Science of Strength and Conditioning Series

NSCA's Guide to TESTS AND ASSESSMENTS

NSCA™
National Strength and Conditioning Association

Todd Miller
EDITOR

NSCA's Guide to Tests and Assessments

National Strength and Conditioning Association

NSCA

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2

Body Composition

Nicholas A. Ratamess, PhD, CSCS*D, FNSCA

Body composition is a term that describes the relative proportions of fat, bone, and muscle mass in the human body. *Anthropometry* is a term that describes the measurement of the human body in terms of dimensions such as height, weight, circumferences, girths, and skinfolds. Body composition and anthropometric tests have become standard practice for coaches, athletes, and fitness professionals. Valuable information regarding percent body fat (i.e., an estimate of the proportion of fat tissue within the human body), fat distribution, lean tissue mass (i.e., the mass of all nonfat tissue such as bones, muscles, and water), and limb lengths and circumferences may be gained through body composition testing.

Body composition tests may be useful for evaluating training, diet, or athletic performance, or for reducing the risk factors associated with musculoskeletal injury. For example, a body composition test may determine that an athlete is approximately 5 pounds (2.3 kg) over his desired weight and that his percent body fat is slightly higher (~1-2%) than normal. This information can help the coach and athlete determine training and dietary strategies. The coach may recommend a small reduction in daily kilocalorie intake (or just limitations in simple sugars or dietary fats), an increase in activity level to increase daily kilocalorie expenditure, or both, to reduce body fat. The athlete may add an additional 15 minutes of low- to moderate-intensity cardiorespiratory exercise at the end of a workout two or three days per week until he attains his ideal body mass and percent fat. Frequent testing will help him monitor his progress and assess the efficacy of the strategies used to attain his target body composition level.

Body composition is one of the five major health-related components of fitness (in addition to muscular strength and endurance, flexibility, and cardiorespiratory endurance), and its assessment has many benefits to children, adolescents and teenagers, adults, and elderly people, as well as performance benefits to athletes (American College of Sports Medicine 2008). In addition, body composition affects the other health-related components of fitness—that is, body mass, lean body mass, and fat content affect muscle strength and endurance, flexibility, and cardiorespiratory endurance. In general, knowledge of one's percent body fat serves as a starting point for comparison; people do not know how they rank compared to others of their gender and age (via classification standards) until their body composition is assessed. They can use this information as a tracking metric for subsequent weight loss, weight gain, or exercise-related training programs.

For example, body composition measurements are useful for athletes in some weight-controlled sports in which body fat levels and hydration (water content) can fall to low levels. Sports such as gymnastics, wrestling, and bodybuilding require athletes to compete at either low weight or low body fat levels. Athletes in these sports can benefit greatly from routine body composition evaluations.

Body composition analysis can also benefit the athlete who is training to increase muscle mass; lean tissue mass measurements can be used to evaluate training programs and measure progress. In addition, body composition tests are very useful for determining health and wellness. An excess amount of body fat, or obesity (especially in the abdominal area), is a risk factor linked to several diseases including type 2 diabetes mellitus, hypertension, hyperlipidemia, cardiovascular disease (CVD), certain types of cancer, low back pain, and osteoarthritis (Despres and Lemieux 2006; Liuke et al. 2005; Wearing et al. 2006).

Historically, some people have attempted to assess obesity via height–weight tables. One popular method involved the use of the Metropolitan Life Insurance table from 1983. This table established an optimal weight range for men and women with small, medium, and large frames. For example, a 6-foot (183 cm) male with a large frame would be considered overweight if he weighed more than 188 pounds (85 kg). Overweight is a weight in excess of the recommended range. However, overweight does not necessarily reflect obesity, because weight alone doesn't necessarily mean that one has a high percentage of body fat. Thus, *overweight* is a term more suited for sedentary populations and not athletes or those who exercise regularly. An athlete with greater lean tissue mass will also have a higher body weight; thus, height–weight tables have little value in the athletic world. Body weight itself is not a direct risk factor per se. However, an excessive amount of body fat poses major health risks. Determining percent body fat yields greater insight into health and fitness levels than body weight does.

Sport Performance and Body Composition

Sport performance is highly dependent on the health- and skill-related components of fitness (power, speed, agility, reaction time, balance, and coordination) in addition to the athlete's technique and level of competency in sport-specific motor skills. All fitness components depend on body composition to some extent. An increase in lean body mass contributes to strength and power development. Strength and power are related to muscle size. Thus, an increase in lean body mass enables the athlete to generate more force in a specific period of time. A sufficient level of lean body mass also contributes to speed, quickness, and agility performance (in the development of force applied to the ground for maximal acceleration and deceleration). Reduced nonessential body fat contributes to muscular and cardiorespiratory endurance, speed, and agility development. Additional weight (in the form of nonessential fat) provides greater resistance to athletic motion thereby forcing the athlete to increase the muscle force of contraction per given workload. The additional body fat can limit endurance, balance, coordination, and movement capacity. Joint range of motion can be negatively affected by excessive body mass and fat as well, and mass can form a physical barrier to joint movement in a complete range of motion. Thus, athletes competing in sports that require high levels of flexibility benefit from having low levels of body fat.

The demands of the sport require that athletes maintain standard levels of body composition. Some sports require athletes to be large in stature, mass, or both, whereas some athletes prosper when they are small in stature. For example, linemen in American football and heavyweight wrestlers need high levels of body mass. Although lean body mass is ideal, these athletes can benefit from mass increases in either form (fat included). Greater mass provides these athletes with more inertia, enabling them to play their positions with greater stability provided speed and agility are not compromised. Strength and power athletes such as American football players, wrestlers, and other combat athletes; powerlifters; bodybuilders; weightlifters; and track and field throwers benefit greatly from high levels of lean body mass. Endurance athletes such as distance runners, cyclists, and triathletes benefit greatly from having low percent body fat. Athletes such as gymnasts, wrestlers, high jumpers, pole vaulters, boxers, mixed martial artists, and weightlifters benefit greatly from having a high strength-to-mass (and power-to-mass) ratio. Training to maximize strength and power while minimizing changes in body mass (and keeping body fat low) is of great value to these sports. Gymnasts, pole vaulters, and high jumpers have to overcome their body weights to obtain athletic success. Thus, minimizing changes in mass enables greater flight height, time, and aerial athleticism.

Wrestlers, boxers, mixed martial artists, powerlifters, and weightlifters compete in weight classes. Because higher weight classes may denote more difficult competition, these athletes benefit from improving strength and power while maintaining their normal weight class. Athletes such as baseball and softball players benefit from increased lean body mass and reduced body fat. The additional lean mass can assist in power, speed, and agility, and keeping body fat low assists with endurance, quickness, speed, and agility as well (for performing skills such as throwing, hitting, fielding, and base running).

Basketball and soccer are two of several combination anaerobic and aerobic sports in which athletes need power, speed, quickness, agility, and strength yet also moderate to high levels of aerobic fitness. Athletes from both of these sports benefit from having low body fat while maintaining or increasing lean body mass. Although some athletes can tolerate higher levels of body mass and perhaps percent body fat, it is generally recommended that data obtained from frequent body composition measurements be used to develop training plans aimed at reducing body fat while maintaining or increasing lean body mass.

Practical Applications

The measurement and quantification of percent body fat is of great importance for fitness practitioners, coaches, trainers, and athletes for several reasons. The measurement of percent body fat allows athletes to identify where they rank (e.g., lean, average, high, obese) according to standards and can be used to identify athletes at the extremes (e.g., at risk for obesity or eating disorders, which are especially a concern for female athletes in weight-controlled sports).

Athletes can use body fat data to modify training, diet, or both, to achieve the desired body fat level for their sports. For example, an athlete with too high a level of body fat can increase aerobic exercise duration, increase volume and decrease rest interval length for resistance exercise (to increase the metabolic demand and energy expenditure), or reduce kilocalorie intake (primarily by decreasing saturated fat and simple carbohydrate intake) to favor a net energy deficit that can lower body fat. If an eating disorder (e.g., bulimia or anorexia nervosa) is identified in an athlete whose body mass and fat levels are lower than expected, attempts can be made to assist the athlete with nutritional and psychological counseling.

Body composition testing generates descriptive data of athletes for various sports and positions. This is particularly useful from a research perspective but can benefit a coach over time when norms are developed. Coaches can use these data to compare their athletes to other athletes in the league or conference and can compare their current athletes to former athletes in the program. This can be used to identify trends in player body composition over time.

Body composition testing also serves as a starting point for program evaluation. For example, if an athlete has 20.8% body fat at the beginning of a program, and after 12 weeks of training has 18.6%, the coach and athlete can conclude that the program resulted in a 2.2% reduction in body fat.

Athletes in weight-controlled sports or making weight for weight classes can use body composition testing to identify a safe percent fat low point, or minimal weight. Percent fat should not be lower than 4% in males and 10% in females for extended periods of time. If percent fat approaches these values, modifications can be made (i.e., no more weight loss or a change in weight class).

Some body composition tests (e.g., DEXA) can yield critical information such as bone mineral density, total body water, and lean tissue mass. Lean tissue mass can be calculated from skinfold analyses or any method used to determine percent body fat. These can be used to evaluate training adaptations particularly to a resistance training program targeting muscle hypertrophy.

Body fat measurement allows for the calculation of ideal body weight or fat mass. For example, an athlete who weighs 215 pounds (98 kg) with a percent fat of 15% targets a percent fat of 13% (or less) and a weight of 210 pounds (95 kg). Initially, this athlete has 32.3 pounds (14.7 kg) of body fat (215 lb × 0.15 = 32.3 lb; or 98 × 0.15 = 14.7). He knows he can safely reach this weight because he has 32.3 pounds (14.7 kg) of fat but only desires to lose 5 pounds (2.3 kg). On the other hand, his ideal body weight can be calculated when he sets a target body fat level (in this case, going from 15 to 13%). Ideal body weight (IBW) can be calculated as follows:

IBW = (body weight – fat weight) / (1.00 – desired % / 100)

IBW = (215 lb – 32.3 lb) / (1.00 – 13% / 100)

IBW = 182.7 lb / (1.00 – 0.13)

IBW = 182.7 lb / 0.87

IBW = 210 lb

Body Composition Measurement

There are no truly direct methods for measuring body composition. Rather, most body composition measurements involve indirect assessment, or estimation. Each method has advantages and disadvantages as noted in the many studies that have made direct comparisons. The decision of which method to use depends on several factors, including the needs of the client, the purpose of the evaluation, the cost of the measurements or equipment needed, the availability of each measurement tool, the training of the technician, and the weighted advantages and disadvantages of each. Several common and practical body composition measurement techniques are discussed in this chapter.

Measuring Height, Body Weight, and Body Mass Index

Height and body weight and mass measurements are easy to perform. They can provide useful body composition data. Height can change throughout the day (based on spinal loading and vertebral disc volume) and more significantly with aging. Because of its relatively low magnitude of daily fluctuation, height in adults does not need to be measured frequently. The measurement of body weight can be performed frequently especially during weight loss or weight gain training programs or when athletes are reducing weight to compete in a weight class.

HEIGHT

EQUIPMENT

Height should be measured with a stadiometer (a vertical ruler mounted on a wall with a wide horizontal headboard). Although many commercial scales have an attached vertical ruler, these devices are less reliable. Failure to follow accepted standards reduces reliability and accuracy.

PROCEDURE

1. The subject removes shoes.
2. The subject stands as straight as possible with heels together near the wall.
3. The subject takes a deep breath, holds it, and stands with head level, looking straight ahead.
4. The height of the subject is recorded in inches or centimeters (1 in. = 2.54 cm).

BODY WEIGHT AND MASS

Body weight and mass represent different kinetic variables. In biomechanics, body mass is the amount of matter an object or person consists of, whereas weight is a force measurement—that is, the product of mass and acceleration due to gravity ($9.81\ m \cdot s^{-2}$) depending on the effects of gravity. Both are measured the same way. However, body mass is expressed in kilograms, whereas body weight is expressed in pounds or sometimes Newtons (N). Clothing is also an issue, and the type and amount of clothing must be standardized. Body weight changes at various times of day as a result of meal and beverage consumption, urination, defecation, and dehydration, or water loss. Therefore, a standard time (e.g., early in the morning) is recommended.

EQUIPMENT

Body weight and body mass are best measured on a calibrated physician's scale with a beam and movable weights.

PROCEDURE

1. Clothing must be standardized and shoes must be removed. Accuracy is greatest with minimal clothing. A subject wearing clothing should empty pockets and remove jewelry.
2. The subject steps onto the scale and the weight is recorded upon stabilization of the beam. Body weight is recorded in pounds, or body mass is recorded in kilograms (1 kg = 2.2 lb; 1 N = 0.224 lb; 1 lb = 4.448 N).

BODY MASS INDEX

Body mass index (BMI) is used to assess body mass relative to height:

$$\text{BMI } (\text{kg} \cdot \text{m}^{-2}) = \text{body mass (kg)} / \text{height squared } (\text{m}^2)$$

BMI has been used to determine the risk of developing diseases such as type 2 diabetes, hypertension, and CVD and is very easy to calculate.

PROCEDURE

Body mass index may also be calculated using the following equation: BMI = body weight (lb) × 703 / height^2 (in.^{2}). For example, a man who is 195 pounds (88.6 kg) and 6 feet 3 inches (190.5 cm, or 1.905 m) would have a BMI of 24.4 kg · m^{-2} and would be considered normal when compared to BMI standards. The current BMI (kg · m^{-2}) standards for men and women in the United States are as follows (American College of Sports Medicine 2007):

BMI < 18.5 indicates underweight

BMI of 18.5 to 24.9 is normal

BMI of 25 to 29.9 indicates overweight

BMI of 30 to 39.9 is obese

BMI > 40 indicates morbid obesity

Although simplistic in its calculation, BMI has greater practical relevance in sedentary and clinical populations. It strongly correlates with disease and is easy to use in large populations. Criticisms of the use of BMI are that it is a relatively poor predictor of body fat percent, is not indicative of weight distribution, and may result in inaccurate classifications (normal, overweight, obese) for muscular people, athletes, and those who play collegiate or professional sports. For example, one study that examined body composition in National Football League players in the United States showed that based on BMI, every player was classified as overweight, obese, or very obese despite having body fat percentages of 6.3 to 18.5% (with offensive linemen at 25.1%) (Kraemer et al. 2005). A recent study examining NCAA Division I American football players showed across all positions a mean BMI of 29.8 kg · m^{-2} despite an average percent body fat of ~15 ± 7% (Kaiser et al. 2008). Another study of American football players showed BMI to be an invalid measure because it overestimated being overweight and obese in more than 50% of the athletes (Mathews and Wagner 2008). This appears to be the case with strength and power athletes from other sports as well. Thus, BMI is not a particularly useful body composition measurement tool in resistance-trained populations.

WAIST-TO-HIP RATIO

The waist-to-hip ratio (WHR) compares the circumferences of the waist to that of the hip and is used as an indicator of body fat distribution (i.e., the apple or pear physique) or as a measure of general health. A high WHR has been recognized as a risk factor for disease. An advantage of this technique is that it is simple to administer and requires only a tape measure. In some cases, WHR may be a better predictor of mortality than BMI. However, because it is a circumference ratio, it does not provide an indication of percent body fat. Skinfold measurement (or other body fat technique) provides a more accurate estimation of percent body fat. Critical to the accuracy and reliability of WHR measurement is standardization of the circumference technique. Standards for WHR values are shown in table 2.1.

EQUIPMENT

A flexible tape measure (such as a Gulick II tape measure)

PROCEDURE

1. All that is needed for this procedure is a flexible tape measure. A Gulick II tape measure is beneficial because it applies a constant amount of tension to the tape, thereby eliminating variability among examiners.
2. The waist circumference should be taken around the smallest area of the waist, typically ~1 inch (2.54 cm) above the navel.
3. The hip circumference is taken around the largest area of the buttocks (with minimal clothing).
4. The WHR is calculated as the waist circumference (cm or in.) / hip circumference (cm or in.) and is expressed with no units because they cancel each other out during the process of division.
5. Multiple measurements should be taken until each is within ¼ inch (0.6 cm) of each other.

TABLE 2.1 Waist-to-Hip Measurement Standards for Men and Women

		RISK			
Population	**Age**	**Low**	**Moderate**	**High**	**Very high**
Men	20-29	<0.83	0.83-0.88	0.89-0.94	>0.94
	30-39	<0.84	0.84-0.91	0.92-0.96	>0.96
	40-49	<0.88	0.88-0.95	0.96-1.00	>1.00
	50-59	<0.90	0.90-0.96	0.97-1.02	>1.02
	60-69	<0.91	0.91-0.98	0.99-1.03	>1.03
Women	20-29	<0.71	0.71-0.77	0.78-0.82	>0.82
	30-39	<0.72	0.72-0.78	0.79-0.84	>0.84
	40-49	<0.73	0.73-0.79	0.80-0.87	>0.87
	50-59	<0.74	0.74-0.81	0.82-0.88	>0.88
	60-69	<0.76	0.76-0.83	0.84-0.90	>0.90

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SKINFOLD MEASUREMENT

Skinfold measurement is one of the most popular and practical methods for estimating percent body fat, and can be relatively accurate provided that a trained technician is performing the measurement with high-quality calipers (e.g., a Lange or Harpenden caliper that provides a constant pressure of ~10 $g \cdot mm^{-2}$). Skinfold analysis is based on the principle that the amount of subcutaneous fat (fat immediately below the skin) is directly proportional to the total amount of body fat.

Following the collection of skinfold measurements, regression analysis (a statistical procedure used to predict a dependent variable based on one or more independent or predictor variables) is used to estimate total percent body fat. The sum of the skinfolds, along with gender and age (which are known significant predictors of body fat), are used in a regression analysis, which ultimately calculates a prediction equation to estimate body density and percent body fat. Variability in percent body fat prediction from skinfold analysis is approximately ±3 to 5% assuming that appropriate techniques and equations have been used (American College of Sports Medicine 2008). Body fat varies with gender, age, race or ethnicity, training status, and other factors. Therefore, numerous regression equations using a combination of skinfold sites have been developed to predict body density and fat from skinfold measurements.

Skinfold measurement is most accurate when prediction equations are used that closely match the population being tested. The number of sites needs to be predetermined based on the regression equation or methods used (i.e., three, four, or seven sites). Both seven- and three-site skinfold equations have shown similar standard errors of estimate in men (±3.4 to 3.6%) and women (±3.8 to 3.9%) (American College of Sports Medicine 2007).

EQUIPMENT

High-quality calipers (e.g., Lange or Harpenden)

PROCEDURE

1. The number of sites and equations should first be selected based on the population tested. Skinfold sites are shown in figure 2.1.
2. A fold of skin is firmly grasped between the thumb and index finger of the left hand (about 8 cm apart on a line perpendicular to the long axis of the site) and lifted away from the body while the subject is relaxed. Following are commonly used skinfold sites:
   - Abdomen: Horizontal fold; 2 centimeters to the right of the umbilicus
   - Biceps: Vertical fold on the anterior aspect of the arm over the belly of the biceps muscle
   - Chest or pectoral: Diagonal fold; half the distance between the anterior axillary line and the nipple (in men), or one third the distance between the anterior axillary line and the nipple (in women)
   - Midaxillary: Horizontal fold on the midaxillary line at the level of the xiphoid process of the sternum
   - Subscapular: Diagonal fold at a 45° angle, 1 to 2 centimeters below the inferior angle of the scapula
   - Suprailiac: Diagonal fold in line with the natural angle of the iliac crest taken in the anterior axillary line
   - Thigh: Vertical fold on the anterior midline of the thigh midway between the proximal border of the patella and the inguinal crease
   - Triceps: Vertical fold on the posterior midline of the upper arm midway between the acromion process of the scapula and the inferior part of the olecranon process of the elbow
3. A slight muscular contraction of the subject or a finger roll of the fold ensures that subcutaneous tissue is measured and not skeletal muscle. For obese people, a large grasping area (i.e., >8 cm) may be needed and could possibly exceed the measurement capacity of the caliper.
4. While the caliper is facing up, the jaws of the caliper are placed over the skinfold 1 centimeter below the fingers of the tester.
5. The caliper grip is released and the measurement is subsequently taken within three seconds.
6. All measurements are taken on the right side of the body in duplicate or triplicate for consistency among measurements to the nearest 0.5 millimeter. If there is more than a 3-millimeter difference between readings, a fourth measurement may be needed.

7. It is important to rotate through the sites as opposed to taking two or three measurements sequentially from the same site.
8. Each site is averaged and summed to estimate body density and percent body fat via a regression equation or prediction table. The total is viewed in a table relative to gender and age, and percent body fat is given.

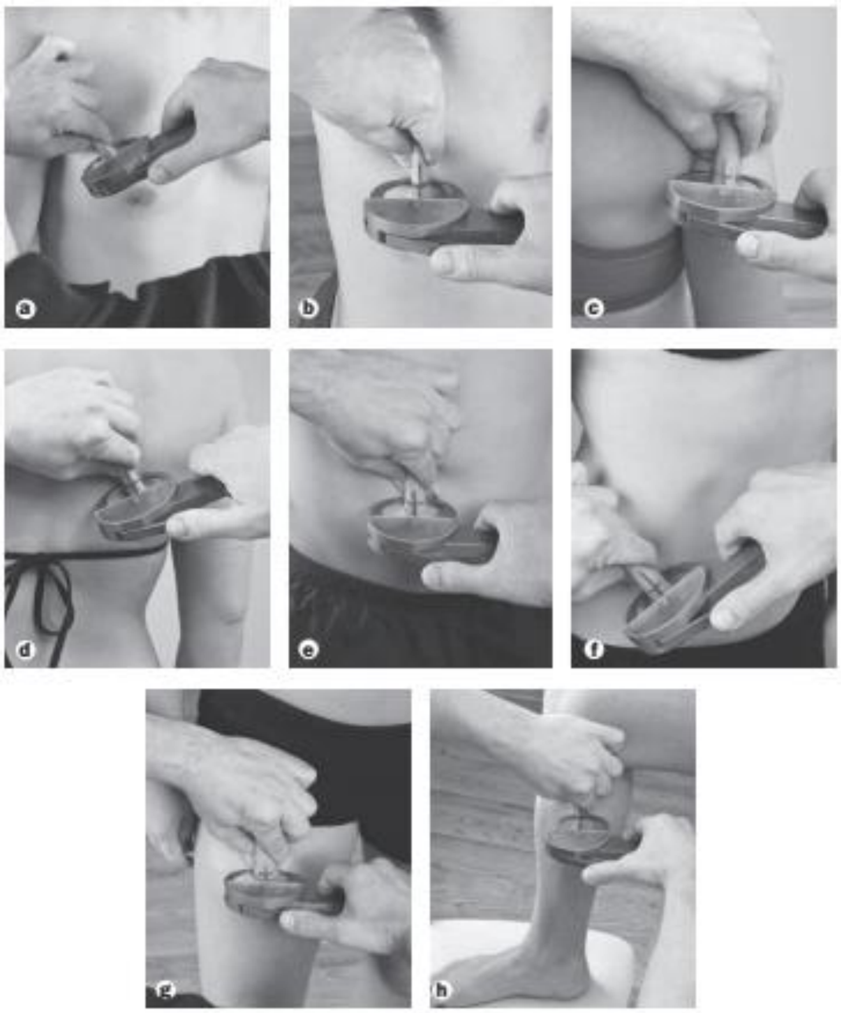

FIGURE 2.1 Skinfold sites.

Reprinted, by permission, from National Strength and Conditioning Association, 2008, Administration, scoring, and interpretation of selected tests, by E. Harman and J. Garhammer. In *Essentials of strength training and conditioning*, 3rd ed., edited by T.R. Baechle and R.W. Earle (Champaign, IL: Human Kinetics), 268-269.

Critical to skinfold analysis is the selection of an appropriate prediction equation. It is important to note that several equations are used to estimate body density, and a subsequent body density calculation is used to estimate percent body fat. Body density is described as the ratio of body mass to body volume. Table 2.2 depicts several equations used to estimate percent body fat from body density estimates. Since the early 1950s, more than 100 regression equations have been developed to predict body density and percent fat. Equations that have been cross-validated in other studies to support their efficacy should be chosen based on gender, age, ethnicity, and activity level. However, general equations have been shown to produce accurate estimates across all segments of the population (i.e., those with very high and low levels of body fat in addition to those whose body fat is near the population mean) and may be easier to use because only one or two equations are used as opposed to several (Graves et al. 2006). Because the relationship between body density and subcutaneous fat is curvilinear, quadratic and logarithmic terms have been added to most regression equations to increase their accuracy. Once body density has been determined, percent body fat can be calculated. Most often, the Siri (1956) or Brozek (Brozek et al. 1963) equations are used:

Siri equation: $(4.95 / B_d - 4.50) \times 100$

Brozek equation: $(4.57 / B_d - 4.142) \times 100$

*where B_d = body density

However, other population-specific equations (see table 2.3 on page 28) have been developed to estimate percent fat from body density based on ethnicity, gender, and age (Harman and Garhammer 2008). See table 2.4 on page 38 for information on when it is beneficial to perform BMI measurement. Table 2.5 on page 39 provides percent body fat classifications.

GIRTH MEASUREMENTS

Girth measurements entail measuring the circumference of a body limb or region. In addition to providing useful information regarding changes in muscle size resulting from training, girth measurements, either alone or in combination with skinfold measurements, provide information regarding body composition. The advantages of taking circumference measurements is that doing so is easy, quick, and inexpensive and does not require specialized equipment. Accurate estimates of percent body fat (i.e., ±2.5 to 4%) can be made via girth measurements. Common sites measured include the right upper arm, abdomen, and right forearm for young men; buttocks (hip), abdomen, and right forearm for older men; abdomen, right thigh, and right forearm for young women; and abdomen, right thigh, and right calf for older women.

TABLE 2.2 Body Density Prediction Equations From Skinfold Measurements

Sites	Population	Gender	Equation	Reference
2: thigh, subscapular	Athletes	Male	B_d = 1.1043 – (0.00133 × thigh) – (0.00131 × subscapular)	Sloan and Weir (1970)
2: suprailiac, triceps	Athletes	Female	B_d = 1.0764 – (0.00081 × suprailiac) – (0.00088 × triceps)	Sloan and Weir (1970)
3: chest, ab, thigh	General	Male	B_d = 1.10938 – 0.0008267 (sum of 3 sites) + 0.0000016 (sum of 3 sites)^2 – 0.0002574 (age)	Jackson and Pollock (1978)
3: triceps, suprailiac, thigh	General	Female	B_d = 1.099421 – 0.0009929 (sum of 3 sites) + 0.0000023 (sum of 3 sites)^2 – 0.0001392 (age)	Jackson et al. (1980)
3: chest, triceps, subscapular	General	Male	B_d = 1.1125025 – 0.0013125 (sum of 3 sites) + 0.0000055 (sum of 3 sites)^2 – 0.000244 (age)	Pollock et al. (1980)
3: triceps, suprailiac, ab	General	Female	B_d = 1.089733 – 0.0009245 (sum of 3 sites) + 0.0000025 (sum of 3 sites)^2 – 0.0000979 (age)	Jackson and Pollock (1985)
4: biceps, triceps, subscapular, suprailiac	General	Male Female 20–29 years old	B_d = 1.1631 – 0.0632 (log sum of 4 sites)	Durnin and Womersley (1974)
4: biceps, triceps, subscapular, suprailiac	General	Male Female 30-39 years old	B_d = 1.1422 – 0.0544 (log sum of 4 sites)	Durnin and Womersley (1974)
7: thigh, subscapular, suprailiac, triceps, chest, ab, axillary	General	Female	B_d = 1.0970 – 0.00046971 (sum of 7 sites) + 0.00000056 (sum of 7 sites)^2 – 0.00012828 (age)	Jackson et al. (1980)
7: thigh, subscapular, suprailiac, triceps, chest, ab, axillary	General	Male	B_d = 1.112 – 0.00043499 (sum of 7 sites) + 0.00000055 (sum of 7 sites)^2 – 0.00028826 (age)	Jackson and Pollock (1978)

EQUIPMENT

Tape measure (preferably a Gulick II tape measure)

PROCEDURE

1. The tape measure (preferably a Gulick II tape measure) is applied in a horizontal plane to the site so it is taut and the circumference is read to the nearest half centimeter. Minimal clothing should be worn.

TABLE 2.3 Population-Specific Equations to Calculate Percent Body Fat From Body Density

Population	Age	Gender	Equation
Caucasian	7–12	Male	$(5.30 / B_d - 4.89) \times 100$
		Female	$(5.35 / B_d - 4.95) \times 100$
	13–16	Male	$(5.07 / B_d - 4.64) \times 100$
		Female	$(5.10 / B_d - 4.66) \times 100$
	17–19	Male	$(4.99 / B_d - 4.55) \times 100$
		Female	$(5.05 / B_d - 4.62) \times 100$
	20–80	Male	$(4.95 / B_d - 4.50) \times 100$
		Female	$(5.01 / B_d - 4.57) \times 100$
African American	18–32	Male	$(4.37 / B_d - 3.93) \times 100$
	24–79	Female	$(4.85 / B_d - 4.39) \times 100$
American Indian	18–60	Female	$(4.81 / B_d - 4.34) \times 100$
Hispanic	20–40	Female	$(4.87 / B_d - 4.41) \times 100$
Japanese	18–48	Male	$(4.97 / B_d - 4.52) \times 100$
		Female	$(4.76 / B_d - 4.28) \times 100$
	61–78	Male	$(4.87 / B_d - 4.41) \times 100$
		Female	$(4.95 / B_d - 4.50) \times 100$

Data from NSCA 2008; Heyward and Stolarczyk 1996.

2. Duplicate measures should be taken at each site, and the average is used. If readings differ by more than 5 millimeters, then an additional measurement is taken.
3. Subjects should remain relaxed while measurements are taken.
4. A large source of error is a lack of standardization of the measurement site. The correct placement of the tape measure per site is as follows:
   - Chest: The tape is placed around the chest at level of the fourth ribs after the subject abducts the arms. Measurement is taken when the subject adducts the arms back to the starting position and at the end of respiration.
   - Shoulder: The tape is placed horizontally at the maximal circumference of the shoulders while the subject is standing relaxed.
   - Abdomen: The tape is placed over the abdomen at the level of the greatest circumference (often near the navel) while the subject is standing relaxed.
   - Right thigh: The tape is placed horizontally over the thigh below the gluteal level at the largest circumference (i.e., upper thigh) while the subject is standing.
   - Right calf: The tape is placed horizontally over the largest circumference of the calf midway between the knee and ankle while the subject is standing relaxed.

- Waist and hip: The tape is placed around the smallest area of the waist, typically ~1 inch (2.54 cm) above the navel. The hip circumference is taken around the largest area of the buttocks (with minimal clothing).
- Right upper arm: The tape is placed horizontally over the midpoint of the upper arm between the shoulder and elbow while the subject is standing relaxed and the elbow is extended.
- Right forearm: The tape is placed horizontally over the proximal area of the forearm where the circumference is the largest while the subject is standing relaxed.

Estimations of percent body fat from circumferences can be made once values have been obtained. Age- and gender-specific equations have been developed to estimate percent fat. Equations for young and older men and women are based on a calculation of constants. Once constants are obtained, these values can be used in the following equations to estimate percent body fat. Circumference estimation of percent fat has an accuracy of ±2.5 to 4.0%. Table 2.4 on page 38 provides percent body fat classifications.

CIRCUMFERENCE PERCENT BODY FAT ESTIMATION EQUATIONS (AMERICAN COLLEGE OF SPORTS MEDICINE 2007; MCARDLE, KATCH, AND KATCH 2007)

Young men: Constant A + B – C – 10.2 = percent body fat

Young women: Constant A + B – C – 19.6 = percent body fat

Older men: Constant A + B – C – 15.0 = percent body fat

Older women: Constant A + B – C – 18.4 = percent body fat

HYDRODENSITOMETRY

Hydrodensitometry (underwater, or hydrostatic, weighing) has historically been considered the criterion method, or gold standard, for body composition analysis even though it is an indirect method. Hydrodensitometry is based on Archimedes' principle for determining body density where a body immersed in water encounters a buoyant force that results in weight loss equal to the weight of the water displaced during immersion. Subtracting the subject's body weight in water from the body weight on land provides the weight of the displaced water. Body fat contributes to buoyancy because the density of fat ($0.9007\ g \cdot cm^{-3}$) is less than water ($1\ g \cdot cm^{-3}$), whereas lean tissue mass ($\geq 1.100\ g \cdot cm^{-3}$) exceeds the density of water.

It is important to note that lean tissue density varies based on ethnicity and maturation. African Americans have been shown to have an average density of $1.113\ g \cdot cm^{-3}$, and Hispanics have shown an average value of $1.105\ g \cdot cm^{-3}$ compared to Caucasians ($1.100\ g \cdot cm^{-3}$) (McArdle, Katch, and Katch 2007). Children and older adults have lower lean tissue densities than young adults. In addition, disproportionately large increases in muscle mass (from resistance training) compared to bone mineral density changes can lower body density and result in an overestimate of percent body fat (McArdle, Katch, and Katch 2007). Body density (mass / volume) is calculated and then converted to percent body fat using an equation such as the Siri (1956) or Brozek (1963) equations. Population-specific equations (e.g., for African Americans, Indians, Hispanics, Japanese, and Caucasians) have been developed to more accurately convert body density data into percent body fat (American College of Sports Medicine 2007).

Because hydrodensitometry is considered a gold standard, other body composition measurement tools (e.g., skinfolds, bioelectrical impedance) are validated against it. Test–retest reliability is high when procedures are followed correctly. However, practical limitations can make hydrodensitometry difficult in certain situations. The cost and specialized use of the equipment needed is great, and may be impractical in certain facilities. The time involved in each measurement is lengthy, which could make other body composition measurements more attractive. Lastly, many subjects express fear and discomfort about needing to be fully submerged in water.

The following variables must be known when performing hydrodensitometry:

- *Residual volume*: The amount of air remaining in the lungs following full expiration. Residual volume can be measured or predicted using a combination of age, gender, and height. A substantial amount of air left in the lungs increases buoyancy, which may be mistaken as additional body fat.
- *Water density*: Water density varies with water temperature, because buoyancy decreases with warmer temperatures.
- *Amount of trapped gas in the gastrointestinal system*: Typically, a predicted constant of 100 milliliters is used.
- *Dry body weight.*
- *Body weight in water.*

EQUIPMENT

A tank made of stainless steel, fiberglass, ceramic tile, Plexiglas, or other material (or a swimming pool) that is at least 4 × 4 × 5 feet (1.2 × 1.2 × 1.5 m). A seat suspended from a scale or force transducer is needed to allow subjects to be weighed while they are completely submerged in water.

PROCEDURE

1. Subjects should wear minimal clothing. A tight-fitting bathing suit that traps little air is recommended.
2. Subjects should remove all jewelry and have urinated and defecated prior to the procedure.

3. Subjects should be 2 to 12 hours postabsorptive and have avoided foods that increase gas in the gastrointestinal tract. Menstruation may pose a problem for females because of associated water gain; thus, women should try to avoid being tested within seven days of menstruation.
4. A seat suspended from a scale or force transducer is needed to allow subjects to be weighed while completely submerged in water. The temperature of the water should be between 33 and 36 °C (91.4 and 96.8 °F).
5. The subject is weighed on land to determine dry weight, and the mass is converted to grams.
6. The subject enters the tank, removes potential trapped air from the skin, hair, suit, and so on, and attains a seated position while supported by a belt to minimize fluctuations.
7. Once the subject is seated and the chair height has been adjusted, the subject fully expires as much air as possible prior to leaning forward to be weighed.
8. The subject is weighed 5 to 10 times while submerged underwater for 5 to 10 seconds. The highest of the weights or the average of the three highest weights are used for analysis. The weight of the chair and belt need to be considered in the calculation.
9. Residual lung volume (RV) can be measured directly (which increases accuracy) in some systems or estimated based on height and age:

Males: RV (L) = [0.019 × ht (cm)] + [0.0155 × age (yrs)] – 2.24

Females: RV (L) = [0.032 × ht (cm)] + [0.009 × age (yrs)] – 3.90

Body density is calculated using the following equation:

BD = Mass in air (g)

[Mass in air (g) – mass in water (g)] – [RV (mL)]

Density of water

10. Body fat can be calculated using the Siri, Brozek, or population-specific equations mentioned previously (p. 26). Table 2.4 on page 38 provides percent body fat classifications.

BIOELECTRICAL IMPEDANCE ANALYSIS

Bioelectrical impedance analysis (BIA) is a noninvasive and easy-to-administer tool for determining body composition. The underlying principle for BIA is that electrical conductivity in the body is proportional to the fat-free tissue of the body (American College of Sports Medicine 2007; McArdle, Katch, and Katch 2007). A small electrical current is sent through the body (from ankle to wrist), and the impedance to that current is measured. Lean tissue (mostly water and electrolytes) is a good electrical conductor (i.e., has low impedance), whereas fat is a poor conductor and impedes an electrical current. Thus, BIA can be used to measure percent body fat and total body water. Single- and multifrequency currents can be used to determine body composition; multifrequency currents are more sensitive to the body's fluid compartments (McArdle, Katch, and Katch 2007). Most studies examining BIA have used the equation $V = pL^2 \cdot R^{-1}$, where V is the volume of the conductor, p is the specific resistance of the tissue, L is the length of the conductor, and R is the observed resistance (Graves et al. 2006).

EQUIPMENT

A variety of BIA analyzers are commercially available and vary widely in price.

PROCEDURE

1. The BIA device should be calibrated according to the manufacturer's instructions.
2. The subject lies supine on a nonconductive surface with arm and legs at the side, not in contact with the rest of the body.
3. The right hand and wrist and right foot and ankle areas are prepared with an alcohol pad and then allowed to dry.
4. BIA electrodes are placed on the metacarpal of the right index finger and the metatarsal of the right big toe, and the reference (detecting) electrodes are placed on the right wrist (bisecting the ulnar and radial styloid processes) and the right ankle (midpoint on the line bisecting the medial and lateral malleoli).
5. The current is applied and the BIA analyzer computes the impedance and percent body fat.
6. New BIA devices are simpler to use than older ones and require only that the subject either stand on the machine (i.e., an electronic digital platform scale with built-in stainless steel foot pad electrodes) with both bare feet or hold the BIA analyzer in both hands. The device provides instructions to the subject (i.e., when to stand on the unit).
7. On occasion, a platform BIA device will produce an error if the subject's feet are dry. Adding some moisture to the feet can solve the problem.

Accuracy among BIA devices varies greatly. Most BIA machines use their own equations that account for differences in water content and body density based on people's gender, age, and race or ethnicity, as well as physical activity levels. The variation for BIA is ±2.7 to 6.3% (Graves et al. 2006), but this method can provide an accurate result when proper methods are used. The subject must not have eaten or consumed a beverage within four hours of the test, exercised within 12 hours of the test, or consumed alcohol or diuretics prior to testing; in addition, the subject must have completely voided the bladder within 30 minutes of the test and had minimal consumption of diuretic agents such as chocolate or caffeine (American College of Sports Medicine 2007). Dehydration can lead to overestimations in percent body fat. Glycogen stores can affect impedance and can be a factor during times of weight loss. If possible, BIA measurements should not be taken before menstruation to avoid the possible effects of water retention.

Although BIA is a valid measure of body composition, percent body fat is consistently overestimated for lean people and underestimated for obese people. In athletes, BIA has been shown to significantly underestimate percent body fat when compared to hydrodensitometry (Dixon et al. 2005). Subject factors, technical skill, the prediction equation used, and the instruments used all affect the accuracy of BIA. For best results, the same BIA unit should be used for multiple testing points. Table 2.4 on page 38 provides percent body fat classifications.

AIR DISPLACEMENT PLETHYSMOGRAPHY

Body volume can be measured by air displacement rather than water displacement. Air displacement plethysmography (ADP) offers several advantages over other methods including safety. It is quick and comfortable and noninvasive, and it accommodates all people. However, a major disadvantage is the cost of purchasing the ADP unit.

The BOD POD (a commercial ADP system) uses a dual-chamber (e.g., 450 L subject test chamber, 300 L reference chamber) plethysmograph that measures body volume via changes in air pressure within the closed two-compartment chamber. It includes an electronic weighing scale, computer, and software system. The volume of air displaced is equal to body volume and is calculated indirectly by subtracting the volume of air remaining in the chamber when the subject is inside from the volume of air in the chamber when it is empty.

Sources of error for ADP testing include variations in testing conditions, the subject not being in a fasted state, air that is not accounted for in the lungs or trapped within clothing and body hair, body moisture, and increased body temperature. Reliability of ADP in adults is good and has been shown to be valid in comparison to hydrodensitometry and dual-energy X-ray absorptiometry (DXA), which we discuss later.

ADP has been shown to produce similar (to DXA and hydrodensitometry) percent fat measurements in collegiate female athletes (Ballard, Fafara, and Vukovich 2004) and collegiate wrestlers (Dixon et al. 2005) and is an effective assessment technique for monitoring changes in percent fat during weight loss. However, some studies have shown that ADP overestimates percent body fat in collegiate female athletes (Vescovi et al. 2002) and underestimates percent body fat (by 2%) in collegiate American football players (Collins et al. 1999).

EQUIPMENT

An ADP unit such as the BOD POD

PROCEDURE

1. The subject's information is entered in the BOD POD computer.
2. The BOD POD is calibrated according to the manufacturer's instructions.
3. The subject is properly prepared. Similar to hydrodensitometry, minimal clothing is worn. Swimsuits, compression shorts, sport bras, and swim caps are recommended. Items such as jewelry and glasses are removed. Percent fat may be underestimated by nearly 3% if a swimming cap is not worn and hair covers a large portion of the face (Higgins et al. 2001).
4. The subject's mass is determined via the digital scale.
5. The subject enters the chamber and sits quietly during testing while a minimum of two measurements (within 150 ml of each other) are taken to determine body volume.
6. Thoracic gas volume is measured during normal breathing (i.e., via the panting method, in which the subject breathes normally into a tube connected within the chamber, followed by three small puffs after the airway tube becomes momentarily occluded at the midpoint of exhalation) or can be predicted via equations.
7. Corrected body volume (raw body volume – thoracic gas volume) is calculated, body density is determined, and percent body fat is calculated using similar prediction equations to hydrodensitometry via the system computer.

DUAL-ENERGY X-RAY ABSORPTIOMETRY

Dual-energy X-ray absorptiometry (DXA) is a body composition measurement tool that is increasing in popularity. In addition to percent body fat, regional and total-body measures of bone mineral density, fat content, and lean tissue mass are given. The principle of absorptiometry is based on the exponential attenuation of X-rays at two energies as they pass through the body. X-rays are generated at two energies via a low-current X-ray tube located underneath the DXA machine. The differential attenuation is used to estimate bone mineral content and soft tissue composition. A detector positioned overhead on the scanning arm and a computer interface are needed for scanning an image.

EQUIPMENT

DXA machine

PROCEDURE

1. The DXA machine must first be calibrated (quality assurance) with a calibration block; it is ready to use once all of the checks pass.
2. The subject's information is entered into the software program.
3. The subject is prepared. Regular clothing may be worn, but everything metallic must be removed. Shorts and a T-shirt will suffice.
4. The subject is placed supine on the scanning table and properly positioned. The body should be centered within the perimeter lines and aligned with the central demarcation line. The head should be at least 2 inches (5 cm) from the top perimeter line to allow the scanning arm a few blank cycles. Hands should be flat on the bed and may need to be placed underneath the hips to fit within the perimeter. Legs should be positioned in alignment with the central demarcation line (the line should be between the legs) and braced at two levels with Velcro straps, near the knees and at the feet, to minimize movement and allow the subject to relax comfortably without moving. Large (tall and heavy) people may have difficulty positioning their entire bodies within the perimeter lines because the scanning bed is designed for people under 6 feet 4 inches (193 cm) and 300 pounds (136 kg). Muscular subjects may also have difficulty fitting within the perimeter. In these cases, the technician must position the subject as best as possible. DXA can be uncomfortable for subjects who have to contract their muscles to constrict their bodies. A different body composition tool (e.g., hydrodensitometry, BIA) may be better for large people despite the loss of data.
5. The subject lies motionless on the bed as the test is initiated. Movement can cause irregularities on the scan.
6. The subject is scanned rectilinearly from head to toe for 5 to 25 minutes, depending on the type of scan and the person's size. Newer DXA units have greatly reduced total scan time making this procedure more practical and easier to administer.
7. Upon completion of the scan, the technician needs to denote the regions of interest (based on the manufacturer's or standardized guidelines) in the subject's software file to obtain accurate regional body composition information prior to analysis.
8. DXA reports give regional (head, trunk, limbs) and total-body bone mass, lean tissue mass, and fat mass (and percent) data.

DXA has many advantages. It is easy to administer, fast, accurate, and comfortable for most subjects; regional measurements are attractive for many populations. In addition, a whole-body measurement produces less than 5 μSv of radiation, which is much less than CT scans, chest X-rays, and lumbar spine X-rays.

However, DXA does have some limitations. The scanning bed is not designed for large people, and the machines (e.g., General Electric Lunar, Hologic, and Norland) are large and expensive. In some areas, a physician's prescription may be needed for a DXA scan. DXA assumes a constant hydration state and electrolyte content in lean tissue, and hydration status could affect the results. Body thickness problems may serve as a source of error, and user error can occur when delineating regional measurements, thereby demonstrating the importance of a single technician for sequential testing. Lastly, the lack of standardization among DXA equipment manufacturers poses a problem. Differences exist in hardware, calibration methodology, imaging geometry (pencil versus fan-beam), and software, which result in different body composition results among machines. Body fat measurements have been shown to vary by approximately 1.7% when repeated measurements are taken on different DXA machines from the same manufacturer (Tataranni, Pettitt, and Ravussin 1996), so it is important to use the same machine for repeated testing.

DXA has been shown to correlate highly with hydrodensitometry and other body composition measurements. However, DXA scans typically register higher body fat percentages (i.e., 2 to 5%) for total-body measurements than other procedures do (Clasey et al. 1999; Kohrt 1998; Norcross and Van Loan 2004). Although the results of most validation studies show DXA to be an accurate tool for body composition measurement, limitations preclude it from becoming a gold standard at the current time.

COMPUTED TOMOGRAPHY SCANS AND MAGNETIC RESONANCE IMAGING

Cross-sectional imaging of the whole body can be viewed with computed tomography (CT) and magnetic resonance imaging (MRI). These techniques produce scans that can noninvasively quantify tissue volume such as regional fat distribution. Total-body composition analysis is possible with sequential "slicing" through the body and assumptions for tissue densities. For CT scans, X-rays (ionizing radiation) pass through the subject and create cross-sectional slices approximately 10 millimeters thick. The image represents a 2-D map of pixels; each pixel has a numerical value (attenuation coefficient) that helps differentiate tissues based on the density and electrons per unit mass.

For MRI scans, electromagnetic radiation excites and aligns hydrogen atoms in water and fat molecules (via a magnet). Hydrogen protons then absorb energy and generate an image. Fat and lean tissue can be quantified by selecting regions of interest on the scan.

Both MRI and CT scans have been validated and are beneficial in that they provide the opportunity to perform relative analyses of muscle, bone density, and intra-abdominal fat. Because the use of radiation in CT scans is a concern, however, they may only be viable for medical or research purposes. In addition, scanning is costly (especially MRI) making it impractical for most people.

NEAR-INFRARED INTERACTANCE

Near-infrared interactance (NIR) is based on principles of light absorption and reflection using near-infrared spectroscopy. A light wand or fiber optic probe is positioned perpendicularly on a body part (typically on the anterior midline surface of the biceps brachii), and infrared light is emitted at specific wavelengths. The absorption of the infrared beam is measured via a silicon-based detector that is expressed as two optical densities. Prediction equations estimate percent body fat via optical density, gender, height, physical activity level, and body weight. Some commercial versions of NIR (e.g., Futrex-5000, -5500, -6000, -6100) are portable and require minimal technician training, making them attractive to the health and fitness industry. However, a major limitation is the small body sampling area.

NIR has been shown to be valid and reliable for determining the body composition of female athletes (Fornetti et al. 1999), but it does produce a higher error rate than other body composition procedures. NIR has been shown to overpredict percent fat by up to 14.7% in young wrestlers (Housh et al. 2004; Housh et al. 1996) and is least effective for monitoring body composition changes following resistance and aerobic training (Broeder et al. 1997). Thus, NIR is not recommended for routine use in healthy and athletic populations.

Body Fat Standards

Interpretation of body fat percent estimates is complicated because all methods are indirect (error needs to be considered) and there are no universally accepted standards for percent fat. Although national standards have been developed in the United States and have been accepted for BMI and WHR, none exist for percent fat estimates. Practitioners must choose from many classifications proposed by various authors. Table 2.5 presents some general percent fat classifications, although many other charts have been used.

A few points of emphasis need to be made. Human body fat may be categorized as essential or nonessential. Essential body fat fulfills several pertinent functions in the body and is needed for good health. It is found throughout the body but especially in the heart, lungs, liver, spleen, kidneys, intestines, muscles, bone, and central nervous system (McArdle, Katch, and Katch 2007). Essential body fat accounts for approximately 5% of body weight in males and 12% in females (this difference accounts for gender-essential fat primarily resulting from hormonal differences and childbearing factors). If percent fat falls below these levels, serious adverse health effects might ensue. This can become an issue for athletes such as wrestlers or bodybuilders who may keep their body fat levels low near competition time. Nonessential, or storage, body fat includes the subcutaneous adipose tissue as well as visceral fat tissue. This type should be kept low for health and athletic purposes because it contributes to the rest of the body fat percentage.

Comparison of Body Composition Techniques

Each body composition technique described has advantages and disadvantages, which are presented in table 2.4. The coach, practitioner, or athlete must weigh the positives with the negatives when determining which technique to use. Ultimately, practicality may be the determining factor. Cost, time, comfort, and accessibility are critical considerations when making this decision, especially when several athletes will be tested on multiple occasions.

TABLE 2.4 Percent Body Fat Classifications

	AGE (YEARS)						
Rating (male)	**<17**	**18–25**	**26–35**	**36–45**	**46–55**	**56–65**	**>66**
Very lean	5	4–7	8–12	10–14	12–16	15–18	15–18
Lean	5–10	8–10	13–15	16-18	18–20	19–21	19–21
Leaner than average	–	11–13	16–18	19–21	21–23	22–24	22–23
Average	11–25	14–16	19–21	22–24	24–25	24–26	24–25
Slightly high	–	18–20	22–24	25–26	26–28	26–28	25–27
High	26–31	22–26	25–28	27–29	29–31	29–31	28–30
Obese	>31	>28	>30	>30	>32	>32	>31
	AGE (YEARS)						
Rating (female)	**<17**	**18–25**	**26–35**	**36–45**	**46–55**	**56–65**	**>66**
Very lean	12	13–17	13–18	15–19	18–22	18–23	16–18
Lean	12–15	18–20	19–21	20–23	23–25	24–26	22–25
Leaner than average	–	21–23	22–23	24–26	26–28	28–30	27–29
Average	16–30	24–25	24–26	27–29	29–31	31–33	30–32
Slightly high	–	26–28	27–30	30–32	32–34	34–36	33–35
High	31–36	29–31	31–35	33–36	36–38	36–38	36–38
Obese	>36	>33	>36	>39	>39	>39	>39

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TABLE 2.5 Advantages and Disadvantages of Body Composition Assessment Techniques

Assessment	Advantages	Disadvantages
BMI	Easy to assess Does not require special equipment Noninvasive clinical tool	Not valid tool for athletes Does not factor large muscle mass
Girth	Easy to administer Minimal training needed Minimal equipment (tape measure) Quick test time Many formulas to select from Good indicator of size changes	Girth size not always related to fat content Less accurate than other methods
Skinfold	Easy to use once trained Time efficient Noninvasive Inexpensive (cost of calipers) Many equations to choose from Can test many athletes in less time	Prone to technician error Less accurate for very lean or obese people Considers mostly subcutaneous fat Potential discomfort to subject (pinching or embarrassment)
Hydrodensitometry	Gold standard Very accurate, valid, and reliable	Time consuming Requires a lot of equipment and space High cost of equipment Requires in-depth examiner knowledge Water submersion can be uncomfortable Requires measure of lung volume
BIA	Requires little technical expertise Testing is very fast Very easy especially when using scale-type or handheld models Testing unit is easily transportable Does not require minimal clothing or much bodily exposure	Several confounding variables must be avoided High degree of error if procedures are not strictly followed
ADP	Relaxed atmosphere for subject Easy to operate Short measurement time Good for every population Accurate	Very expensive Equipment not very accessible Must wear minimal, tight clothing
DXA	Very accurate Radiation exposure is low Comprehensive measurements Can wear regular clothing Relatively quick measurement time Subject relaxed during test Gives regional measurements	Very expensive Less accurate when going from one DXA unit to another May require prescription from physician
NIR	Safe and noninvasive Fast and convenient Portable Little training needed	Least accurate assessment tool
CT/MRI	Very accurate Many applications	Very expensive Limited access Time consuming

Professional Applications

Strength and conditioning professionals should include frequent body composition measurements in athletes' general training macrocycles. Body composition measurements are easy to perform and are not fatiguing to the athlete the way performance tests can be. Two major issues may be encountered. The first is the cost of equipment. A few measurement tools are inexpensive, whereas some technology may be cost prohibitive. For example, DEXA, MRI, CT scans, and air displacement plethysmography units are expensive and may be beyond the budget of many athletic programs. In addition, a facility that has these technologies will typically have only one unit. Thus, testing a large group of athletes could be very time consuming. Bioelectrical impedance units are affordable and can be advantageous for testing athletes because they are quick and portable, and multiple units can be purchased to permit the testing of large groups of athletes in a short period of time. However, athletes' hydration status and activity level need to be carefully monitored prior to testing. Underwater weighing may be an option (although it could be cost prohibitive for some programs) but generally takes longer and requires longer testing sessions because only one athlete can be tested at a time. A period of familiarization is needed so athletes understand the importance of expelling as much air as possible, and some athletes may find holding their breath underwater uncomfortable.

The most practical solution for the strength and conditioning professional is to develop a body composition measurement program based on body weight, skinfold, and girth measurements. Body weight measurements require only a scale, which is not cost prohibitive. These can be performed frequently including multiple times a day. This is especially important when monitoring athletes who may be making weight (i.e., wrestlers and other athletes in combat sports) or monitoring hydration status, such as when weighing American football players before, during, and after practice in hot, humid conditions to quantify fluid weight loss. Skinfold calipers are relatively inexpensive, and multiple calipers can be purchased, which makes testing large groups of athletes in a short period of time easy. Population-specific equations (or tables) can be used for quick body fat percentage calculations. Using a spreadsheet to calculate the data increases the speed of testing; an assistant can immediately input data, obtain a fat percentage, and give the athlete rapid feedback. Tape measures can be purchased at low prices and are very useful for girth measurements. Girth measurements can also be useful for indirectly assessing muscle hypertrophy from a resistance training program. Thus, the strength and conditioning professional can be well equipped economically for large-scale body composition testing by having one or more accurate scales, skinfold calipers (preferably Lange), and tape measures (preferably Gulick tape measures because tension can be standardized) at their facilities.

The second issue facing the strength and conditioning professional is homogeneity of the testing staff and procedures. Because a large number of athletes may need to be tested, multiple staff members or personnel may be performing the tests. It is very important that technique be standardized among the staff.

In fact, one coach or assistant should be assigned to each athlete for consistent and accurate data acquisition. For example, with skinfold analysis two practitioners' techniques may be slightly different yielding two different values for the athlete. In this case, the body fat difference is due to tester error rather than physiological changes.

Calibration sessions for single athletes can be helpful. In such sessions, multiple testers perform the skinfold analysis on the same athlete, and the results are compared. Consistent results from staff members confirm data consistency. However, because athletes with more body fat have more variation, calibration sessions are most productive when small, medium, and large athletes are examined. This gives good practice to those learning proper technique. Thus, multiple athletes can be used as subjects, but the results must be compared among the same individual athletes. That is, athletes A, B, and C are tested, but testers compare results for A to calibrate technique, then compare results for B, and subsequently compare results for C. If the data vary glaringly, the staff must alter the technique to produce greater consistency.

With girth measurements, a slight variation in the location of the tape measure or a difference in tension applied to the tape measure can yield variable results. Body weight measurements, on the other hand, are standard provided the scale is functioning properly.

The head strength and conditioning coach must ensure that the staff uses consistent techniques. The most accurate system is to assign certain staff members to certain athletes. This standardizes the procedures per athlete and provides more accurate measurements of body composition over time.

SUMMARY

- Excess body fat is detrimental to health and performance, so measurement of body composition is of great importance for health professionals, fitness practitioners, athletes, and coaches.
- Several methods exist to indirectly measure body composition. Simple methods such as girth measurements, BMI, and skinfolds can be performed with little equipment and at low cost, and are fast and easy to perform, which is advantageous when testing large numbers of people over time.
- BIA is another simple body composition tool that can be attractive for use with athletic populations. However, equipment is more costly than that for skinfold and girth measurements, and BIA is prone to error.
- Advanced body composition estimates (hydrodensitometry, ADP, DXA, CT, and MRI) can be made when specific information is needed, equipment is available, and trained technicians perform the procedures. These methods are less practical for many athletes, but show greater accuracy, reliability, and validity than simpler methods.