of cholesterol in the blood; product of very low-density lipoprotein metabolism.

lower body obesity—Type of obesity in which excess body fat is localized in the lower body; gynoid obesity; pear-shaped body.

low intensity–high repetitions—Optimal training stimulus for development of muscular endurance; ≤60% 1-RM or 15- to 20-RM.

lumbar stabilization—Maintaining a static position of the lumbar spine by isometrically cocontracting the abdominal wall and low back muscles during exercise.

macrocycle—Phase of periodized resistance training program usually lasting 9 to 12 mo; comprised of mesocycles.

maintenance stage—Stage of exercise program designed to maintain level of fitness achieved by end of improvement stage; should be continued on a regular, long-term basis.

masked hypertension—Condition in which individuals exhibit elevated BP readings outside the physician's office but have normal BP values in the office.

masked obesity—Condition in which individuals have a normal body mass index but carry an excessive amount of body fat.

maximal exercise test—Graded exercise test in which exercise intensity increases gradually until the $\dot{V}O_2$ plateaus or fails to rise with a further increase in workload.

maximum oxygen consumption—Maximum rate of oxygen utilization by muscles during exercise; $\dot{V}O_2max$.

maximum oxygen uptake ($\dot{V}O_2max$)—Maximum rate of oxygen utilization of muscles during aerobic exercise.

maximum voluntary isometric contraction (MVIC)—Measure of the maximum force exerted in a single contraction against an immovable resistance.

McArdle's syndrome—Inherited metabolic disease characterized by inability to metabolize muscle glycogen, resulting in excessive amounts of glycogen stored in skeletal muscles.

mesocycle—Phase of a periodized resistance training program usually lasting 3 to 4 mo; comprised of microcycles.

metabolic equivalents (METs)—The ratio of the person's working (exercising) metabolic rate to the resting metabolic rate.

metabolic syndrome—A combination of cardiovascular disease risk factors associated with hypertension, dyslipidemia, insulin resistance, and abdominal obesity.

MET·min—Index of energy expenditure; product of exercise intensity (METs) and duration (min) of exercise.

microcycle—Phase of a periodized resistance training program usually lasting 1 to 4 wk.

miscuffing—Source of blood pressure measurement error caused by use of a blood pressure cuff that is not appropriately scaled for the client's arm circumference.

moderate CHD risk—Characterizing asymptomatic individuals having two or more net risk factors.

multicomponent model—Body composition model that takes into account interindividual variations in water, protein, and mineral content of the fat-free body.

multimodal exercise program—Type of exercise program that uses a variety of exercise modalities.

multiple correlation coefficient (Rmc)—Correlation between reference measure and predictor variables in a prediction equation.

murmur—Low-pitched fluttering or humming sound.

muscle balance—Ratio of strength between opposing muscle groups, contralateral muscle groups, and upper and lower body muscle groups.

muscular endurance—Ability of muscle to maintain submaximal force levels for extended periods.

muscular strength—Maximal force or tension level produced by a muscle or muscle group.

musculoskeletal fitness—Ability of skeletal and muscular systems to perform work.

myocardial infarction—Heart attack.

myocardial ischemia—Lack of blood flow to the heart muscle.

myocarditis—Inflammation of the heart muscle caused by viral, bacterial, or fungal infection.

myxedema—Disease associated with an underactive thyroid gland that secretes lower than normal amounts of thyroid hormones; also known as hypothyroidism.

near-infrared interactance (NIR)—Field method that estimates %BF based on optical density of tissues at the measurement site; presently, validity of this method is questionable.

negative energy balance—Excess of energy expenditure in relation to energy intake.

net $\dot{V}O_2$—Rate of oxygen consumption in excess of the resting $\dot{V}O_2$; used to describe the caloric cost of exercise.

neuromotor training—Exercises to improve balance, agility, gait, coordination, and proprioception; especially beneficial as part of comprehensive exercise programs for older adults.

nonaxial joint—Type of joint allowing only gliding, sliding, or twisting rather than movement about an axis of rotation; gliding joint.

non-insulin-dependent diabetes mellitus (NIDDM)—Type 2 diabetes; caused by decreased insulin receptor sensitivity.

normotensive—Referring to normal blood pressure, defined as values less than 120/80 mmHg.

obesity—Excessive amount of body fat relative to body mass; BMI of 30 kg/m^2 or more.

objectivity—Intertester reliability; ability of test to yield similar scores for a given individual when the same test is administered by different technicians.

objectivity coefficient—Correlation between pairs of test scores measured on the same individuals by two different technicians.

occlusion—Blockage or restriction of blood flow to body part or organ.

omnikinetic exercise—Type of accommodating-resistance exercise that adjusts for fluctuations in both muscle force and speed of joint rotation throughout range of motion.

one-repetition maximum (1-RM)—Maximal weight that can be lifted with good form for one complete repetition of a movement.

optical density—Measure of the amount of near-infrared light reflected by the body's tissues at specific wavelengths.

oscillometry—Method for measuring blood pressure that uses an automated electronic manometer to measure oscillations in pressure when the cuff is deflated.

osteoarthritis—Degenerative disease of the joints characterized by excessive amounts of bone and cartilage in the joint.

osteopenia—Low bone mineral mass; precursor to osteoporosis.

osteoporosis—Disorder characterized by low bone mineral and bone density; occurring most frequently in postmenopausal women and sedentary individuals.

overcuffing—Using a blood pressure cuff with a bladder too large for the arm circumference, leading to an underestimation of blood pressure.

overload principle—Training principle; physiological systems must be taxed beyond normal to stimulate improvement.

overweight—BMI between 25 and 29.9 kg/m^2 in adults; BMI greater than or equal to 95th percentile for age and sex in children.

pallor—Unnatural paleness or absence of skin color.

palpation—Method used to measure heart rate by feeling the pulse at specific anatomical sites.

palpitations—Racing or pounding of the heart.

passive stretching—Stretching technique that involves a body part being moved by an assistant as the client relaxes the target muscle group.

pedometer—A device used to count the number of steps taken throughout the day.

pelvic stabilization—Maintenance of a static position of the pelvis during performance of exercises for the low back extensor muscles.

percent body fat (%BF)—Fat mass expressed relative to body mass; relative body fat.

percent heart rate maximum (%HRmax)—Method used to prescribe exercise intensity as a percentage of the measured or age-predicted maximum heart rate.

percent heart rate reserve (%HRR)—Method used to prescribe exercise intensity as a percentage of the heart rate reserve (HRR = HRmax – HRrest) added to the resting heart rate; Karvonen method.

percent $\dot{V}O_2$ reserve (%$\dot{V}O_2R$)—Method used to prescribe exercise intensity as a percentage of $\dot{V}O_2$ reserve ($\dot{V}O_2R = \dot{V}O_2max - \dot{V}O_2rest$) added to the resting $\dot{V}O_2$.

pericarditis—Inflammation of the pericardium caused by trauma, infection, uremia, or heart attack.

periodization—Advanced form of training that systematically varies the volume and intensity of the training exercises.

persuasive technology—A computer system, device, or application that is intentionally designed to change a person's attitude or behavior.

physical activity level (PAL)—The ratio of total energy expenditure to basal metabolic rate; PAL = TEE / BMR.

physical fitness—Ability to perform occupational, recreational, and daily activities without undue fatigue.

population-specific equations—Prediction equations intended only for use with individuals from a specific homogeneous group.

positive energy balance—Excess of energy intake in relation to energy expenditure.

prediabetes—Medical condition identified by fasting blood glucose or glycated hemoglobin levels above normal values yet below the threshold for diagnosis of diabetes.

prehypertension—Systolic blood pressure of 120 to 139 mmHg or diastolic pressure of 80 to 89 mmHg.

PR interval—Part of ECG tracing that indicates delay in the impulse at the atrioventricular node.

progression principle—Training principle; training volume must be progressively increased to impose overload and stimulate further improvements.

proprioceptive neuromuscular facilitation (PNF)—Mode of stretching that increases range of joint motion through spinal reflex mechanisms such as reciprocal inhibition.

prosthesis—An artificial replacement of a missing body part, such as an artificial limb or joint.

pulmonary ventilation—Movement of air into and out of the lungs.

pulse pressure—Difference between the systolic and diastolic blood pressures.

P wave—Part of ECG tracing that reflects depolarization of the atria.

pyramiding—Advanced resistance training system in which a relatively light weight is lifted in the first set and progressively heavier weights are lifted in subsequent sets; light-to-heavy system.

QRS complex—Part of ECG tracing reflecting ventricular depolarization and contraction.

ramp protocols—Graded exercise tests that are individualized and that provide for continuous, frequent (every 10–20 sec) increments in work rate so that $\dot{V}O_2$ increases linearly.

range of motion (ROM)—Degree of movement at a joint; measure of static flexibility.

rating of perceived exertion (RPE)—A scale used to measure a client's subjective rating of exercise intensity.

reactance (Xc)—Measure of opposition to electrical current flowing through body due to the capacitance of cell membranes; a vector of impedance.

reactive balance—Ability to compensate and recover from perturbations while standing or walking.

reciprocal inhibition—Reflex that inhibits the contraction of antagonistic muscles when the prime mover is voluntarily contracted.

reference method—Gold standard or criterion method; typically a direct measure of a component used to validate other tests.

regression line—Line of best fit depicting relationship between reference measure and predictor variables.

relative body fat (%BF)—Fat mass expressed as a percentage of total body mass; percent body fat.

relative strength—Muscular strength expressed relative to the body mass or lean body mass; 1-RM/BM.

relative $\dot{V}O_2max$—Rate of oxygen consumption expressed relative to the body mass ($ml \cdot kg^{-1} \cdot min^{-1}$) or lean body mass ($ml \cdot kgFFM^{-1} \cdot min^{-1}$).

reliability—Ability of a test to yield consistent and stable scores across trials and over time.

reliability coefficient—Correlation depicting relationship between trial 1 and trial 2 scores or day 1 and day 2 scores of a test.

repetition maximum (RM)—Measure of intensity for resistance exercise expressed as maximum weight that can be lifted for a given number of repetitions.

repetitions—Number of times a specific exercise movement is performed in a set.

residual score—Difference between the actual and predicted scores (Y – Y').

residual volume (RV)—Volume of air remaining in lungs following a maximal expiration.

resistance (R)—Measure of pure opposition to electrical current flowing through body; a vector of impedance.

resistance index (ht2/R)—Predictor variable in some BIA regression equations that is calculated by dividing standing height squared by resistance.

respiratory exchange ratio (RER)—Ratio of expired CO_2 to inspired O_2.

resting energy expenditure (REE)—Energy required to maintain essential physiological processes at rest; resting metabolic rate.

resting metabolic rate (RMR)—Energy required to maintain essential physiological processes in a relaxed, awake, and reclined state; resting energy expenditure.

reverse linear periodization (RLP)—Strength training method that progressively decreases training intensity as training volume increases between microcycles.

reversibility principle—Training principle; physiological gains from training are lost when individual stops training (detraining).

rheumatic heart disease—Condition in which the heart valves are damaged by rheumatic fever, contracted from a streptococcal infection (strep throat).

rheumatoid arthritis—Chronic, destructive disease of the joints characterized by inflammation and thickening of the synovial membranes and swelling of the joints.

sagittal abdominal diameter (SAD)—Measure of the anteroposterior thickness of the abdomen at the umbilical level.

sarcopenia—Age-related loss in muscle mass.

self-determination theory—Theory describing how the presence or absence of specific psychological needs affects behavior.

self-efficacy—Individuals' perception of their ability to perform a task and their confidence in making a specific behavioral change.

sensitivity—Probability of a test correctly identifying individuals with risk factors for a specific disease.

set—Defines the number of times a specific number of repetitions of a given exercise is repeated; single or multiple sets.

simple carbohydrates—Simple sugars (e.g., glucose and fructose) found in fruits, berries, table sugar, honey, and some vegetables.

skeletal diameter (D)—Measure of the width of bones.

skinfold (SKF)—Measure of the thickness of two layers of skin and the underlying subcutaneous fat.

social cognitive model—Psychological theory of behavior change; based on concepts of self-efficacy and outcome expectation.

specificity—Measure of a test's ability to correctly identify individuals with no risk factors for a specific disease.

specificity principle—Training principle; physiological and metabolic responses and adaptations to exercise training are specific to type of exercise and muscle groups involved.

sphygmomanometer—Device used to measure blood pressure manually, consisting of a blood pressure cuff and a manometer.

spinning—Group-led exercise that involves stationary cycling at various cadences and resistances.

split routine—Advanced resistance training system in which different muscle groups are targeted on consecutive days to avoid overtraining.

sprint interval training (SIT) —Subclass of high-intensity interval training; based on repeated combinations of short (e.g. 30 sec) sprints and extended (e.g. 4 min) rest or recovery intervals.

stages of motivational readiness for change model—Psychological theory of behavior change; ability to make long-term behavioral change is based on client's emotional and intellectual readiness; stages of readiness are precontemplation, contemplation, preparation, action, and maintenance.

standard error of estimate (SEE)—Measure of error for prediction equation; quantifies the average deviation of individual data points around the line of best fit.

static balance—Ability to maintain the center of gravity within the supporting base during standing or sitting.

static contraction—Type of muscle contraction in which there is no visible joint movement; isometric contraction.

static flexibility—Measure of the total range of motion at a joint.

static stretching—Mode of exercise used to increase range of motion by placing the joint at the end of its range of motion and slowly applying torque to the muscle to stretch it further.

steep ramp cycling protocol (SRP)—Maximal exertion cycling protocol utilizing stage changes every 10 sec; magnitude of stage increments are determined by the rider's height.

stress relaxation—Decreased tension within musculotendinous unit when it is held at a fixed length during static stretching.

stretch tolerance—Measure of the amount of resistive force to stretch within target muscles that can be tolerated before experiencing pain.

stroke—Rupture or blockage of blood flow to the brain caused by an aneurysm, blood clot, or some other particle.

ST segment—Part of ECG tracing reflecting ventricular repolarization; used to detect coronary occlusion and myocardial infarct.

submaximal exercise test—Graded exercise test in which exercise is terminated at some predetermined submaximal heart rate or workload; used to estimate $\dot{V}O_2$max.

super circuit resistance training—Type of circuit resistance training that intersperses a short, aerobic exercise bout between each resistance training exercise station.

supersetting—Advanced resistance training system in which exercises for agonistic and antagonistic muscle groups are done consecutively without rest.

syncope—Brief lapse in consciousness caused by lack of oxygen to the brain.

systolic blood pressure (SBP)—Highest pressure in the arteries during systole of the heart.

tachycardia—Resting heart rate >100 bpm.

talk test—Method to monitor exercise intensity; measure of the client's ability to converse comfortably while exercising; based on the relationship between exercise intensity and pulmonary ventilation.

tare weight—Weight of chair or platform and its supporting equipment used in hydrostatic weighing.

telomeres—Repeated DNA sequences that determine structure and function of chromosomes.

terminal digit bias—Tendency of the technician to round BP values to the nearest 0 or 5 mmHg.

theory of planned behavior—An extension of the theory of reasoned action that takes into consideration the individual's perception of behavioral control.

theory of reasoned action—Theory that proposes a way to understand and predict an individual's behavior; intention is the most important determinant of behavior.

thoracic gas volume (TGV)—Volume of air in the lungs and thorax.

thrombus—Lump of cellular elements of the blood attached to inner walls of an artery or vein, sometimes blocking blood flow through the vessel.

thyrotoxicosis—Overactive thyroid gland that secretes greater than normal amounts of thyroid hormones; also known as Graves' disease or hyperthyroidism.

tonic vibration reflex—Reflex that activates muscle spindles and alpha motor neurons of muscles stimulated by vibration loading.

total cholesterol (TC)—Absolute amount of cholesterol in the blood.

total energy expenditure (TEE)—Sum of energy expenditures for resting metabolic rate, dietary thermogenesis, and physical activity.

total energy expenditure (TEE) method—Method for determining energy expenditure measured by doubly labeled water or predicted from equations.

total error (TE)—Average deviation of individual scores of the cross-validation sample from the line of identity.

training volume—Total amount of training as determined by the number of sets and exercises for a muscle group, intensity, and frequency of training.

transcranial magnetic stimulation (TMS)—Method used to study adaptations in the central nervous system in response to strength training.

transcriptome signature of resistance exercise—The approximately 660 genes that are affected by resistance training.

transtheoretical model—Model describing the process a client goes through when adopting a change in health behavior.

treading—Type of group-led interval training that involves walking, jogging, and running at various speeds and grades on a treadmill with relief intervals interspersed.

triaxial joint—Type of joint allowing movement in three planes; ball-and-socket joint.

tri-sets—Advanced resistance training system in which three different exercises for the same muscle group are performed consecutively with little or no rest between the exercises.

T wave—Part of ECG tracing corresponding to ventricular repolarization.

two-component model—Body composition model that divides the body into fat and fat-free body components.

type A activity—Endurance activity requiring minimal skill or fitness, for example walking.

type B activity—Endurance activity requiring minimal skill but average fitness, for example jogging.

type C activity—Physical activity requiring both skill and physical fitness, for example swimming.

type D activity—Recreational sports that may improve physical fitness, for example basketball.

type 1 diabetes—Insulin-dependent diabetes, caused by lack of insulin production by the pancreas.

type 2 diabetes—Non-insulin-dependent diabetes, caused by decreased insulin receptor sensitivity.

undercuffing—Using a blood pressure cuff with a bladder too small for the arm circumference, leading to an overestimation of blood pressure.

underwater weight (UWW)—Method used to estimate body volume by measuring weight loss when the body is fully submerged; hydrostatic weighing.

underweight—BMI < 18.5 kg/m^2.

undulating periodization (UP)—Strength training method that varies training intensity and volume weekly or even daily.

uniaxial joint—Type of joint allowing movement in one plane; hinge or pivot joint.

upper body obesity—Type of obesity in which excess fat is localized to the upper body; android obesity; apple-shaped body.

uremia—Excessive amounts of urea and other nitrogen waste products in the blood associated with kidney failure.

validity—Ability of a test to accurately measure, with minimal error, a specific component.

validity coefficient—Correlation between reference measure and predicted scores.

valvular heart disease—Congenital disorder of a heart valve characterized by obstructed blood flow, valvular degeneration, valvular stenosis, and regurgitation of blood.

variable-resistance exercise—Type of exercise in which resistance changes during the range of motion due to levers, pulleys, and cams.

ventilatory threshold—Point at which there is an exponential increase in pulmonary ventilation relative to exercise intensity and rate of oxygen consumption.

ventricular ectopy—Premature (out of sequence) contraction of the ventricles.

ventricular fibrillation—Cardiac dysrhythmia marked by rapid, uncoordinated, and unsynchronized contractions of the ventricles, so that no blood is pumped by the heart.

vertigo—Dizziness or inability to maintain normal balance in a standing or seated position.

very high risk—Category of CVD risk estimate along the risk continuum; criteria are documented CVD, diabetes mellitus (type 2 or type 1 with microalbuminuria), chronic kidney disease, and calculated 10 yr risk SCORE ≥10%.

very low-density lipoprotein (VLDL)—Lipoprotein made in the liver for transporting triglycerides.

viscoelastic creep—A small increase in joint angle during constant-torque stretching, due to elongation of the muscle-tendon unit.

viscoelastic properties—Tension within the muscle-tendon unit caused by the elastic and viscous deformation of the unit when force is applied during stretching.

viscous deformation—Deformation of the muscle-tendon unit that is proportional to the speed at which tension is applied during stretching.

volume of exercise—Quantity of exercise determined by frequency, intensity, and time of exercise.

$\dot{V}O_2$max—Maximum rate of oxygen utilization of muscles during exercise.

$\dot{V}O_2$peak—Measure of highest rate of oxygen consumption during an exercise test regardless of whether or not a $\dot{V}O_2$ plateau is reached.

$\dot{V}O_2$reserve—The $\dot{V}O_2$max minus the $\dot{V}O_2$rest.

waist-to-height ratio (WHTR)—Waist circumference divided by standing height; used as a measure of abdominal obesity.

waist-to-hip ratio (WHR)—Waist circumference divided by hip circumference; used as a measure of upper body or abdominal obesity.

white coat hypertension—Condition in which individuals have normal blood pressure but become hypertensive when blood pressure is measured by a health professional.

whole-body vibration training (WBV)—Training method that uses whole-body mechanical vibration to increase strength, balance, and bone integrity.

wireless body area network (WBAN)—Integrated data sensors, receivers, and transmitters that collect physiologic data and transmit it to a central data repository through a wireless type of technology.

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