11 Weight and Body Composition

Learning Objectives

1. Describe the various components that make up the body's composition.
2. Describe how body composition and body weight are measured, how these results should be interpreted, and how each relates to performance.
3. Explain error of measurement and compare and contrast the measurement error of each method used for estimating body composition.
4. Understand how the relative need for size (weight), strength, and speed in a particular sport is reflected in the body composition of elite athletes in those sports.
5. Calculate target body weight and minimum body weight.
6. Outline the basic principles associated with gaining lean body mass and losing body fat and the most appropriate times during the yearly training cycle to change body composition or weight.
7. Define weight cycling and explain the effects it may have on performance and health.
8. Discuss the legality, ethics, safety, and effectiveness of muscle-building supplements such as anabolic/androgenic steroids and prohormones and weight-loss supplements such as ephedrine and caffeine.

Pre-Test: Assessing Current Knowledge of Body Composition and Body Weight

Read the following statements and decide if each is true or false.

1. Percent body fat and fat mass can be precisely measured in athletes with a number of different methods.
2. The most accurate method of measuring body fat for any athlete is underwater weighing.
3. In sports in which body weight must be moved or transported over a distance (e.g., distance running), it is a performance advantage to have the lowest weight possible.
4. To increase muscle mass, most athletes need a substantial increase in their usual protein intake.
5. For athletes who want to restrict energy intake to lose body fat, the recommended time to do so is at the beginning of the preseason or during the off-season.

Body composition and body weight are related to performance, appearance, and health. Body composition, particularly the relative amount of **muscle mass,** has the potential to positively impact exercise and performance. Weight and body composition may have a substantial impact on performance in certain sports, but may play a much lesser role in others. In some sports body weight must be certified before the athlete can participate in that day's competition and the focus, at least temporarily, is achieving a particular scale weight. Body composition and weight influence body image, and the desire to attain a particular body image or weight can be a powerful motivator. An excessive or rapid loss of body weight can produce harmful medical consequences in otherwise healthy individuals. Excess body fat, especially fat that accumulates deep in the abdominal cavity, may influence the onset or progression of chronic diseases and long-term health. Keeping all three areas in mind—performance, appearance, and health—helps athletes maintain the proper perspective when setting body weight and composition goals.

In many sports attaining a relatively high percentage of lean mass and a relatively low percentage of body fat is an appropriate goal that has the potential to improve performance. However, it is not possible to predict the percentage of body fat associated with optimal performance and "lowest" is not necessarily "optimal." Achieving the "most" muscle mass or the "lowest" percentage of body fat possible may not be desirable. For example, the excess weight from skeletal muscle can damage joints and ligaments. Like many other aspects of human physiology, the extremes can be dangerous and most athletes find that their desirable body composition does not lie at the extreme ends of the body composition continuum.

The percentage of body fat of elite athletes in a number of sports has been measured and the results are sometimes used as a guideline for lesser-trained athletes in those sports. Measurements of body fat are just *estimates,* however, and should be interpreted with caution. Individual characteristics such as genetic predisposition to fatness or leanness must be considered so that realistic goals can be set. Trying to obtain an unrealistic percentage of body fat that has been arbitrarily chosen (e.g., a male who wants to be 4 percent body fat) can be unproductive, ineffective, and dangerous.

In sports in which weight must be certified (e.g., wrestling) or judging of performance is subjective and influenced by appearance (e.g., figure skating), a low body weight may be beneficial. Some athletes naturally have a low body weight, but others find themselves using dangerous practices (e.g., voluntary starvation, dehydration) to produce the large or rapid weight loss needed to "make weight." In acrobatic sports, such as gymnastics, a high **power-to-weight ratio** is desirable (i.e., having a lot of muscle to produce force at a minimal body weight). The establishment of a safe minimum body weight is important and must take into account the athlete's current amount of muscle mass, frame size, genetic predisposition to leanness or fatness, and biologically comfortable weight range. Attaining too low of a body weight can come at a cost to both performance and health—reduction of muscle mass, loss of body water, loss of bone mineral density, and initiation of disordered eating behaviors.

Aside from performance-related reasons, appearance may motivate athletes to make body composition changes. Athletes who achieve a body composition that is held in high esteem by society (e.g., lean and muscular, thin and **prepubescent**) receive praise and positive reinforcement. For some, self-esteem is closely tied to body image, and thus, body weight or composition. For these individuals, changes in body composition, especially increases in body fat, may be a source of great concern and unwanted media attention.

Body composition and weight are important in sports with weight classes (e.g., wrestling) or subjective judging that is influenced by appearance (e.g., figure skating, gymnastics).

To change body composition or weight the athlete must alter energy intake, energy output, or both. The athlete will need a well-thought-out exercise and diet plan that correlates with the demands of each training cycle. To increase muscle mass, an athlete must engage in strength training, consume a sufficient amount of energy (kcal), and be in positive nitrogen balance to support tissue growth. To decrease body fat, energy expenditure must be greater than energy intake. The active recovery (off-season) or the early preseason periods, when training volumes are lower than the precompetition period, are typically the best times for substantial losses of body fat. Many athletes want to simultaneously increase muscle mass and decrease body fat, and achieving both of these goals takes an individualized plan and some trial and error.

In the United States, anything related to the topic of weight loss receives automatic attention, in part, because overweight and obesity are epidemic. Most trained athletes do not need to lose large amounts of body fat. However, small increases or decreases in body fat have the potential to affect performance and appearance, so fat loss is also a hot topic among athletes. Some athletes can gain substantial amounts of body fat in the

Muscle mass: The total amount of skeletal muscle in the body. Expressed in pounds or kilograms.

Power-to-weight ratio: An expression of the ability to produce force in a short amount of time relative to body mass.

Prepubescent: Stage of development just before the onset of puberty.

An athlete's body composition can be important for reasons other than performance.

off-season and want to reduce fat stores rapidly prior to the return to training camp. Athletes are not immune to advertisements or rumors that promise fast and easy fat loss.

For most people, reducing body fat is a relatively slow process, but the loss of body weight can be rapid when achieved primarily by water loss. Athletes who want to reduce body weight rapidly to "make weight" often use a combination of methods including diuretic use and excessive sweating in addition to fasting and increasing exercise. These techniques can result in mild to serious or fatal medical complications.

Measuring body weight and body composition can provide information that can help athletes attain their performance, appearance, and health goals. However, the usefulness of body weight and composition measures depends on their accuracy. Additionally, the results must be interpreted correctly so appropriate goals may be set and progress can be monitored. This chapter begins with a discussion of body composition and weight and some of the methods used to assess each as accurately as possible.

Understanding Weight and Body Composition

The term *body composition* refers to all of the components that make up the body. The human body is composed of an extraordinary variety of different types of cells and materials. Because they are so numerous, these components are often grouped into more general categories for their study and discussion. In the fields of exercise physiology and sports nutrition, body composition is often subdivided into the broad categories of **fat mass** and **fat-free mass.** Fat mass is all of the fat material in the body and fat-free mass is composed of all other tissues in the body that are not fat, the most prominent nonfat tissue being skeletal muscle. Athletes are also interested in the ratio of fat mass to total body mass, which may be expressed as **percent body fat.** The weight of the body is also a factor, particularly in sports with weight categories.

CONCEPTS OF BODY MASS, WEIGHT, AND COMPOSITION

Of primary importance are the specific components of body tissues—total **body mass** (weight), body fat (fat mass), muscle mass, bone mass and density, and fluids. The term *mass* is often used interchangeably with weight, but technically they are not the same. *Mass* is the term that describes the amount of matter or material that makes up an object, while weight is an expression of the force that is exerted by that object due to gravity. To illustrate the difference, consider the mass and weight of astronauts during a space mission. They have the same body mass in space as they do on Earth, but they "weigh" much less in space due to the greatly reduced force of gravity. Because the difference on Earth is minute, the terms *mass* and *weight* are used interchangeably in this text. Other terms commonly used are defined in Spotlight on Enrichment: Understanding Body Composition Terminology.

SPOTLIGHT ON ENRICHMENT

Understanding Body Composition Terminology

Body Mass: Total amount of matter or material of the body; commonly used interchangeably with weight. Expressed in pounds (lb) or kilograms (kg).

Fat Mass (FM): Total amount of fat in the body. Expressed in pounds or kilograms.

Percent Body Fat (% BF): The amount of fat relative to body mass. Expressed as a percentage of body weight.

Fat-Free Mass (FFM): The total amount of all tissues in the body exclusive of fat including muscle, bone, fluids, and organs. Expressed in pound or kilograms.

Essential Fat: The minimum amount of body fat necessary for proper physiological functioning; estimated to be approximately 3 percent of body weight for males and 12 percent for females.

Lean Body Mass (LBM): Total amount of all physiologically necessary tissue in the body; Fat-Free Mass and essential fat (FFM + essential fat). Often used incorrectly to mean the same as FFM. Often used generically when referring specifically to muscle mass (e.g., "strength training results in an increase in LBM"). Expressed in pounds or kilograms.

Muscle Mass: Total amount of skeletal muscle in the body. Expressed in pounds or kilograms.

Bone Mass or Bone Mineral Content (BMC): Total amount of bone in the body. Expressed in pounds or kilograms.

Bone Mineral Density (BMD): The amount of bone per unit area. Expressed in grams per cubic centimeter (g/cm^2).

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Males and females may store fat in different sites, either predominantly in the abdominal area or in the hips, thighs, or buttocks.

Both for athletes and for the general public, the most common distinction in body composition is body fat. Fat in the body is typically categorized as essential or storage fat. **Essential fat** is the minimum amount of body fat necessary for proper physiological functioning and is estimated to be approximately 3 percent of body weight for males and 12 percent of body weight for females. Of the 12 percent, approximately 9 percent is considered sex-specific fat, the fat necessary for proper hormonal and reproductive functions. When compared to male athletes in similar sports, females typically have a higher percentage of body fat than their male counterparts. For example, both male and female bodybuilders are extremely lean; however, the leanest elite female bodybuilders will have a greater percent of body fat than the leanest elite male bodybuilders simply because of the differences in gender.

Storage fat is composed of **subcutaneous fat** and **visceral fat.** Subcutaneous fat is located under the skin and is typically the largest amount of fat in the body. Visceral fat surrounds organs and is located well below the skin, for example, in the abdominal area. Males and females may store fat in different sites, displaying a gender-specific physiological preference for the pattern and location of fat storage. Male fat distribution is described as android and is characterized by fat storage predominantly in the abdominal area. Normal-weight females generally store fat in the hips, thighs, and buttocks, a pattern known as gynoid fat distribution. These typical fat distribution patterns have led to body shape being described as similar to a pear (gynoid) or an apple (android), and may have health implications (see Chapter 12).

However, gender alone cannot explain fat distribution patterns. Females do not always exhibit the typical gynoid pattern due to genetics, menopausal status, and obesity, which may result in a tendency to store excess fat in the abdominal area. Males also differ from one another due to differences in fat distribution within the abdominal region. In some males, excess fat is more readily stored in deep abdominal (i.e., visceral) fat than in subcutaneous abdominal fat. Visceral fat is more metabolically active than subcutaneous fat and is a factor in some chronic diseases as explained in Chapter 12.

Although athletes are interested in body fat, they are also concerned about fat-free mass or the tissues in the body that are not fat. Fat-free mass includes muscle, bone, fluids, and organs. In particular, athletes focus on muscle mass. As with body fat, estimating only muscle mass is difficult, so it is more common to estimate **lean body mass (LBM).** LBM refers to the total amount of all physiologically necessary tissue in

Fat Mass (FM): Total amount of fat in the body. Expressed in pounds or kilograms.

Fat-Free Mass (FFM): Total amount of all tissues in the body exclusive of fat; includes muscle, bone, fluids, organs, etc. Expressed as pound or kilograms.

Percent Body Fat (% BF): Amount of fat relative to body mass. Expressed as a percent of total body weight.

Body mass: Total amount of matter or material of the body; commonly used interchangeably with weight. Expressed in pounds or kilograms.

Essential fat: Minimum amount of body fat necessary for proper physiological functioning; estimated to be approximately 3 percent of body weight for males and 12 percent for females.

Subcutaneous fat: Fat that is stored in a layer under the skin.

Visceral fat: Fat that is stored around the internal organs.

Lean Body Mass (LBM): Total amount of all physiologically necessary tissue in the body; i.e., Fat-Free Mass and essential body fat. Expressed in pounds or kilograms.

$$\text{BMI} = \frac{\text{Weight (kilograms)}}{\text{Height}^2\text{ (meters)}}$$

◀ BMI = body mass index

Figure 11.1 Body Mass Index (BMI) kg/m^2

the body and includes fat-free mass and essential body fat. In everyday language, the term *muscle mass* is interchanged with the term *lean body mass* (e.g., "strength training results in an increase in LBM"), but muscle is only one component of lean body mass. Body composition discussions usually focus on body fat and muscle mass and these two components will be the focus of this chapter. Bone density is discussed in Chapters 9 and 12 and fluids are covered in Chapter 7.

Body shape can also enter into body composition discussions. Individuals may be divided into one of three categories based on somatotype or body build: Endomorph, mesomorph, or ectomorph, based upon the work originally published by Sheldon in 1940. Endomorphs are characterized as being stocky with wide hips and a tendency to easily gain body fat, especially visceral fat. Ectomorphs are typically described as being slightly built with less developed muscle mass and fat stores. Many ectomorphs have difficulty gaining weight. Mesomorphs, especially males, can gain muscle mass relatively easily and typically do not have excessive amounts of body fat. Somatotypes may be useful when discussing genetic predisposition and body composition, especially with those who have set unrealistic goals and are struggling with body image problems.

Many people, including athletes, know their usual body weight. Body weight has been used in various ways, either alone or in relation to some other factor such as height. Body weight can be assessed relative to body height, a measurement known as Body Mass Index (BMI). The formula for calculating BMI is shown in Figure 11.1. Appendix N features a nomogram with precalculated BMI. BMI is a screening tool for the general population that helps individuals determine a "healthy weight" range and is not used with athletes. The BMI formula assumes that adult height is stable and that any increase in scale weight is a result of an increase in body fat. The use of BMI as a tool to screen for chronic disease risk in the general population is explained in Chapter 12.

It is inappropriate to use BMI with pregnant females (whose increase in weight is due to more muscle, blood, and fluid, as well as fat), people who have decreased in height due to osteoporosis, or trained athletes. Trained athletes typically have more skeletal muscle and less body fat than sedentary adults. To illustrate, a 6'3" (1.9 m) male athlete who weighs 240 lb (109 kg) would have a BMI of 30 and be classified as obese. As is clear from the photo on the next page, this athlete is not obese; rather, he is lean and his percentage of body fat is

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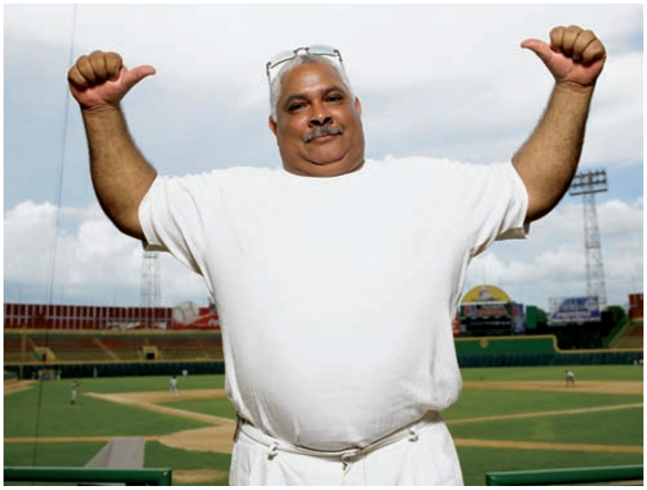

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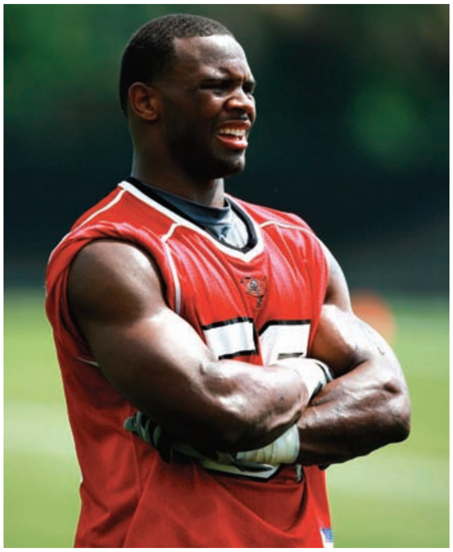
Body shape is often categorized as ectomorphic, mesomorphic or endomorphic.



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This athlete is lean and muscular but falls into the obese category by body mass index (BMI).

relatively low. BMI is not an appropriate disease risk screening tool for athletes.

While the use of weight for comparison to others or for tracking individual change over time might be useful, the major problem with the use of body weight is that it gives no information about body composition. Weight is also an imprecise measure of health. In most cases it is more important to know the absolute amount of certain tissues and their relative proportion to other tissues in the body than to focus on body weight.

Body fat is expressed as an absolute amount (fat mass in pounds or kilograms) or as a percentage of the total body mass (percent body fat). Normative values for percent body fat for adult men and women by decade are found in Appendix M.

The value in distinguishing body composition, particularly body fat, can be seen in an example of a sumo wrestler and a bodybuilder. These two athletes have the same body weight, yet dramatically different body composition. The sumo wrestler has a much larger percentage of body fat while the bodybuilder has much less body fat and more muscle tissue. Similarly, two females may both weight 110 lb (50 kg) and appear to be "thin" because they have a relatively low body weight. However, one may have a high percentage of body fat and a lack of muscle tissue compared to the other who has more developed skeletal muscle and a smaller amount of body fat.

Discussion and determination of body composition are complicated by the vast array of tissue types in the body. Various models have been proposed to simplify the estimation and analysis of body composition, and each accounts for the major constituents of the body in a different way (see Figure 11.2). The simplest is the two-compartment model, which accounts for fat mass (FM) as one compartment and fat-free mass (FFM) as a single compartment consisting of all tissues in the body except for fat. The major assumption with the two-compartment model is that all tissues in the FFM have the same density. This assumption obviously builds some error into the model, as it is well known that tissues as different as muscle and bone do not have a uniform density. In addition, the density of certain tissues, such as bone, may differ substantially between individuals or in the same individual over the life span. The two-compartment model is simple, but is based upon assumptions that reduce its accuracy.

To determine body composition with greater accuracy, three- and four-compartment models were created once the technology was developed to measure specific tissues (Figure 11.2). For example, dual-energy X-ray

Photo Japan/Alamy

Robert Cianflone/Getty Images

The sumo wrestler and the bodybuilder have similar body weight yet dramatically different body composition.

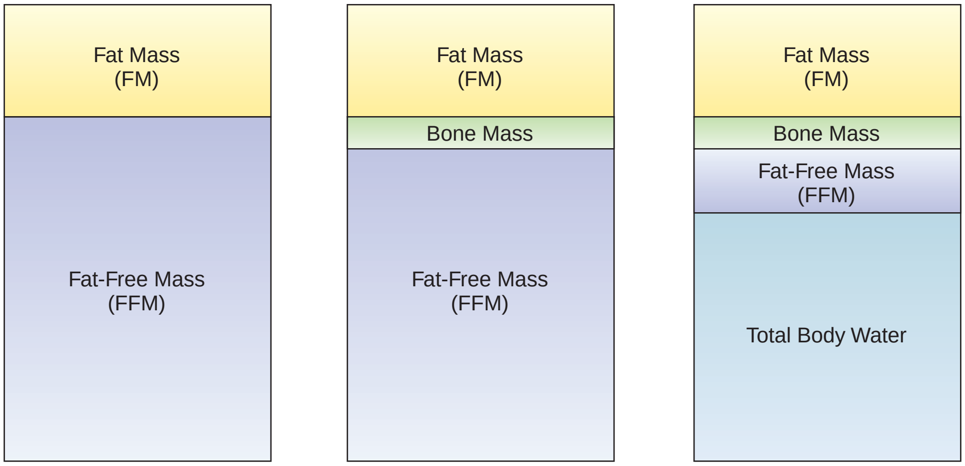


Figure 11.2 Two-, Three-, and Four-Compartment Models of Body Composition

absorptiometry (DEXA) technology allowed for the measurement of bone mineral density and bone mass and led to the development of the three-compartment model. Use of isotope dilution and bioelectrical impedance analysis (BIA) to determine total body water provided the information necessary for a four-compartment model, which provides better estimates of body composition by accounting for more types of tissues than the other models.

Measuring Weight and Body Composition

To understand weight and body composition, one must understand the techniques used to estimate them and the errors that result from any type of measurement. Weight or body composition measures are meaningless if accurate procedures are not used. A detailed discussion of the exact procedures involved with each method is beyond the scope of this text, and good reviews can be read in a number of fitness assessment resources (Whaley et al., 2006; Nieman, 2007). Even when the procedure is performed correctly, the results can be misinterpreted if the standard error of the estimate is not considered. The purpose of this section is to enable students in sports-related fields to acquire a practical, working knowledge of this potentially confusing subject with a strong understanding of the appropriate use and limitations of body composition assessment.

MEASURING BODY WEIGHT

A balance beam scale or a digital scale should be used to determine body weight (see Figure 11.3). To ensure accuracy, the scale should be calibrated monthly or quarterly and immediately after being moved. Scale weight should be taken as soon as the individual is awake, after emptying the bladder, and before any food or drink is consumed. On a balance beam scale, weight should be recorded to the nearest 0.5 lb or 0.2 kg (Modlesky, 2006). Home scales are convenient but most lack the accuracy of a balance beam scale. Repeated scale weights (e.g., daily, weekly) should be taken on the same scale under similar conditions (e.g., time of day).

Andy Doyle

Figure 11.3 Balance Beam Scale

METHODS FOR ESTIMATING BODY COMPOSITION

There are a variety of methods available to determine body composition, each with advantages and disadvantages (see Table 11.1). Some of the factors that must be considered with any method are the accuracy or precision of measurement, practicality, ease of use, time

Table 11.1 Comparison of Methods Used to Estimate Body Composition

Method	Accuracy	Practicality and Portability	Ease of Use	Time	Cost	Subject Comfort and Effort	Technician Training
Underwater (hydrostatic) weighing	SEE = ±2.7%	Practical in exercise physiology laboratories or large fitness centers; Not portable	Requires subject to submerge, exhale, and hold breath	~ 30 minutes because the procedure should be repeated 5 to 10 times	Initial purchase of equipment is expensive	Subject may be uncomfortable wearing a bathing suit, submerging in water, and exhaling air	Training is needed but is not difficult
Plethysmography	SEE = ±2.7–3.7%	Requires 8' × 8' space; Can be moved with proper equipment, but takes effort	Requires subject to sit quietly	~ 5 minutes	Initial purchase of equipment is expensive	Subject may be uncomfortable wearing a bathing suit and cap and sitting in an enclosed space	Minimal training needed
Skinfold measurements	SEE = ±3.5%	Practical in settings that have a private area; Very portable	Requires subject to be still; Measurement sites must be determined and marked	< 5 minutes	Initial purchase of equipment is relatively inexpensive	Subject may be uncomfortable partially disrobing; Some skinfolds are difficult to grasp	Training and consistency are critical; Technique improves with experience
Bioelectrical Impedance Analysis (BIA)	SEE = ±3.5%	Practical in most settings; Very portable	Easy to use	< 5 minutes	Initial purchase of equipment is moderately expensive	Procedure is simple but pre-measurement guidelines require substantial subject compliance	Minimal training needed
Near-infrared Interactance (NIR)	SEE = ±4–5%	Practical in most settings; Very portable	Easy to use	< 5 minutes	Initial purchase of equipment is moderately expensive	Simple procedure; Generally no problems	Minimal training needed
Dual-Energy X-ray Absorptiometry (DEXA)	SEE = ±1.8%; more research needed to verify SEE	Practical in imaging centers, physicians' offices, or research facilities; Not portable	Easy to use	~ 5 to 10 minutes	Initial purchase of equipment is very expensive	Simple procedure; Subject is exposed to a very small amount of radiation; Use prohibited during pregnancy	Training is needed; License to operate is required
Computed Tomography Scans (CT) and Magnetic Resonance Imaging (MRI)	Not yet established	Practical in imaging centers and research facilities; Not portable	Requires subject to be still throughout the entire procedure	~ 30 minutes	Initial purchase of equipment is very expensive	Procedure is relatively simple with some subject discomfort	Training is needed; License to operate is required

Legend: SEE = Standard Error of the Estimate required to obtain the measurement, cost, portability, comfort, effort required by the subject, and training required of the technician. Accuracy is the most important element, but some of the most accurate measurement technologies cannot be used outside a research setting. Methods with lesser accuracy are sometimes used for practical reasons. Some easy-to-use methods are practical but their accuracy is low and they may give athletes a false picture of their true body composition. In some cases the accuracy is so low the estimate is essentially meaningless.

The most important point to understand at the outset is that body composition, specifically body fat, cannot be directly measured except by chemical analysis of human cadavers. All other methods of determining body composition estimate or predict body composition using data from the direct chemical analysis of a relatively limited number of human cadavers. It is even difficult to accurately estimate body fat in cadavers. If one thinks about the different roles of fat (e.g., cell membranes, covering nerve cells, surrounding internal organs) and where it is distributed in the body (e.g., adipocytes, under the skin, muscle cells, blood), then one can gain an appreciation for the difficulty in accounting for all of the fat mass in the body.

Error of Measurement. Because the only true measurement of the amount of fat in the body is by chemical analysis of cadavers, all current approaches to determining body composition estimate or predict body fat from some other measurement. Therefore, all of these methods are indirect determinations and will have some built-in or **inherent** error. In addition, there is potential for technical error in the assessment method itself. It is extremely important to understand the potential for these errors and how they might affect body composition results and recommendations based on those results.

To illustrate measurement error, consider underwater weighing as a method of determining body composition, specifically percent body fat. This technique is used to determine the density of the body from which the percentage of body fat is predicted. The original studies from which these prediction equations were developed show there is a strong correlation between body density and percent body fat, but there is not 100 percent accuracy (Brozek et al., 1963; Siri, 1956). This type of error is expressed as the Standard Error of the Estimate (SEE) and represents the degree to which the measured factor is likely to vary above or below the result obtained.

The SEE for percent body fat determined from underwater weighing is approximately ± 2.7 percent (Lohman, 1992). This means that if percent body fat is determined as accurately as possible by the underwater weighing technique for a group of people, it is likely that the result obtained will be within a range that is 2.7 percent above or below the figure determined for two-thirds of the people measured. In other words, even if this technique is performed flawlessly, a person whose body fat result by underwater weighing is determined to be 15 percent may actually have body fat as high as 17.7 percent or as low as 12.3 percent. Out of a group of 100 people with a body fat estimate of 15 percent, 67 will actually have a percentage of body fat within the range of 12.3 to 17.7 percent. While this is a fairly large range, one also must be aware that the remaining one-third of the group, or 33 people, are likely to have their "real" body fat percentage be even further outside the ± 2.7 percent range.

Underwater weighing is one of the more "accurate" methods, so one can easily see where caution must be taken in interpreting body composition results. Those who work with athletes should be aware of the error associated with various body composition assessment methods and, in particular, should not assume false precision for these methods. For example, body fat percentages expressed to 2 or 3 decimals suggest a degree of measurement precision that is unrealistic (e.g., a printout of a body composition test that states "Your body fat is 15.35%"). Caution must also be used when interpreting small changes in body fat percentage. Changes in body composition of 1 or 2 percent, particularly over a short period of time (i.e., days to weeks), should be interpreted carefully because this amount of change is within the measurement error of the method.

All measurement methods have a certain amount of error that is inherent in the methodology. This error assumes the technique is administered with the highest degree of adherence to the appropriate procedures. There is additional error, however, in all of these methods that may be associated with how the body composition technique is performed, either by the subject or by the technician responsible for the measurement. Technical error that may be added to the error inherent in the method must be carefully considered, both in choosing an appropriate technique and in interpretation of the results. Simply stated, body composition that is assessed by any indirect method is not precise because of measurement error.

Athletes may wonder which method of measuring body composition is the most accurate. Underwater weighing was used to establish some of the early estimations of body fat from cadavers and has therefore long been considered the gold standard of body composition methods. It has also been used as the **criterion** for the establishment of other methods such as the skinfold technique. Underwater weighing is no longer considered the gold standard because there are now more sophisticated methods (e.g., magnetic resonance imaging and computed tomography) that are used as criterion methods, although there is still a lack of data from these newer methods to establish population norms (Modlesky, 2006). These methods are also not practical to use in most cases, so underwater weighing is often considered to be the most accurate method readily available to athletes.

$$\textbf{Body density} = \frac{\text{Mass}}{\text{Volume}}$$

$$\textbf{Body density} = \frac{\text{Weight in air}}{\dfrac{\text{Weight in air - weight in water}}{\text{Density of water}} - \text{Residual volume}}$$

Figure 11.4 Hydrostatic (Underwater Weighing) Formulas

Body density is determined from the mass divided by the body's volume. Mass is measured as weight (weight in air). Volume is determined as the buoyant force in water; the difference between the body's weight in air and submerged in water. Other factors to account for in the equation are the density of the water and the residual volume (air that remains in the lungs).

DENSITOMETRY (UNDERWATER WEIGHING AND PLETHYSMOGRAPHY)

One approach to estimating body composition is by determining the overall density of the body. Fat tissue has a lower density (0.9 g/ml) than other tissues, so theoretically, the less dense a person's body is the more body fat is present. How is body density determined? Body density can be calculated as the ratio of body mass (weight) to body volume. Mass (weight) is easily measured on a scale, but what about volume? Archimedes' Principle is used by two techniques to determine body volume and density.

Hydrodensitometry or Underwater Weighing. Underwater weighing is a technique of estimating body composition that has been utilized for decades and may be the most accurate method available to many athletes for determining body fat. Mass can be determined easily by measuring the person's weight, and density can be calculated if the body's volume is known (Figure 11.4). Submersion in water can be used to determine volume, either by the amount of water that is displaced (e.g., water rising as one slips into the bath tub) or by determining the buoyant force acting on the submerged object. In the human body, two things are less dense than water and act to help the body float—air and fat. In underwater weighing, the air is accounted for by having the subject exhale as much air from the lungs as possible (down to **residual volume**) and by accounting for the residual volume in the prediction equation (Figure 11.4). A person that has more body fat will float more readily (i.e., have a greater buoyant force) and will therefore have a larger volume and a lower density. Conversely, a person of the same weight with less body fat and more muscle will tend to sink more easily (i.e., have less buoyant force), exhibiting a smaller body volume and higher density. Higher body density is associated with lower body fat.

The underwater weighing procedure requires the subject to exhale as much air as possible, submerge the body completely underwater, and remain motionless long enough for the technician to obtain an accurate reading of the underwater weight (see Figure 11.5). Many individuals have great difficulty with these procedures, particularly those not comfortable in the water. Therefore, substantial error can be introduced by the subject's inability to adhere to the procedures required by this method. While underwater weighing may be an accurate assessment of body composition for some, it may not be the most accurate method for all subjects. Another potential source of error is the determination of the amount of air in lungs of the subject. The greatest accuracy is obtained when lung volume is measured with one of several gas dilution techniques, but this type of apparatus may not be available or practical to use outside a

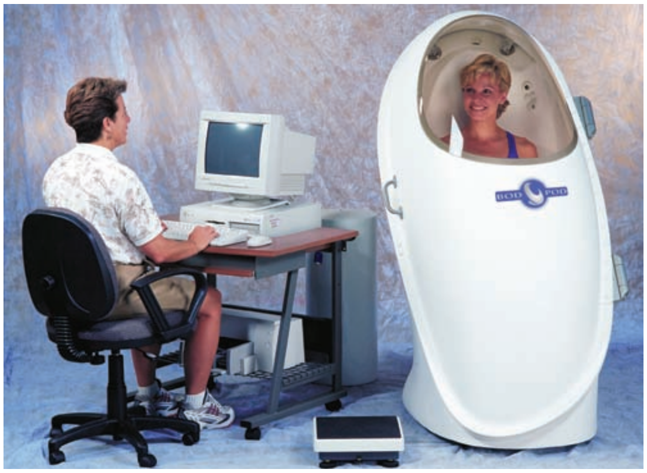
Figure 11.5 Hydrostatic Weighing Procedure

Subjects are seated in the water in a seat suspended from a scale. The subject must exhale as much air as possible (down to residual volume), submerge their body completely under water, and remain as motionless as possible until an accurate scale weight (underwater weight) can be determined. To ensure consistent results, 5 to 10 measurements are required.

Inherent: Unable to be considered separately.

Criterion: Accepted standard by which other decisions are judged.

Residual volume: The amount of air left in the lungs after a maximal, voluntary exhalation.



Life Measurement, Inc., www.bodpod.com

Figure 11.6 Air Plethysmography

Air displacement is used to determine body volume, body density, and body composition.

laboratory or research setting. More potential error is introduced when lung volume is estimated using prediction equations. Further error is introduced if the subject is unable to exhale all of the air down to residual volume; the extra air in the lungs makes the person more buoyant, and if unaccounted for, results in an error that overestimates body fat. In a study of trained athletes, a relatively small difference (~175 ml) in the amount of air in the lungs contributed to an average difference of over 1 percent in the final estimated body fat percentage (Morrow et al., 1986).

Other disadvantages of the underwater weighing method include the large, cumbersome, and not easily portable equipment needed. A water-filled tank large enough to accommodate a human body is not easily moved and is generally fixed in a laboratory or fitness-testing location. The gas dilution systems to measure lung residual volume are expensive, require technical expertise to operate, and need maintenance and sanitary cleaning of the breathing tubes. There are also issues related to the subjects and the facilities, such as the need for changing and clothes storage areas (e.g., locker facility) that are compatible with wet activities. Subjects must wear bathing suits (preferably with minimal material for greatest accuracy), which may be an issue of modesty or cultural sensitivity. Because of the need to repeat the procedure for greater accuracy, an underwater weighing session can be time consuming, easily taking 30 minutes or more, particularly for an inexperienced subject.

Plethysmography. Due to the problems associated with using underwater weighing to determine body volume and density, **plethysmography** (displacement of air to determine body volume) was developed. The subject sits in an air-tight enclosure (see Figure 11.6) while the amount of air displaced by the subject's body is sensed by a special diaphragm and pressure transducer. Once the body volume is determined, body density can be calculated and body fat estimated.

Studies show this method correlates well with body fat percentage determined from underwater weighing (McCrory et al., 1995) and has good test-retest reliability. The SEE is 2.2–3.7 percent (Fields et al., 2002). The major advantage of this system is the absence of water submersion, which can be a concern for subjects and a source of substantial error. It is also much less time consuming than underwater weighing. Studies suggest that this method can be used with approximately the same degree of accuracy as underwater weighing (McCrory et al., 1995). For greatest accuracy, subjects should wear tight-fitting clothing and a swim cap (to compress air pockets in the hair), which may lead to modesty concerns. The disadvantages include the high cost of the device, limited portability, the finite size of the seating area (i.e., larger athletes such as some basketball players or football linemen may not fit), and claustrophobic fears.

SKINFOLD MEASUREMENT

A certain proportion of fat in the body is stored subcutaneously (under the skin). Body composition that is estimated from skinfold thickness is based on the assumption that a measurement of the thickness of the subcutaneous fat layer is directly related to the total amount of fat in the body. A skinfold thickness may be determined by pinching a fold of skin and measuring with calipers (see Figure 11.7). Just one site may be used, but the sum of several different sites (two, three, and seven sites are frequently measured) is more accurate. Common sites used with men are chest, abdomen, and thigh while sites used with females are typically triceps, **suprailium,** and thigh. Most commonly used skinfold prediction equations have been derived using body density or body fat determined from underwater weighing, which means this method of estimation is twice removed from the original body density and fat measurements.

Generalized equations such as the commonly used three- and seven-site Jackson and Pollock equations (Jackson and Pollock, 1978; Jackson et al., 1980) were developed using diverse subjects (i.e., both genders and a wide age range) so that the equations would be suitable for use in a broad population of men and women. These equations have an SEE of approximately ±3.5 percent. To put this error in context, recall that two-thirds of the people being measured would have their "real" percent body fat fall within this range (e.g., 11.5 to 18.5 percent for an estimated body fat of 15 percent). Other specialized equations have been developed for use in very specific populations such as certain ethnic groups. Heyward and Stolarczyk (1996) provide an excellent guide for determining the most appropriate skinfold equation to

Figure 11.7 Skinfold Measurement

The thickness of the fold of skin is determined with calipers on predetermined locations on the body. Equations incorporating the sum of each skinfold thickness measured are used to predict body density and percent body fat.

Figure 11.8 Bioelectrical Impedance Analysis

A nonharmful electrical current is conducted through the body and the impedance to the flow of that current is measured and used in an equation to predict body composition.

use for specific populations, an important consideration when working with diverse populations.

Compared to other methods, the equipment required is relatively inexpensive (ranging from $10 to $500 for skinfold calipers) and is very portable. Little space is required but a relatively private area is needed because access to some skinfold sites requires partial disrobing. As with other methods, privacy or modesty may be an issue. Results are easily calculated, either by using electronic automatic calipers (e.g., Skyndex) or commercially available software. Programmable calculators and computer spreadsheets can easily be configured with the body density and body fat formulas needed to calculate body composition.

The skinfold technique can provide a reasonable degree of accuracy if performed correctly by a trained technician. Proper location of the skinfold sites is critical, as is the accurate pinching of the skinfold, the measurement of its thickness, and the choice of the most appropriate equation. Proper training of the technician is important, as is a substantial amount of experience in grasping the skinfolds with appropriate force (too much force can compress the skinfold and lead to an underestimate of the thickness and vice versa) and reading the skinfold caliper. This method may be difficult to employ with some subjects, as some skinfolds are very difficult to grasp and measure accurately, particularly the chest skinfold on many overfat males and the thigh skinfold on many females and males. In addition, individuals with very large amounts of subcutaneous fat may have skinfold thicknesses that exceed the measurement capacity of the skinfold calipers. The skill of the technician is a critical element because an unskilled technician introduces too much error and the resulting estimate cannot be used with confidence.

In addition to estimating percent body fat, skinfold measurement may provide valuable **anthropometric** information for tracking changes over time. For example, if an athlete's skinfold thicknesses decrease over the course of the off-season to the competitive season, one can be confident that body fat has decreased. Specific skinfold sites can be tracked in a longitudinal fashion for athletes in this way. An important issue is the accuracy of the measurements, which should be conducted by the same trained technician if possible.

BIOELECTRICAL IMPEDANCE ANALYSIS

The Bioelectrical Impedance Analysis (BIA) body composition methodology is based upon the rationale that body tissues can be distinguished based upon their relative ability to conduct electrical currents. Water and tissues containing a high proportion of water conduct electrical currents easily, while tissues that contain little water, such as fat, impede the flow of electrical currents. With this method, a nonharmful electrical current is conducted through the body and the impedance to the flow of that current is measured (see Figure 11.8). Body composition is not measured directly; rather, an algorithm, or prediction equation is used to predict body composition from a three-compartment model: fat mass, fat-free

Plethysmography: Measuring and recording changes in volume of the body or a body part.

Suprailium: An area of the body directly above the crest of the ilium, the hip bone.

Anthropometric: Body measurements such as height, weight, waist circumference, or skinfold thickness.

mass, and body water. These algorithms or equations are generally **proprietary** (private) to the company that has developed them so it is difficult to conduct independent scientific studies of the formulas.

Commercially available BIA units typically have one of three configurations, measuring impedance between arms and legs, between the legs, or between the arms. The first approach requires the subject to lie down and have electrodes placed on their ankles and wrists. The latter two devices require the subject to stand in bare feet on a scalelike platform or hold onto the device with metal contacts with bare hands. BIA devices range from very expensive, multi-frequency devices that measure whole body impedance and estimate total body water (both intracellular and extracellular) to inexpensive, low-frequency devices marketed for use in the home.

Accuracy of the body composition estimate is based largely upon the accuracy of determining the electrical impedance and the underlying assumptions used in the equations regarding water content of various tissues. Differences in water content and body density, which may vary due to age, gender, ethnicity, recent physical activity, and hydration status, must be considered. If all conditions are controlled appropriately and subject and technical error is minimized, the estimate obtained via BIA is comparable to that of skinfold assessments, an SEE of approximately ± 3.5 percent.

BIA has some distinct advantages as a method of estimating body composition. Other than removing shoes and socks, the method requires no special clothing or disrobing, reducing concerns of privacy and modesty. The devices are easily portable, can be used in a variety of settings, and generally require only a few minutes for the assessment to be completed. The devices are computerized and are programmed to calculate the results and generally have an option for printing out the results. In addition, there is not a large potential for subject or technician error as long as data entry is done correctly and fairly simple procedures are followed (e.g., correct electrode placement).

Major error or variation can occur, however, if the technician or subject does not adhere to premeasurement factors that may affect body water. Changes in hydration status and physical activity may affect bioelectrical impedance analysis, particularly if changes occur near the time of measurement. For that reason, preassessment guidelines should be given and adhered to by the subject and confirmed by the technician before any measurement takes place:

Abstain from eating or drinking within 4 hours of the assessment

Avoid moderate or vigorous physical activity within 12 hours of the assessment

Abstain from alcohol consumption within 48 hours of the assessment

Ingest no diuretic agents, including caffeine, prior to the assessment unless prescribed by a physician

Bioelectrical impedance can be a relatively quick and easy assessment method for estimating body composition, but careful attention must be paid to these preassessment directions to avoid introducing excessive error. This is especially true for athletes who would need to schedule the test around their training schedule. Additionally, any information provided by the subject (e.g., weight, physical activity) must be accurate, a potential problem for recreational and nonathletes who may underestimate body weight and overestimate physical activity. A major disadvantage of BIA is the cost of the device, which may be substantially greater than other methods with similar accuracy (e.g., skinfold calipers).

NEAR-INFRARED INTERACTANCE

Near-infrared interactance (NIR) is based upon the ability of different tissues to absorb or reflect light. A near-infrared light emitting and sensing wand is placed over a body part such as the belly or center of the biceps. A light beam is directed into the tissue, some of which is absorbed and some of which is reflected back and is measured by spectroscopy in the wand. Less dense tissue absorbs more near-infrared light and more dense tissues reflect more light back to the sensor. The differential absorption and reflection of the near-infrared light is used in prediction equations to estimate percent body fat. Similar to bioelectrical impedance, body composition is not measured directly.

NIR devices are portable, easy to operate, and are not exposed to substantial technician or subject error if the information provided by the subject about weight and physical activity is reliable. The procedures are not disruptive for the subject as only one site on the body is typically measured (e.g., the biceps of the dominant arm). Concerns are raised about the use of only one site for predicting percent body fat. Studies of the accuracy of body composition estimated by NIR shows an error of approximately $\pm 4 - 5$ percent (Hicks et al., 2000; McLean and Skinner, 1992), making this method less accurate by comparison to the methods discussed previously. Until greater accuracy is achieved, the estimates obtained by NIR may have too much potential error to be used with confidence.

DUAL-ENERGY X-RAY ABSORPTIOMETRY

Dual-Energy X-Ray Absorptiometry (DEXA) is a method that uses low-intensity, focused X-rays to scan the body for determination of bone mineral density and content. Originally developed for clinical use for measuring loss of bone density, the bone mineral information can

Figure 11.9 Dual-Energy X-ray Absorptiometry

Using low-intensity, focused X-rays, bone and soft tissue can be scanned and percent body fat estimated.

also be used as part of a three-compartment model for estimating body composition. The potential exists for this to be a precise method for body composition determination because it accounts for one of the tissue compartments that can vary substantially between people and within an individual over a lifetime.

In this procedure, the subject lies motionless on the scanning table for a few minutes while a full body scan is performed, yielding both skeletal and soft tissue images (see Figure 11.9). Based upon proprietary algorithms developed by each company, body composition is determined, with estimates of **bone mass,** fat mass, and fat-free mass provided. Some software programs use anatomical landmarks to digitally section the body into segments for analysis of regional body composition (e.g., trunk, arms, and legs).

Because of the expense of the equipment and the associated radiation safety requirements, DEXA is a method of body composition assessment that is not likely to be found outside specialized clinical facilities, research laboratories, or doctors' offices. The equipment also contains an X-ray generating device, and is therefore subject to state or local licensing and safety regulations. Technicians operating the DEXA equipment must be trained in the use of the equipment and in radiation safety. While the dosage of radiation a subject is exposed to for a whole body scan is very small, there is a potential for accumulated radiation exposure with repeated scans, and there are some conditions (e.g., pregnancy) that prohibit use. The devices do have size limits for subjects due to the available scanning area. Subjects that are very tall (over 6'4" [193 cm]) or that are severely obese may not be scanned accurately, as their body may not fit within the limits of the available scanning area.

Whole-body scans for body composition are relatively fast on newer DEXA equipment, generally taking only a few minutes. Other than adhering to the directions to eliminate metal objects from the body (e.g., jewelry) or clothing (e.g., belt buckle, underwire bra), the subject has little to do other than to remain motionless until the scan is completed. There is little opportunity for technician error other than positioning the subject correctly on the scanning table and entering the subject information correctly. The error has been reported to be approximately ±1.8 percent (Whaley et al., 2006), but additional research must be performed before DEXA can be considered the new gold standard method of body composition assessment (Kohrt, 1995).

COMPUTED TOMOGRAPHY SCANS (CT) AND MAGNETIC RESONANCE IMAGING (MRI)

Advanced clinical imaging techniques have also been used to assess body composition. Two such methods are computed tomography (CT) and magnetic resonance imaging (MRI). Similar to DEXA, these methods are generally only found in specialized clinical facilities or research laboratories and are not commonly used in assessment of body composition outside research studies. These devices are able to image tissues in the body in cross-sectional slices. The amount of tissue in each section is estimated and whole-body composition is estimated by summing the sequential section images. These technologies have not been used on a sufficient number or breadth of subjects to establish the SEE. The specialized nature of these technologies makes their widespread use in body composition assessment unlikely in the near future.

What's the point? All body composition measurement methods are indirect predictions of body fat. They all have some inherent error and the potential for technical error, which must be considered when selecting a measurement method and interpreting the results.

Interpretation of Body Composition and Weight

Once the appropriate body composition assessments have been completed and the results are known, the subject will likely ask, "What do these numbers mean?" The health, fitness, or nutrition professional may wonder, "What do I do with these results?" The initial

Proprietary: Privately owned and administered.

Bone mass: Total amount of bone in the body. Expressed in pounds or kilograms.

caution about body composition bears repeating here: Assessments of body composition are only estimates. Each method of assessment has a degree of error that must be taken into account when analyzing and interpreting the results, and this error may be compounded by technical, technician, or subject error. Suggesting to athletes that body composition assessment is overly precise or using the information to establish rigid goals is incorrect and inappropriate.

INTERPRETING BODY COMPOSITION RESULTS

Body composition results should be presented as a range that includes the error of measurement. As mentioned previously, if percent body fat is estimated to be 15 percent using the underwater weighing method, then this figure should be interpreted as the percentage of body fat that is likely to be within the range of 12.3 to 17.7 percent. The athlete should also be informed that there is a possibility the actual body composition may be higher or lower than this range. Percent body fat and lean body mass estimates can be used to determine an appropriate scale weight that reflects desired body composition (demonstrated later in this chapter). Excessive body fat likely has an impact on performance and health, and body composition assessment can help to establish and monitor progress toward a more desirable body composition. Measurement of body composition can also help athletes assess if their training program and dietary intake needs to be adjusted to meet body composition goals.

Knowledge and experience in assessment of body composition and good old-fashioned common sense need to be employed when evaluating these results and making recommendations. For example, if an athlete has a body composition assessment showing an increase in body fat of 0.5 percent over a three-month period of time, at the same time that training volume has increased, scale weight has decreased and clothes are looser-fitting, then the accuracy of that body composition assessment must be questioned and reevaluated.

INTERPRETING BODY WEIGHT

Weight is reported as a single number and is generally compared to previous weights. A change in body weight can reflect a change in muscle mass, body fat, hydration status, or a combination of these factors. Weight can fluctuate on a daily basis and is most useful to athletes as a way to track hydration status, especially for those who are training in hot, humid conditions and are losing large amounts of fluid each day as sweat. In this instance, daily weight may be an appropriate means of checking hydration status and ensuring adequate rehydration. Although athletes in some sports must be focused on body weight because of weight restrictions or classes, it is probably not appropriate for most athletes to be overly concerned about checking their weight on a daily basis. For purposes other than hydration status or "making weight," a reasonable approach might be for an athlete to check weight on a less frequent basis, such as once each week. Care should be taken to measure body weight using the same scale if possible and under the same conditions (e.g., same time of day, same timing in relation to exercise, food, and beverage consumption).

Visual monitoring, along with scale weight, can be used as a "check" on body composition, but this technique is highly subjective. As an example, consider a 24-year-old male athlete who usually weighs 185 lb (84 kg) when he is in a state of **euhydration.** Based on assessment of body composition at this weight, this athlete's percent body fat is estimated to be 8 to 10 percent. He knows that when he gains body fat the fat tends to be deposited in his abdominal area. At 185 lb (84 kg) and 8 to 10 percent body fat, this athlete understands what his body "looks" like and can visually monitor his body composition. If his weight increases to 190 lb (~86 kg) and the 5-lb (~2-kg) increase in weight reflects an increase in abdominal body fat, then he should be able to detect this increase in the mirror and by the fit of his clothes. The usefulness of visual monitoring depends on honest assessment. If this athlete held his breath and tightened his abdominal muscles while looking in the mirror, he could pretend that the 5-lb increase was not a result of increased body fat. Those with a distorted body image should not use frequent scale weights and visual monitoring because each can be misinterpreted and lead to practices that harm physical and mental health.

Body Composition and Weight Related to Performance

Changes in body composition and body weight may have the potential to improve performance; thus, some athletes want to define "optimal" ranges. Optimal weight or body composition cannot be predicted, and even among elite athletes in the same sport there are individual differences due to genetics, training, and nutrition. The lowest body weight or percent body fat is not always the best and, in some cases, may be detrimental to performance. This section reviews current knowledge of body composition, body weight, and performance.

RELATIONSHIP OF BODY COMPOSITION TO PERFORMANCE

Body composition and other body anthropometric characteristics (e.g., height) are physical characteristics that can have an impact on an athlete's performance, but these factors play a more important role in some

Figure 11.10 Comparison of Body Composition of Different Athletes in the Same Sport

sports, and for different positions within certain sports, than others. For example, body composition may play a minor role in certain skill-oriented sports. Athletes that are successful in baseball or golf display a wide variety of body types and body composition that may be more similar to the general population (see Figure 11.10). Successful baseball players at the highest level may be fit and lean like Derek Jeter or may have a body composition more similar to the average, sedentary adult like David Wells. Golf is another example in which athletes with different body compositions have been successful (e.g., Tiger Woods, Phil Mickelson, John Daly).

There is an inverse relationship between body fatness and performance in some sports, particularly those in which body weight must be transported, as in distance running or other endurance sports. Excessive body fat comprises "dead weight" for the athlete—weight that must be carried but does not contribute in a positive way to the activity. Carrying excess weight makes the athlete less energy efficient so he or she must exert more effort to transport the weight. This doesn't mean that performance will always be improved if these athletes attain an absolute minimum weight, however. There is a point of diminishing returns, both for performance and for health that the athlete must consider. At some point the caloric restriction and training that is needed to further reduce body weight and fat may become counterproductive.

INTERRELATIONSHIP OF SIZE (WEIGHT)/STRENGTH/SPEED

The "optimal" body composition for an athlete must consider the mass, strength, speed, and power demands of the sport, or the position within the sport. At one extreme, the sumo wrestler represents an athlete that

Euhydration: "Good" hydration (eu = good); a normal or adequate amount of water for proper physiological function.

Gray Mortimore/Stone/Getty Images

In sports in which explosive power provides a competitive advantage, having a high power to weight ratio is important.

• NCAA Division I football	
All positions	10.2–23.8
Defensive backs	7.0–14.4
Receivers	8.8–16.4
Quarterbacks	14.0–21.8
Linebackers	12.4–23.6
Defensive linemen	14.4–24.8
Offensive linemen	18.4–28.6
• Basketball*[a]	
All positions	6.9–16.1
Centers	8.8–20.0
Forwards	6.9–13.7
Guards	6.8–13.1
• Cycling	
Road*	6.9–10.1
• Ice hockey*	8.0–12.0
• Rugby*	9.1–19.6[b]
• Running (females)	
Middle distance*	7.9–16.5
Long distance*	11.9–18.3
• Soccer (females)	13.3–18.9
• Soccer	7.6–18.0[c]
• Swimming/diving (females)	
Middle distance or diving	16.8–29.8
Long distance	20.3–33.7[d]
• Wrestling	6.6–11.3[e]

Figure 11.11 Estimated Percent Body Fat Ranges for Collegiate or Professional Athletes in Selected Sports.

Legend: NCAA = National Collegiate Athletic Association

These values represent reported percent body fat ranges and not optimal ranges for collegiate or professional athletes, ages 18–29 years. Values are for males unless noted.

*Professional or elite athletes, not collegiate athletes.
[a]French and Serbian players only.
[b]Forward players have higher percent body fat than back players.
[c]Midfielders have higher percent body fat than backs or forwards.
[d]Masters swimmers, ages 21–73 years.
[e]NCAA Division I, II, III championship wrestlers.

Compiled from research studies measuring body composition by hydrostatic weighing, skinfolds, or DEXA. Hoffman et al., 2006; Montgomery, 2006; Petersen et al., 2006; Ostojic, Mazic, and Dikic, 2006; Sallet et al., 2005 and 2006; Silvestre et al., 2006; Clark et al., 2003; Tuuri, Loftin, and Oescher, 2002; Noland et al., 2001; Deutz et al., 2000; Collins et al., 1999; Kreider et al., 1998.

must possess a very large body mass. This large body mass is difficult to push out of the competitive ring due to inertia and lack of momentum. Strength and speed are important for these athletes, but a very large body mass is critically important—a strong and fast sumo wrestler will have little success if he is outweighed by several hundred pounds by his competitors. The other extreme may be represented by a ski jumper. A certain amount of strength is required for controlling the skis and for propelling the body into the air at the end of the ski jump, but low body weight is a great advantage for these athletes to stay in the air longer. Other athletes fall somewhere in between these extremes in terms of body mass, body fat, and muscle. In sports or positions in which explosive power is a requirement or provides a competitive advantage, having a large amount of muscle mass and a high power-to-weight ratio is important. Excess body fat may diminish this power-to-weight ratio and is therefore undesirable. Athletes such as male gymnasts, ice hockey players, short-distance runners (e.g., 100-m runners), speed skaters, and (American) football linebackers and running backs are often very muscular and lean and have a high power-to-weight ratio.

Although summaries (see Figure 11.11) or averages of body fatness for athletes across a variety of sports are available (Hoffman et al., 2006; Petersen et al., 2006; Ostojic, Mazic, and Dikic, 2006; Silvestre et al., 2006; Clark et al., 2003; Tuuri, Loftin, and Oescher, 2002; Noland et al., 2001; Deutz et al., 2000; Collins et al., 1999; Kreider et al., 1998; Wilmore, 1983;), individual athletes must be considered on a case-by-case basis. Additionally, athletes within a particular sport may have varying body composition characteristics. Interior linemen in (American) football typically have requirements for greater body mass, even if some of that mass is fat. Along with muscle, the additional body mass prevents them from being "pushed around" as easily. Players at other positions must run faster and farther (e.g., linebacker, wide receiver, running back) and excessive body fat may impair their performance. Body fat among a group of football players may therefore range from approximately 7 to 28 percent.

In addition to performance and appearance, athletes may also want to change their weight or body composition for health-related reasons. Weight, as a sole measure, is not an accurate predictor of health. However, there is an association between body weight, chronic disease risk, and mortality (Hu et al., 2004; Lee, Blair, and Jackson, 1999). This association is very much influenced by cardiovascular fitness. It is important for individuals to assess if their current weight and percent body fat are within a healthy range. In addition to the amount of body fat, the distribution of body fat is a disease risk factor. All of these issues are discussed in Chapter 12, Diet and Exercise for Lifelong Fitness and Health.

Changing Body Composition to Enhance Performance

Many athletes want to change their body composition. Highly trained athletes are typically lean but may want to gain muscle mass to increase strength or lose a small amount of body fat to improve their power-to-weight ratio or their appearance. Lesser-trained athletes often wish to increase muscle mass and lose body fat, sometimes in substantial amounts. Some recreational athletes want to lose moderate to substantial amounts of body fat. This loss of body fat may positively affect performance, but in many cases the desire to lose body fat is related more to appearance and the desire for better health. A minority of athletes need to gain body weight and need to increase body fat in addition to increasing muscle mass. Regardless of the athlete's priorities, the same questions are frequently asked: 1) How much should I weigh? 2) What percentage of body fat should I have? 3) How do I increase muscle mass? 4) How do I lose or gain body fat? and 5) How do I increase muscle mass and lose body fat at the same time? This section explains how a target weight based on body composition is determined and briefly outlines the changes in exercise and training that are needed to achieve muscle mass or body fat goals.

DETERMINING A TARGET BODY WEIGHT BASED ON DESIRED BODY COMPOSITION

After body composition has been estimated as accurately as possible, athletes can use that information to establish their "optimal" body composition goals. Athletes should be cautioned to choose realistic lean body

SPOTLIGHT ON ENRICHMENT

Athletes and Appearance—Meeting Body Composition Expectations

Athletes in subjectively scored sports must consider their body's appearance because it may influence their scores. The most obvious case is that of bodybuilders because the appearance of the body is a fundamental element of the sport. Sports such as women's gymnastics and figure skating have "cultural" standards for appearance that relate to body composition.

Holly Stein/AVP via Getty Images

Many athletes' bodies are judged by the large audiences reached through the visual media.

Weight and body shape dissatisfaction and body image disturbances are prevalent in these and other appearance-dependent sports. Psychological issues related to body image should not be overlooked in subjectively scored sports, as they may lead to disordered eating, which is discussed in depth in Chapter 13 (Ziegler et al., 2005 and 1998; Jonnalagadda, Ziegler, and Nelson, 2004).

While most athletes' bodies are not scored, they are judged by the large audiences reached through the visual media. Fashionable, tight-fitting clothing is part of the sports scene. Television coverage of sports is so extensive that many athletes are celebrities and the general population often expects celebrities to be thin, and in the case of athletes, muscular with a low percentage of body fat. Youth sports, such as high school football and the Little League World Series, are now shown on local or national TV. It is not surprising that some athletes at all levels of competition feel pressure to attain a body composition that is held in high esteem by society. Appearance is one reason that athletes, even high school athletes, consume supplements and drugs, some of which are obtained illicitly. In fact, an athletic appearance is so powerful that high school nonathletes use anabolic steroids to attain the higher muscularity and lower body fat that is typical of trained athletes (Calfee and Fadale, 2006). Anabolic steroid use by trained and recreational athletes for appearance purposes appears to be increasing (Copeland, Peters, and Dillon, 2000).

$$\text{Target Body Weight} = \frac{\text{Current FFM}}{1 - \text{Desired \% BF}}$$

The formula assumes euhydration and a constant fat-free mass.

Figure 11.12 Target Body Weight Formula

Legend: FFM = fat-free mass; BF = body fat

mass and body fat goals that consider their genetic predisposition to leanness and fatness. Once body composition goals are chosen, the weight that reflects those goals can be estimated. This weight is referred to as a target body weight or body weight goal. The target body weight is only an estimate, and rigid adherence to attaining a given scale weight or body composition is never recommended. However, a target body weight can be a helpful guideline, and a formula for calculating such a weight is shown in Figure 11.12. The formula assumes euhydration (Rankin, 2002).

For example, a baseball player currently weighs 190 lb (~86 kg) and is approximately 16 percent body fat (body fat range ~13–19 percent). His current fat-free mass is 84 percent of his weight, or ~160 lb (~72.5 kg), and he has approximately 30 lb (~13.5 kg) of body fat. His goal is ~10 percent body fat (i.e., 90 percent fat-free mass), a figure that is consistent with his genetic predisposition to fatness and his sport (long-ball hitter and outfielder). As shown in Figure 11.13, if all weight is lost as fat, his target body weight to reflect a body composition of 10 percent body fat is ~178 lb (~81 kg).

The target weight formula considers the athlete's current amount of fat-free mass. What if the athlete wishes to gain muscle mass and lose body fat? A target weight can still be determined, but the desired increase in muscle mass must be added to the current fat-free mass. Continuing with the previous example, the 190-lb (~86-kg) baseball player wishes to gain 5 lb (~2.2 kg) of muscle mass (from 160 to 165 lb [72.7 to 75 kg]) and reduce body fat to ~8 percent for performance and appearance reasons. If he achieved these goals his target weight would be ~179 lb (~81 kg) (see Figure 11.14). It should be noted that *choosing* desirable amounts and proportions of fat-free mass and body fat is not difficult, but *achieving* such levels may be. Above all, body composition and weight goals must be realistic and achievable via diet and training programs that do not put the athlete's health at risk.

Current weight = 190 lb

Current % BF = 16 % (obtained via underwater weighing)

Current % FFM 84 % or 0.84 (calculated from % BF)

Current FFM = 190 lb × 0.84 = 160 lb

Desired % body fat = 10 % or 0.10

$$\text{Target Body Weight} = \frac{160\text{ lb}}{1 - 0.10} = \frac{160\text{ lb}}{0.90} = 178\text{ lb}$$

Figure 11.13 Calculation of a Target Body Weight

Legend: lb = pound; FFM = fat-free mass; BF = body fat

In this example, the athlete wants to lose body weight as fat.

$$\text{Target Body Weight} = \frac{\text{Current FFM} + \text{Desired FFM increase}}{1 - \text{Desired \% BF}}$$

$$\text{Target Body Weight} = \frac{160\text{ lb} + 5\text{ lb}}{1 - 0.08} = \frac{165\text{ lb}}{0.92} = {\sim}179\text{ lb}$$

Figure 11.14 Calculation of a Target Body Weight

Legend: lb = pound; FFM = fat-free mass; BF = body fat

In this example, the athlete wants to change both lean body mass and fat mass. (see text for details)

INCREASING MUSCLE MASS

When the appropriate stimulus is applied to skeletal muscle and the necessary hormonal and nutritional environment is present, muscle mass can increase. First, an overload stimulus must be applied consistently over time—the muscle must be stimulated to produce force at a greater frequency, intensity, and/or duration than is accustomed. Athletes generally accomplish this through one of many strength-training approaches. The increase in muscle mass is referred to as **hypertrophy,** and is a result of individual muscle fibers being stimulated to increase in size by synthesizing more contractile protein.

Role of Exercise. For the sedentary adult or the athlete that is not accustomed to strength training, virtually any strength-training protocol will result in increases in strength and some initial increase in muscle mass. Once athletes are accustomed to basic strength training, further increases in muscle mass can be achieved through periodized strength training. The hypertrophy phase of periodized strength training is designed to maximize the potential for increasing muscle mass and is characterized by an emphasis on increasing the total volume of strength training. Increasing strength-training volume is accomplished by structuring a large number of sets and repetitions of a variety of strength-training exercises. The intensity or load (amount of weight lifted) is kept in the moderate range so that the prescribed number of sets and repetitions can be completed.

The amount of increase in muscle mass in response to strength training is difficult to accurately predict and is dependent upon a number of factors such as genetics, body type, hormonal status, and nutritional status. Those individuals with ectomorphic body types may not have the genetic disposition to add large amounts of muscle mass compared to those with more mesomorphic body types. Testosterone and growth hormone are the primary hormones responsible for stimulating an anabolic, or tissue-building, state in the body, particularly for muscle and connective tissue. There are large **interindividual** differences in circulating testosterone concentrations, certainly between males and females, but even among males.

Role of Nutrition. Proper nutrition is necessary to support the increase in muscle size that is associated with resistance-training programs described above. While many nutrients are important for muscle growth, two areas receive the majority of attention—energy (kcal) and protein. Synthesis of muscle tissue requires positive energy balance (i.e., caloric intake is greater than caloric expenditure). The athlete must also be in positive nitrogen balance (NB) and positive muscle protein balance (MPB). Positive nitrogen balance occurs when total nitrogen (protein) intake is greater than nitrogen lost via the urine and feces. In other words, the athlete must be consuming a sufficient amount of dietary protein. Positive muscle protein balance occurs when muscle protein synthesis is greater than muscle protein breakdown. To achieve positive energy, nitrogen, and muscle protein balance, an adequate energy intake is just as important as an adequate protein intake (Gropper, Smith, and Groff, 2005; Phillips, Hartman, and Wilkinson, 2005; Phillips, 2004; Tipton and Wolfe, 2001).

Athletes who wish to increase muscle mass should determine their baseline energy intake, which is the approximate amount of kilocalories needed daily to maintain current body weight and composition. Daily energy intake is greatly influenced by the amount of energy expended through physical activity. As discussed in Chapter 2, daily energy requirement for females and males is estimated to be approximately 35 and 38 kcal/kg, respectively, when daily activity is equivalent to walking two miles. When energy expenditure is higher due to moderate to heavy exercise on most days, baseline energy requirement may be as high as approximately 44 kcal/kg for females and 50 kcal/kg for males.

It is estimated that an additional 5 kcal above baseline energy need is required to support the growth of 1 gram of tissue (Institute of Medicine, 2002). One pound of tissue weighs 454 g; thus, a rule of thumb estimate is that approximately 2,300 kcal are needed to support the growth of 1 pound of muscle (454 g × 5 kcal/g = 2,270 kcal). Assuming that a male can gain 1 pound of muscle tissue per week (less for a typical female), it is estimated that, at a minimum, an additional 330 kcal per day need to be added to the baseline energy intake to support 1 pound of muscle growth a week. However, there is little research in this area, so the general recommendation is higher than the estimated minimum value. At present, to promote the growth of muscle tissue it is generally recommended that males increase daily caloric intake by 400 to 500 kcal (females to a lesser extent).

Some additional dietary protein is also needed to support the growth of muscle tissue. Approximately 22 percent of muscle is protein, so it is estimated that increasing muscle tissue by 1 pound would require the incorporation of approximately 100 g of protein (454 g × 0.22 = 100 g). If calculated on a daily basis, approximately 14 g of additional protein would be needed daily (100 g ÷ 7 days = 14 g), which in itself would provide ~56 kcal. These figures are by no means exact, but they do give athletes some guidelines for the additional energy and protein needed to support an increase in muscle tissue. The additional amount of protein needed is probably less than most athletes would estimate, however.

The following example illustrates the application of these guidelines. Sal is a 25-year-old male who was active in intramural sports while in college. Since graduation he has not participated in any kind of formal recreational activity but he walks about a mile each way to the subway station to commute to work. He has maintained his current weight of 161 lb (~73 kg) for the past year. Recently, he joined a gym and fitness center, which he plans to go to immediately after work. His goal is to lift weights and gain approximately 5 pounds (~2.2 kg) of muscle mass. Figure 11.15 shows Sal's current energy and protein intakes and his estimated energy and protein needs to increase 5 pounds of muscle mass.

Sal's case is typical of many athletes who find that their current protein intake already exceeds the amount needed for muscle growth. Sal needs to concentrate on increasing his caloric intake, including additional carbohydrate calories that will be needed for the resynthesis of muscle glycogen reduced by the resistance

Hypertrophy: An increase in size due to enlargement, not an increase in number; in relation to muscle refers to an increase in the size of a muscle due to an increase in the size of individual muscle cells rather than an increase in the total number of muscle cells.

Interindividual: A comparison or observation made between people.

Determine baseline intake:
Current energy need to maintain body composition: 2,774 kcal (73 kg × 38 kcal/kg)
Current daily protein need: 58 g (73 kg × 0.8 g/kg)

Recommended changes to increase 5 lb lean mass (assumes resistance exercise):
Daily energy intake:
3,174 kcal (2,774 kcal + ~400 kcal)
Daily protein intake: ~72 g (58 g + ~14 g)

Current dietary intake:
Energy: ~2,800 kcal
Macronutrient distribution: Carbohydrate: 420 g (60% of total caloric intake), protein: 84 g (12%), fat: 78 g (25%), alcohol: 12 g (3%)

Figure 11.15 Baseline and Projected Energy and Protein Needs of a Recreational Athlete to Increase Muscle Mass

Legend: kcal = kilocalorie; kg = kilogram; kcal/kg = kilocalorie per kilogram body weight; g = gram; g/kg = gram per kilogram body weight; lb = pound

exercise. Since Sal will be going to the gym after work, he could eat a substantial snack while commuting to the gym. A 6-inch turkey deli sandwich and 8 ounces of orange juice would provide approximately 390 kcal, 72 g of carbohydrate, 19 g of protein, and 4.5 g of fat. Note that some of the additional calories are in the form of proteins but that the majority is provided by carbohydrates. This kind of snack daily, in addition to his usual intake, provides the additional nutrients he needs to support muscle growth.

DECREASING BODY FAT

The general principles for the loss of body fat are the same for athletes and nonathletes: an increase in energy expenditure (activity or exercise), a decrease in food (energy) consumption, or a combination of both. There are thousands of weight-loss diets, but the common denominator is a decrease in caloric intake that results in fat loss over time. For the obese, sedentary individual the restriction of total energy intake and the length of the energy restriction seem to be more important than the carbohydrate, protein, and fat content (i.e., macronutrient composition) of the diet. Higher-protein, low-energy diets may be beneficial for athletes because they may help to protect against the loss of lean body mass, but carbohydrate intake must be sufficient to support the resynthesis of muscle glycogen depleted by training (Layman et al., 2005).

Role of Exercise. Exercise plays an important role in weight loss and change in body composition. The strategy for long-term weight loss and reduction of body fat is to achieve a moderate caloric deficit, or to expend more calories than are consumed. As discussed below, this can be achieved solely through reductions in food and beverage consumption, but this is generally not the recommended approach. Particularly if the caloric deficit is large, weight loss can be substantial, but a relatively large proportion of the weight lost is from the fat-free component of the body. In other words, lean body mass is lost, which is not desirable, particularly for the athlete.

Exercise can be used to increase caloric expenditure, which contributes to the caloric deficit necessary for weight and fat loss. In addition, the stimulus of exercise helps maintain fat-free mass while body weight and body fat decline. Manipulations of frequency, intensity, and duration of exercise, particularly aerobic-type exercise, can substantially increase caloric expenditure. In the face of a moderate caloric deficit, an athlete who is performing aerobic exercise will generally maintain fat-free mass or may only experience small declines. An athlete who incorporates strength training into his or her training program while experiencing a mild caloric deficit may experience increases in muscle mass and therefore fat-free mass, while losing a small amount body fat at the same time. This example illustrates the concern of relying too much on scale weight rather than body composition when the goal is to lose body fat. If muscle mass is slowly increasing at the same time that body fat is slowly decreasing, the scale weight the athlete takes each morning may not be changing perceptibly. The athlete may be discouraged by this lack of change in scale weight and misinterpret it to mean that no progress is being made when, in fact, desirable changes in body composition are occurring.

Role of Nutrition. To lose body fat, energy expenditure must be greater than energy intake. It is recommended that activity or exercise be increased and food intake decreased. However, athletes must consider the impact that increased exercise or decreased food intake will have on their ability to train and perform. Too much exercise can result in injury, and low energy, carbohydrate, and protein intakes can result in inadequate muscle glycogen resynthesis and loss of lean body mass. For many trained athletes, the extent to which they can increase exercise and decrease food consumption is limited and these limitations result in a slow loss of body fat.

Recall from Chapter 4 that an athlete's daily carbohydrate intake should not be less than 5 g/kg body weight to ensure adequate muscle glycogen resynthesis. Athletes who restrict energy intake should increase protein intake to at least 1.4 g/kg body weight to protect against large losses of lean body mass (see Chapter 5). Meeting these two nutrient recommendations requires an energy intake of approximately 26 kcal/kg (6.5 g × 4 kcal/g). The diet should not be too low in fat for many reasons, including the difficulty involved with complying with a very-low-fat diet. Considering minimum carbohydrate, protein, and fat guidelines, it is generally recommended that athletes who wish to lose body fat not restrict energy intake to less than 30 kcal/kg daily. To meet vitamin and mineral requirements, these diets need to contain many nutrient-dense foods. Some athletes, such as bodybuilders preparing for a contest, may employ more drastic reductions in energy intake but such diets are short term. Diets containing less than 30 kcal/kg daily typically do not meet daily vitamin and mineral requirements and tend to be extremely low in fat.

Athletes who restrict energy to lose body fat look for ways to do so while preserving muscle mass. Unfortunately, scientific study in this area using athletes as subjects is sparse. There are some studies in obese men to suggest that the loss of skeletal muscle could be **attenuated** when an energy-restricted diet is combined with resistance exercise. Although these studies were not conducted in athletes, athletes are often advised to include resistance exercise along with a higher protein (but still energy-restricted) diet in the hope that muscle mass can be preserved. Much more research is needed regarding the best ways to protect against the loss of muscle mass in both athletes and nonathletes, but this seems to be prudent advice (Stiegler and Cunliffe, 2006).

SIMULTANEOUSLY INCREASING MUSCLE MASS AND DECREASING BODY FAT

Many athletes want to simultaneously increase muscle mass and decrease body fat. In other words, they want to remain the same weight but they want to "replace" 5–10 lb (~2.2–4.5 kg) of fat with 5–10 lb of muscle. Although this sounds as if it would be easy for the body to accomplish, anabolism (synthesis) and catabolism (breakdown) are biologically opposite processes and it is difficult to estimate an appropriate daily caloric intake to achieve both simultaneously. A prudent recommendation is to focus on one goal at a time. For many athletes, there is a greater benefit to increasing muscle mass than to decreasing body fat. Weight may eventually be the same but it will probably fluctuate as muscle mass is increased and then body fat is decreased.

SEASONAL TIME COURSE OF BODY COMPOSITION CHANGES

The magnitude of the desired fat loss or lean body mass gain is a factor in deciding the best time in the training cycle to make body composition changes. Small losses of body fat and weight may be a consequence of the athlete's return to preseason training from the relatively sedentary active recovery (off-season) period. If the athlete continues to consume approximately the same amount of energy (kcal), then the increase in energy expenditure from a return to training will result in a loss of body fat. Similarly, an athlete who experiences a small loss of muscle mass in the off-season will see a gain in lean body mass with a properly designed preseason resistance exercise and nutrition program. Athletes can maintain a relatively stable body composition and weight by adjusting their energy intake to meet the energy expenditure requirements of each training cycle.

Larger decreases in body fat require a moderate reduction in food intake along with an increase in energy expenditure, because training alone would not likely create a large enough energy deficit to lose a substantial amount of fat in the preseason training period. Severe reduction in food intake (e.g., fasting, very-low-caloric diet) is not recommended because it interferes with the athlete's ability to train. A moderate reduction in food intake will result in a slow weight loss; therefore, losing considerable amounts of body fat means that weight-loss strategies must be initiated well before the competitive season. In fact, the athlete who wishes to lose relatively large amounts of body fat should begin the process after the competitive season ends (i.e., the active recovery period) and, if necessary, continue the weight-loss plan through the early part of the preseason. Trying to lose large amounts of body fat during the later part of the preseason when training volume is high or during the precompetition and competition periods can be detrimental to training and performance, because energy intake must be reduced at a time when energy and carbohydrate needs are high.

The active recovery period (off-season) is characterized by a reduction in exercise compared to the competitive season. It is also time away from the rigors of training. Some athletes may wish for time away from the rigors of following a diet that supports training, such as high daily carbohydrate consumption, timing of food intake, and monitoring of energy intake. The off-season can be an important break from disciplined eating although it is not a time for reckless abandon of all dietary restraint. However, the loss of a large amount of body fat takes time and some of that time will likely be during the off-season when a moderate restriction of energy intake is feasible and will not interfere with training. The suggestion to lose some weight in the active recovery period may come as a surprise to many athletes and may be difficult for some who prefer to have few dietary restrictions during the off season. Some of these athletes believe that large and rapid fat loss will be possible early in the preseason and do not use the active recovery period to lose body fat (or prevent a gain of body fat). Many are disappointed that preseason losses are not larger and that fat is not lost as rapidly as they had hoped and some engage in **"crash diets"**

Attenuate: Reduce the size or strength of.

Crash diet: Severe restriction of food intake in an attempt to lose large amounts of body fat rapidly.

Body composition as well as athleticism is important for cheerleading.

that produce large and rapid weight loss but are detrimental to training, hydration status, and health.

Large increases in muscle mass also take time. Male strength athletes in their 20s, such as (American) football players or bodybuilders, may increase lean body mass by 20 percent in the first year of a regular, heavy-resistance training program supported by a diet with adequate energy, carbohydrate, and protein intakes (Lemon, 1994). A 190-lb (~86-kg) football player might add up to 30 to 35 lb (~13.5 to 16 kg) of lean body mass in the first year of a dedicated training program for collegiate football. However, after the first year, gains in lean body mass are much smaller and increases of 1 to 3 percent are more likely in subsequent years. In other words, untrained athletes can experience large initial gains but trained athletes are likely to experience small gains. The 190-lb (~86-kg) collegiate freshman football player who is 220 lb (100 kg) at the beginning of his sophomore year could reasonably expect to gain 2 to 6 lb (~1 to 3 kg) of lean body mass, and not an additional 30 to 35 lb (~13.5 to 16 kg). Women cannot expect to gain as much muscle mass as men and it is estimated that women will experience approximately 50 to 75 percent of the gains seen in men (Stone, 1994).

LIGHTWEIGHT SPORTS: PUSHING THE BIOLOGICAL ENVELOPE

Some sports have designated weight categories because differences in body size make it impossible for all athletes to fairly compete among one another. Examples include wrestling, boxing, martial arts, and lightweight rowing. In sports in which weight must be moved, such as distance running, gymnastics, high jumping, or ski jumping, participants with a low body weight (but sufficient muscularity) generally have a performance advantage over

$$\text{Minimum body weight} = \frac{\text{Current FFM}}{1 - \text{Minimum \% BF}}$$

Figure 11.16 Minimum Body Weight Formula

Legend: FFM = fat-free mass; BF = body fat

those with a higher body weight due to larger amounts of body fat. Women's gymnastics, rhythmic gymnastics, and figure skating have a subjectively scored element and a low body weight may influence artistry scores. Cheerleading and ballet dancing, which require athleticism, are not scored, but being chosen for participation may depend on body composition.

All of these athletic events could attract athletes who are naturally light in weight and who could easily maintain a biologically comfortable low body weight. *Biologically comfortable weight* and *naturally lightweight* are terms used to describe individuals who do not need to engage in chronic energy restriction or acute fluid loss to maintain a low body weight. Indeed, these individuals are found in all of these sports from the recreational to the elite level. However, studies of wrestlers, rowers, boxers, and jockeys have reported that the majority of athletes are competing in a weight class that is below their natural weight (Kazemi, Shearer, and Choung, 2005; Hall and Lane, 2001; Filaire et al., 2001). One group of researchers found that the majority of lightweight rowers surveyed were not naturally lightweight and that 76.5 percent of the males and 84 percent of the females studied reduced their body weights in the four weeks before a major lightweight rowing competition (Slater et al., 2005).

As described previously, a target weight based on desirable body composition can be determined. For athletes competing in low-body-weight sports, it is critical that a *minimum* body weight also be calculated. A minimum body weight calculation takes into account the lowest percentage of body fat that an athlete could likely achieve without putting health at risk. A minimum weight formula is shown in Figure 11.16. The Spotlight on a Real Athlete: Sondra, a Superlightweight Kickboxer, illustrates how this calculation could be used to provide the athlete with important information.

Minimum body weight formulas are now used in wrestling to determine the appropriate weight category for competition. The National Federation of State High School Associations instituted rule changes beginning with the 2006–07 season that included: 1) a body fat assessment no lower than 7 percent in males and 12 percent in females, 2) a monitored weight-loss program that does not exceed 1.5 percent loss of body weight per week (seven days), and 3) a specific gravity of urine not to exceed 1.025 (a measure of hydration status). Many high schools are depending on certified athletic trainers to administer and monitor the program (National Federation of State High School Associations).

Weight Cycling in Athletes. Weight cycling is defined as repeated bouts of weight loss and weight gain. Weight cycling is common in sports where there are weight classes and an athlete's weight must be certified before competition (e.g., wrestling, lightweight rowing, boxing, judo, and tae kwon do). In these sports weight cycling is an established part of the sports' culture. The following section will focus on sports in which athletes frequently want to "make weight."

Athletes whose weight must be certified for competition often believe that weight cycling is necessary. Hall and Lane (2001) studied 16 amateur boxers and found that each had four weight goals during the year. These weights included 1) natural weight, 2) training weight, 3) competitive weight, and 4) championship weight. Figure 11.18 illustrates the average weights for these 16 boxers and shows the progression of weight loss from the preseason (natural weight) through the competitive season—74.7 kg (~164 lb) → 71.87 kg (~158 lb) → 69.93 kg (~154 lb) → 67.87 kg (~149 lb). On average the difference between natural and championship weight was approximately 5 percent of body weight. All the subjects in this study believed that weight loss was necessary and that the loss of weight would improve their performance. They also believed that food and fluid intake after the certification of

SPOTLIGHT ON A REAL ATHLETE

Sondra, a Superlightweight Kickboxer

Sondra, a 28-year-old superlightweight kickboxer, weighs 136 lb (61.8 kg) and is already lean, having an estimated 14 percent body fat. She would like to compete in the lightweight category, which has a maximum weight limit of 132 lb (60 kg). Sondra's dilemma is that she is not competitive with the other superlightweight kickboxers, so she is considering competing in a lower weight category although she has not weighed 132 lb (60 kg) or less since high school. Sondra is sure that she could lose 4 pounds if she put her mind to it; after all, discipline is one of the characteristics of the martial arts. She meets with a sports dietitian who is sympathetic to her goal to be a lightweight kickboxer, but indicates that it is important to consider all the effects weight loss can have on an already lean athlete's performance and health. To Sondra's surprise the detrimental effects are far reaching and include hormonal, bone mineral density, lean body mass, and mental changes. The sports dietitian calculates a minimum weight and explains its meaning (see Figure 11.17).

The minimum weight formula uses current weight and minimum percentage of body fat. At 136 lb (61.8 kg) and an estimated 14 percent body fat, Sondra has approximately 117 lb (~53 kg) of fat-free mass. Assuming that she could lose weight only as body fat and achieve 12 percent body fat, both of which would be a challenge, Sondra's weight would only be 133 lb (~60.5 kg). She would need to chronically undereat or voluntarily dehydrate before weigh-in to be certified as a lightweight. The sports dietitian points out that chronic low energy intake would put her at risk for losing some of her lean body mass and possibly developing disordered eating, amenorrhea, and low bone mass (see Chapter 13).

Sondra realizes that she is setting a goal weight that would be difficult to attain and maintain, yet she finds it hard to let go of the belief that getting to 132 lb (60 kg) is just a matter of having enough discipline. The dietitian encourages her to articulate her goals and reflect on what is needed to achieve them. Sondra's three main goals are to perform her best, be physically fit, and have fun. Good performance requires disciplined training, which Sondra enjoys because it is a challenge, but she knows that she does not have the skill to compete at the highest levels of competition. She also realizes that she loves to eat and her high level of training gives her the ability to eat a lot of food and easily maintain her natural weight and a fit and muscular body. She knows that some of the women who compete in the lower weight categories struggle to "make weight" and she has observed that these women often looked wan, tired, and sad.

The minimum weight formula may help an athlete like Sondra to realize in which body compartments the "weight" would need to be lost and if weight loss would likely mean loss of lean body mass or body water. Considering all of the factors, not just if she has the discipline to reach a certain scale weight, Sondra decides to remain a superlightweight kickboxer. The minimum weight formula helped her to understand that 132 lb (60 kg) was not the right weight goal for her.

$$\text{Minimum body weight} = \frac{\text{Current FFM}}{1 - \text{Minimum \% BF}}$$

$$\text{Minimum body weight} = \frac{117 \text{ lb}}{1 - 0.12} = \frac{117 \text{ lb}}{0.88} = 133 \text{ lb}$$

Figure 11.17 Calculation of a Minimum Body Weight

Legend: lb = pound; FFM = fat-free mass; BF = body fat

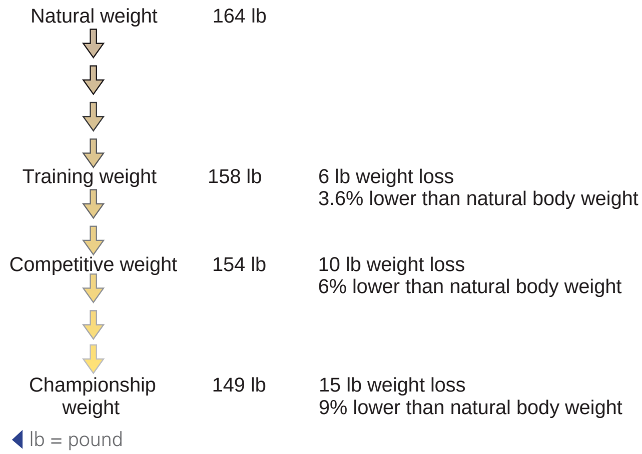


Figure 11.18 Progression of Weight Loss in Amateur Boxers

weight restored the nutrients and strength lost as a result of making weight. Weight cycling, both gradually over the season and rapidly during a given week in the season, is also documented in wrestling, judo, and tae kwon do and parallels boxing in many respects.

Weight is typically lost by increasing exercise, reducing food intake, and restricting fluid intake. Reducing natural weight to a training weight may be relatively easy since the energy expended during training is substantially greater than the energy expended during the off-season. Food intake is often reduced at the same time that exercise is increased, so weight loss is an expected outcome. However, reducing training weight to precompetition and competition weights, which may be considerably below natural weight, typically require more extreme interventions.

During the precompetition and competition phases, athletes often find that it is harder to reach the desired weight or to attain that weight each week. In studies of boxing and tae kwon do participants, researchers report that nearly all subjects restricted their food intake to a greater degree during the competition phases than during the training phase. One to two days prior to weigh-in, many engaged in partial or full fasting (restricting food intake only or both food and fluid intake, respectively). Fluid intake was frequently restricted at least 24-hours prior to weigh-in. On the day of the weigh-in, exercise (e.g., skipping rope, running) was used to further reduce weight and rapid water-loss methods (e.g., exercising in the heat or with sweat-inducing plastic suits, use of diuretics) were employed if goal weight was not likely to be obtained by any other means (Hall and Lane, 2001; Kazemi, Shearer, and Choung, 2005).

In 1994, Scott, Horswill, and Dick reported the results of a study of collegiate wrestlers competing in the 1992 season-ending National Collegiate Athletic Association (NCAA) tournament. At the time of the study there were approximately 20 hours between weigh-in and competition. The average weight gain after weigh-in was 3.73 kg (~8 lb). The wrestlers gained an average of 4.9 percent of body weight after weigh-in, with the wrestlers in the lower weight categories gaining the most weight. These results confirmed anecdotal reports of widespread use of weight cycling among elite collegiate wrestlers.

In the United States, rule changes were made in both NCAA and high school wrestling following the deaths of three collegiate wrestlers in 1997. Perhaps the most important NCAA rule change was moving the weigh-in to approximately two hours prior to competition. In 1999, the second year of the rule change, NCAA tournament wrestlers gained approximately 0.66 kg (~1.5 lb) after weigh-in (Scott et al., 2000). However, international-style wrestling (i.e., freestyle and Greco-Roman) has not made the time-of-weigh-in rule change and in 2004 Alderman et al. found that rapid weight loss and gain was still widely practiced. Their sample of 2,600 international-style wrestlers found that the average weight gain after weigh-in was 3.4 kg (~7.5 lb) or 4.8 percent of body weight. The more successful wrestlers, who were also older, gained significantly more weight after weight certification than the younger, less successful wrestlers.

Although it is not easy to study, there is some research documenting the effects of weight cycling, particularly rapid weight loss and gain, on performance, mental state, and health. Most studies have found that physical performance was not impaired, at least for measures of short-term, high-intensity exercise. Smith et al. (2001) found no significant differences in the performance of eight amateur boxers in a crossover study when they restricted food and fluid intake compared to when they did not. Fogelholm et al. (1993) found no decline in measures of sprinting, jump height, or anaerobic performance in wrestling or judo, with a 5 percent or less loss of body weight achieved either gradually (over three weeks) or rapidly (2.4 days). In the study of the 16 amateur boxers (Hall and Lane, 2001), the subjects were asked to set a goal for the number of repetitions they wanted to perform on a circuit-training protocol that simulated a boxing match. There was no significant difference between the number of repetitions achieved at the training weight and the championship weight, a difference of about 5 percent of body weight. However, the boxers *expected* that they would be able to perform approximately 15 more repetitions at their championship weight; none did. In other words, these boxers believed that losing ~5 percent of their weight would improve performance but it did not.

There has been speculation that weight cycling results in a decrease in resting metabolic rate (RMR). This is one theory behind the observation that athletes have a more difficult time making weight week after week, especially near the end of the season. However, most research in athletes does not demonstrate that weight cycling results in a measurable reduction in RMR in the short term (week by week in season) or the long term (over two or three seasons). Most of these studies were conducted in the 1990s and there are no recent studies of athletes and the effect of weight cycling on RMR (McCargar et al., 1993; McCargar and Crawford, 1992; Horswill, 1993; Schmidt, Corrigan, and Melby, 1993; Melby, Schmidt, and Corrigan, 1990).

Mental state, however, seems to change with weight cycling. Higher scores on measures of anger, tension, and fatigue and lower vigor scores are reported in amateur boxers and judoka (judo athletes). These changes are likely due to low energy intake (i.e., semi-starvation), low carbohydrate intake, and hypohydration (Hall and Lane, 2001; Filaire et al., 2001).

The biggest area of concern is the health of the athlete who needs to "cut" weight, a term used to indicate extreme diet and exercise measures to produce rapid weight loss. Alderman et al. (2004) found that more than 40 percent of wrestlers who engaged in rapid weight loss experienced headache, dizziness, or nausea at least once during the season. Other side effects, such as nosebleeds, disorientation, or a racing heart rate, also occurred in some wrestlers but with less frequency. The medical consequences associated with hyperthermia (elevated body temperature) and hypohydration as a result of rapid weight-loss techniques are well known. These conditions, some of which may be fatal, are discussed in Chapter 7.

A 2006 study of former Finnish athletes raises the possibility that weight cycling by athletes may predispose them to obesity later in life. Approximately 1,800 male elite athletes completed questionnaires in 1985, 1995, and 2001. The 370 weight cyclers, former boxers, weight lifters, and wrestlers had an average weight gain of 5.2 BMI units (~26 lb or 12 kg) compared to 3.3 BMI units (16.5 lb or 7.5 kg) in nonweight-cycling former athletes (Saarni et al., 2006).

What's the point? Weight and body composition measurements can be useful information for athletes, but these measures must be accurately obtained and interpreted and applied correctly.

WEIGHT GAIN IN UNDERWEIGHT ATHLETES

Some athletes are underweight and want to increase both muscle mass and body fat. This population has not been well studied. It is generally recommended that energy intake be increased by 500 kcal daily (Rankin, 2002). The additional energy should come from nutritious foods such as fiber-containing carbohydrates, proteins, and heart-healthy fats. Fat is the most energy-dense nutrient, however, simply adding large amounts of additional fats to the diet may be counterproductive. In some underweight people, a high-fat meal or snack is so **satiating** that food is not consumed again for many hours and results in a net decrease in the total energy (kcal) intake for the day. More information on dietary strategies for underweight athletes can be found in Chapter 10.

Supplements Used to Change Body Composition

Changing body composition through diet and exercise demands daily attention and discipline, and is typically a slow process. Therefore, it is not surprising that athletes look to supplementation of substances that promise to build muscle and reduce body fat easily and quickly. Some of these supplements may contain substances that are banned by sports-governing bodies. Before taking *any* supplement athletes should ask four critical questions: 1) Is it **legal**? 2) Is it **ethical**? 3) Is it **safe**? and 4) Is it **effective**?

MUSCLE-BUILDING SUPPLEMENTS

Perhaps no group of supplements holds more promise in the eyes of athletes than those involved in muscle protein synthesis. Increased muscle size and strength are important performance factors in many sports. As discussed previously, the building of muscle tissue through training and diet is a slow process that requires hard work and discipline. Substances that have received tremendous attention include testosterone and testosterone precursors.

Anabolic Steroids. Testosterone is a hormone that influences muscle protein synthesis. The use of anabolic steroids, scheduled drugs that are nearly identical to testosterone, is known to increase muscle mass and, in some individuals, muscle strength (American College of Sports Medicine, 1984). The self-prescribed use of anabolic steroids is illegal, prohibited by sports-governing bodies for ethical and safety reasons, and associated with some substantial medical risks, especially for females because of their irreversibility.

Satiate: To satisfy hunger.

Legal: Allowed under the law.

Ethical: Consistent with agreed principles of correct moral conduct.

Safe: Unlikely to cause harm, injury, or damage.

Effective: Causing a result, especially one that is intended or desired.

Those who work in sports-related fields might encounter athletes who use or are considering using anabolic steroids to increase muscle mass. A National Institute on Drug Abuse (NIDA) study reports that 2.6 percent of high school seniors have used anabolic steroids at least once. The prevalence in adults in not known but is estimated to be in the hundreds of thousands of adults (NIDA, 2005).

Athletes should be aware of the many legal, ethical, and safety issues involved. The impact on health may be mild to severe and, in rare cases, may result in death. Blood pressure and low-density lipoprotein concentration may increase while high-density lipoprotein concentration may decrease, which are risk factors for cardiovascular disease (see Chapter 12). Aggression, depression, and other psychological effects have been reported. Use by males may result in reduction in testicle size, accelerated baldness, and the development of breast tissue. Use by females may result in changes in menstruation and reproductive organs, baldness, lowering of the voice, and growth of facial hair. Adolescents, because they are typically still in a growth state, risk premature skeletal maturation before reaching their genetic potential for height. The National Institute on Drug Abuse and most sports-governing bodies have anabolic steroid information available for athletes.

Prohormones. Because athletes can be permanently banned from their sport for testing positive for anabolic steroids, many look for dietary supplements that would provide similar benefits. Among the most popular are the prohormones, compounds that are precursors to testosterone. Many prohormones, such as androstenedione, are banned by sports-governing bodies.

As shown in Figure 11.19, many compounds are involved in the synthesis of testosterone. Cholesterol is the precursor to testosterone and related compounds. Action by various enzymes results in the conversion of

SPOTLIGHT ON A REAL ATHLETE

One Wrestler's True Story

"I was a senior in high school, 18-years-old, and trying to lose weight for wrestling. I was 5'8" tall and started out weighing 145 pounds. Within about three weeks I had lost 17 pounds to make the 128 pound weight class. I was on a strict diet of 1,100 calories per day. Two days before I had to make weight, I would stop eating. The day before weigh-ins, I would not drink anything. I was always trying to burn off "extra" pounds by jumping rope or jogging. Whenever I worked out, I always wore two pairs of sweats in order to lose water weight. I jogged 12 miles one day to make weight for a match that evening. I would fast, and dehydrate myself by sweating and spitting in a cup in order to make weight. I never took laxatives, diuretics, or vomited to make weight. After weigh-ins, I ate as much as I wanted to without eating so much as to hinder my performance. On weekend tournaments I also ate between matches and afterwards. On Sunday, I started cutting back on my caloric intake and by Monday I was back down to 1,100 calories. I was usually at least 10 pounds overweight on Monday, also. I weighed myself around four times per day. It was such a physical and emotional strain on me to make weight I could only make the 128-pound class about once every two weeks. The other times I only had to make the 134-pound weight class. The trainer did a skinfold measurement to check my body composition and came up with a figure of below 3 percent body fat. I was probably in the best cardiovascular shape in my life due to my constant cardiovascular workouts. However, I did lose strength and muscle mass. I looked much thinner than I did before, and my cheeks and eyes were sunken in and I had dark circles under my eyes. I had trouble falling asleep at night. I constantly felt cold. I never seemed to generate enough body heat to keep warm. I was the only one wearing a jacket in my classes, and I had to sit on my hands to keep them warm. When I saw my friends with food or a soft drink, I would cuss at them. Fortunately, I was able to maintain a 4.0 grade point average. I became obsessed with food because I was so hungry and I couldn't eat. To compensate for that, I used to go to the grocery store a couple of times per week and walk up and down every aisle and make a mental list of all the foods I was going to eat when the season was over. I also used to do a lot of cooking and baking, but not eat any of it. By the end of the season, it had taken its toll on me. I secretly hoped that I would be eliminated and not qualify for the next tournament, so my season would be over and I could eat as much as I wanted to. I always tried my best to win, and I never tried to lose on purpose, but I think that it subconsciously affected my performance. Why would anyone do this to himself? My coaches told me they needed me to compete at that weight class. They told me I was the best wrestler at that weight class and it would make the team stronger if I competed there. One of my coaches told me how he did the same thing in high school and that if he could do it, I could do it, and I believed him. What they, and I, didn't realize was that I probably would have wrestled better, and been more of an asset to the team, if I had wrestled at a higher weight. If I had known then what I now know about the relationship between nutrition and athletic performance, I would have wrestled at the 140-pound weight class instead."

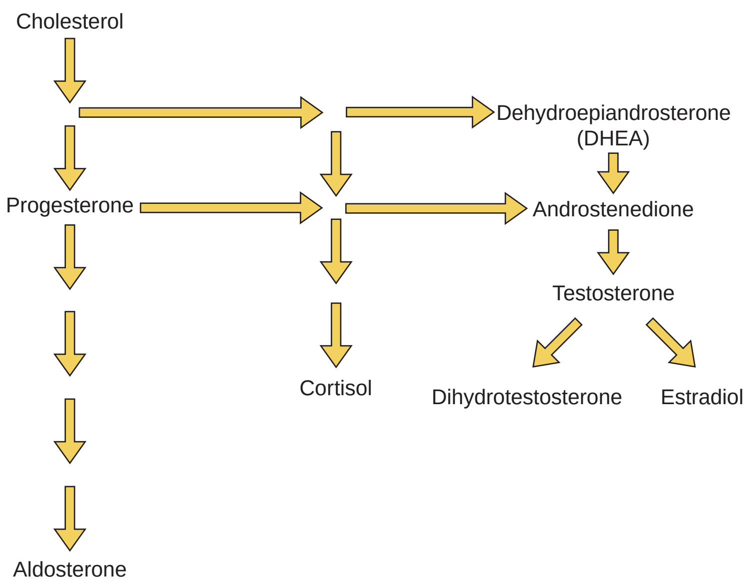


Figure 11.19 Testosterone Synthesis

The biochemical pathway of testosterone synthesis.

cholesterol to progesterone to androstenedione and to testosterone. Using a different biochemical pathway, cholesterol can also be converted to testosterone via dehydroepiandrosterone. Androstenedione and testosterone are precursors to estrogens such as estrone and estradiol.

Androstenedione, androstenediol, and, to a lesser extent, DHEA are often referred to as *prohormones*. They are precursors to testosterone and have similar, but not exact, chemical structures. Athletes hope that these prohormones will elevate testosterone concentration and consequently increase muscle protein synthesis. Studies of all of these compounds have yet to confirm this hope. Although some studies showed a short-term rise in testosterone concentration with supplementation, this short-term rise has no effect on muscle size, strength, or power (Broeder et al., 2000). In fact, androstenedione supplementation preferentially increases estradiol (via estrone), not testosterone, which can result in the development of breast tissue in males (Wolfe, 2000).

Androstenedione supplements became extremely popular when baseball star Mark McGwire admitted to taking "andro" during his home run record-setting season in 1998. His taking this supplement may have influenced many younger and less accomplished players to do so (Brown, Basil, and Bocarnea, 2003). The purity and safety of androstenedione supplements has been questioned. Suspicions have been raised about whether some androstenedione supplements may have been "spiked" with anabolic steroids.

In March 2004, the Food and Drug Administration (FDA) released a **white paper** that listed more than 25 potential androgenic and estrogenic effects associated with androstenedione use (FDA, 2004). This review of the scientific literature prompted the FDA to crack down on dietary supplements containing androstenedione. The FDA considers these supplements to be adulterated (impure), and therefore illegal to market. Androstenedione is a banned substance by most sports-governing bodies, which consider its use unethical and unsafe.

Dehydroepiandrosterone (DHEA) is also a precursor to testosterone and estrogen, but it is considered a weak androgen (steroid). It has a more general effect on tissues than anabolic steroids or androstenedione. DHEA diminishes substantially after early adulthood, probably due to a decrease in the number of cells that produce it (Hornsby, 1997). Thus, supplements are often advertised as being "a fountain of youth." There is no scientific evidence that DHEA has an anabolic effect or can enhance athletic performance (Corrigan, 2002). However, interest in DHEA supplements increased after androstenedione supplements were no longer legally available in the United States.

DHEA was a prescription drug in the United States prior to the passage of the Dietary Supplement Health and Education Act in 1994. DHEA is now available over the counter and in dietary supplements. In other countries, such as Australia and New Zealand, it remains a controlled substance due to the potential for abuse. Because the long-term safety is currently unknown and effectiveness related to athletic performance is unproven, DHEA supplements for athletes are not recommended (Corrigan, 2002).

White paper: Official, well-researched government report.

WEIGHT-LOSS SUPPLEMENTS

Most people find it difficult to lose body fat and to maintain the loss. Any dietary supplement that may increase the amount lost or accelerate the rate of weight loss will be popular. Because dietary supplement manufacturers do not have to prove either safety or efficacy before a supplement is sold, there is an endless stream of weight-loss supplements on the market. Perhaps the most controversial weight-loss supplements are those that contain ephedrine (e.g., ephedra), which may be used alone, but is usually found in combination with caffeine.

Ephedra, Ephedrine Alkaloids, and Ephedrine. *Ephedra, ephedrine alkaloids,* and *ephedrine* are different terms and should not be used interchangeably. *Ephedra* is a botanical term and refers to a genus of plants. Some species of ephedra contain ephedrine alkaloids in the stems and branches. One of the ephedrine alkaloids is ephedrine. In common usage, dietary supplements that contain any of the ephedrine alkaloids are referred to as *ephedra*.

In traditional Chinese medicine, ma huang is extracted from a species within the plant genus *Ephedra*. This species, *Ephedra sinica* Stapf, contains six different ephedrine alkaloids. Of the six, the primary active ingredient is ephedrine. Ephedrine can also be synthesized in the laboratory. Traditionally, the Chinese have used ma huang to treat asthma and nasal congestion. In the United States, ephedrine is added to over-the-counter medications for the same purposes. But ephedrine and related compounds have been marketed as dietary supplements for two other purposes: weight loss and increased energy. Both are common goals for athletes. Are ephedrine and related compounds safe and effective for these purposes?

Safety of Ephedrine-Containing Compounds. The safety of ephedrine-containing dietary supplements has always been controversial and reviewing its history helps to underscore some important issues about safety, purity, and supplement regulation in the United States. After the passage of the Dietary Supplement Health and Education Act in 1994, the sale of dietary supplements containing ephedrine began to increase. The FDA expressed concern, in part, because of the number of adverse event reports (AER) they received. Consumers can report adverse events to a hotline and by 1997 half of the AER received involved ephedrine. The adverse events reported included known side effects such as headache, increased heart rate, increased blood pressure, and insomnia. The AER also included deaths to otherwise healthy middle-aged and young adults.

Adverse event reports are anecdotal evidence because they are personal accounts of an event. These reports were hard to interpret because many lacked information about the dose consumed. Some consumers may have used these supplements despite the manufacturer's warnings. Most warn against use by pregnant or lactating women, and those with a history of heart disease, diabetes, or high blood pressure.

A scientific review of 16,000 adverse event reports found that 21 were serious events: two deaths, nine strokes, four heart attacks, one seizure, and five psychiatric problems. In these cases ephedrine was believed to be the sole contributor, *but* there was not enough scientific evidence to establish a cause-and-effect relationship. In addition to the 21 serious events, ephedrine contained in dietary supplements was implicated as a contributing (but not sole) factor in 10 other cases with serious side effects (Shekelle et al., 2003).

Further complicating the issue of safety was that experts do not agree on the dosage that is considered safe. The FDA proposed that not more than 8 milligrams (mg) of ephedrine alkaloids be used in a 6-hour period *and* not more than 24 mg in a 24-hour period. Use should not exceed seven days (FDA, 2000). Another group of experts suggested that a single dose should not exceed 30 mg of ephedrine alkaloids and that up to 90 mg in a 24-hour period is safe. They suggest usage should not exceed six months (CANTOX report, 2000).

Another safety issue was quality control. In 2000, Gurley, Gardner, and Hubbard published a study of the ephedrine alkaloid content of 20 dietary supplements. The content of 10 of the products varied by more than 20 percent when compared to the amount listed on the label. The worst example was a product that contained more than 150 percent of the amount listed on the label. One product had no active ingredient, and particularly troublesome, five contained norpseudoephedrine, a controlled substance (drug). This study clearly illustrates why athletes must be concerned about the purity of dietary supplements.

Athletes should particularly be aware of the risk associated with using ephedrine-containing dietary supplements prior to strenuous workouts in the heat. In 2001, the National Football League (NFL) banned the dietary supplement ephedra after the death of an interior lineman during training camp. Although toxicological tests were not conducted on autopsy, an ephedrine-containing dietary supplement was found in the player's locker. In 2003, the safety of ephedrine-containing dietary supplements was again in the news with the death of a major league pitching prospect at spring training. In this case, the coroner implicated ephedrine as the cause of death. Contributing circumstances appear to include a history of borderline hypertension and liver abnormalities, exercising in hot and humid conditions, and restricting food and fluid intake in the previous 24-hours in an effort to lose weight.

The 2003 spring training death brought the issue of ephedrine in dietary supplements back to the forefront. In December 2003, the FDA issued an alert that advised consumers to stop buying and using dietary supplements containing ephedrine. In April 2004, the FDA banned the sale of ephedrine-containing dietary supplements. Although the alert was issued in December, the ban could not go into effect until the following April because there must be a 60-day period between the official notification of the ban and its enactment.

The ban is controversial. Under the Dietary Supplement Health and Education Act, the FDA can stop the sale of a dietary supplement if there is a demonstrated "significant or unreasonable risk of illness or injury." The legal issue boils down to this question: Do the serious events reported to date, including deaths in which ephedrine was the sole contributor but in which cause and effect cannot be established, constitute an unreasonable risk of illness or injury?

Proponents of the ban point to documented deaths. They also question whether there are any health benefits and suggest that the risk/benefit ratio meets the "unreasonable risk" portion of the criterion. Opponents of the ban counter that the risk is very small. In 1999, approximately 3 million people purchased ephedrine-containing dietary supplements and consumed an estimated 3 billion "servings." The risk of a serious adverse event is estimated to be less than 1 in 1,000 and a cause-and-effect relationship has not been established. The debate is often passionate, political, and polar (FDA, 2003).

In April 2005, a federal judge struck down a portion of the ban. In that decision, the judge ruled that the FDA did not establish that an unreasonable risk of illness or injury was associated with low-dose (10 mg or less) ephedrine-containing supplements. The federal ban remains in place for doses greater than 10 mg. Some states (e.g., California, Illinois, New York) have banned the sale of all ephedrine-containing dietary supplements and these state laws are not affected by the federal court's decision.

Most ephedrine-containing supplements also contain caffeine, a member of a group of stimulants known as the methylxanthines. Since caffeine sometimes carries a negative connotation with consumers, the source of methylxanthine may be herbal, either guarana or kola nuts. Methylxanthine enhances the effectiveness of ephedrine as a weight-loss agent. Look carefully at the label shown in Figure 11.20. A dietary supplement may contain both ephedrine and caffeine but those

SUPPLEMENT FACTS	
Serving size: 1 tablet	
Servings per container: 60	
Amount per serving	% Daily Value
Vitamin B_{12} 50 mcg	833%
Megatherm™ proprietary blend 350 mg	**
Ma huang	**
Guarana seed	**
Yerba mate	**
Green tea leaf	**

** Daily value not established

Ingredients: Megatherm™ proprietary blend, pyridoxine HCL, sorbitol, guar gum.
Storage: Keep in a cool dry place, tightly closed.
Suggested Use: As a dietary supplement, take one tablet daily.

Keep out of reach of children
Expiration date: Dec 2012

Figure 11.20 Label of an Ephedrine-Containing Supplement. This dietary supplement contains both caffeine and ephedrine, but these terms do not appear on the label.

words will not appear if, for example, the source of those ingredients is ma huang and guarana.

Effectiveness of Ephedrine for Weight Loss. Studies have shown that the use of ephedrine and caffeine by obese people can produce a short-term weight loss of 8 to 9 lb (~3.5 to 4 kg). Studies to date have not been conducted for longer than six months, so it is unknown what the long-term effect might be or the effect of discontinuing the ephedrine and caffeine. It is also not known if an ephedrine-induced short-term weight loss has any long-term health benefit (Shekelle et al., 2003). Most athletes are not obese, so it is not known if, or how much, weight would be lost by athletes with ephedrine use.

Some athletes claim that ephedrine- and caffeine-containing dietary supplements give them "more energy." This is likely due to the stimulant effect of

THE EXPERTS IN…

Weight and Body Composition

Over the course of a long professional career, Jack Wilmore, Ph.D., helped athletes and sports-related professionals to correctly interpret information obtained from measuring body composition. As technology changed the measurement methods, Linda Houtkooper, Ph.D., R.D., emerged as an expert in some of the more sophisticated body composition techniques, such as DEXA scans. These and other experts have authored numerous scientific articles about accurately measuring body composition.

One of the more difficult areas of study has been the best ways for athletes to increase muscle mass and decrease body fat. Janet Walberg Rankin, Ph.D., has conducted research on weight control and body composition, particularly in resistance-trained athletes.

The Internet Café

Where Do I Find Reliable Information about Body Composition and Body Weight?

There are hundreds of noncommercial websites and hundreds of thousands of commercial websites with information about body composition and body weight. The prevention section of the Dietary Guidelines for Americans website includes a calculator for body mass index as well as information about a healthy weight. Shape Up America!, founded by former Surgeon General C. Everett Koop, is dedicated to raising awareness of obesity as a health-related issue as well as reducing the incidence and prevalence of childhood obesity. These are just two examples of websites with comprehensive information about body weight and composition.

Dietary Guidelines for Americans, 2005
http://www.healthierus.gov/prevention.html

Shape Up America!
http://shapeup.org

these compounds, which can mask fatigue. Some brands may be "spiked" with norpseudoephedrine, a stimulatory drug. Caffeine, ephedrine, and other stimulants are addictive and individuals will experience symptoms upon withdrawal, including headache, fatigue, drowsiness, depressed mood, irritability, and inability to concentrate (Juliano and Griffiths, 2004). These characteristics are undesirable and may interfere with training, making it difficult or uncomfortable for athletes to stop using stimulatory dietary supplements.

Effectiveness of Ephedrine on Performance. A small number of studies have been conducted on the use of nonherbal ephedrine and caffeine preparations in healthy males as a performance enhancer. Research in this area has been limited due to the ethical issues related to administering potentially harmful substances to human subjects. Ephedrine and caffeine administered together has been reported to increase performance by delaying time to exhaustion by up to 30 percent (Schekelle et al., 2003). Athletes also report a decrease in perceived exertion (Magkos and Kavouras, 2004). These results are not surprising given the stimulatory properties of these substances. Studies have not shown that ephedrine and caffeine, alone or in combination, are effective in increasing muscle strength, muscle size, or anaerobic capacity.

Other Weight-Loss Supplements. A quick search of the Internet reveals an astounding number of dietary supplements available for purchase for the purpose of weight (fat) loss. Many of these supplements are described as "fat burners," a loosely defined term that is used to describe compounds that help individuals to lose body fat, typically by increasing metabolism or enhancing fat breakdown. Many of the compounds are described as *natural*, which generally means that the active ingredient comes from an herbal rather than a synthetic source.

Ephedrine and ephedrine alternatives (with added caffeine) are examples of fat burners and have already been discussed. Other supplements promoted for fat loss include yerba mate, yohimbe, and hydroxycitric acid (*Garcinia cambogia*). Pittler and Ernst (2004) conducted a systematic review of 12 dietary supplements for weight loss and concluded that none could be recommended because scientific evidence was lacking for safety or effectiveness.

Summary

The body is composed of various tissues, including fat, muscle, bone, organs, and fluids. The relative percentage of these components, particularly body fat, may

KEEPING IT IN PERSPECTIVE

Body Composition, Body Weight, Performance, Appearance, and Health

Athletes are typically very interested in measuring their body composition. While weight and body composition are factors in athletic performance, the impact of either will vary depending on the sport. A lean, muscular athletic body usually has high social value, and many athletes wish to alter their weight and body composition for both performance and appearance reasons. Most athletes are not obese, so body weight is often not a chronic disease-related issue, but how rapidly and dramatically athletes lose weight may negatively impact their health.

Perspective can be lost when a certain body composition or weight is the ultimate goal instead of a means for potential improvements in performance or health. Trying to attain an ever-lower weight can result in declining or poor performance and does not make sense. Becoming too focused on a number can lead athletes to engage in risky behaviors, such as severe hypohydration, and lose sight of the bigger picture, which is optimal performance. It is easy to forget that body composition measurement is not precise and that reaching a certain percent of body fat may be at odds with performance and health goals.

affect performance, appearance, and health. There are a number of ways to measure body composition, but all have inherent measurement error and are considered only estimates of actual body composition. The subject or technician can introduce additional error. Therefore, body composition results should be interpreted carefully.

Body composition results can be used to determine an appropriate scale weight, establish percent fat and **lean body mass** goals, and assess the impact of training and nutrition strategies. Changing body composition may improve performance, but attaining an inappropriate body composition or weight can be detrimental to performance and health. Athletes in sports in which weight must be certified can calculate a realistic, attainable, and sustainable minimum weight.

Athletes may wish to change body composition and can do so with an exercise and diet plan that promotes maintenance or gains in lean body mass and/or loss of body fat. These goals are typically accomplished over time and should be a planned part of the athlete's training schedule. The timetable for achieving these goals may be slower than the athlete would like or imagines. Muscle building and "fat burning" supplements may be tempting to those desiring rapid results, but some of these supplements are not legal, ethical, safe, and/or effective. Athletes should consider performance, appearance, and health when setting weight and body composition goals.

Post-Test: Reassessing Knowledge of Body Composition and Body Weight

Now that you have more knowledge about body composition and body weight, look again at the statements that were listed at the beginning of the chapter. The answers can be found in Appendix O.

1. Percent body fat and fat mass can be precisely measured in athletes with a number of different methods.
2. The most accurate method of measuring body fat for any athlete is underwater weighing.
3. In sports in which body weight must be moved or transported over a distance (e.g., distance running), it is a performance advantage to have the lowest weight possible.
4. To increase muscle mass, most athletes need a substantial increase in their usual protein intake.
5. For athletes who want to restrict energy intake to lose body fat, the recommended time to do so is at the beginning of the preseason or during the off-season.

Review Questions

1. What is essential fat and how does it differ from storage fat?
2. Are lean body mass and muscle mass the same or different? Explain.
3. Compare and contrast the body build of endomorphs, mesomorphs, and ectomorphs. How might this information be used to help athletes set realistic body composition goals?
4. Why is body mass index (BMI) inappropriate to use with athletes?
5. Explain why percent body fat results should be given as a range rather than as a single number.
6. Describe various ways that error may be introduced into the measurement of body composition.
7. Compare and contrast the various body composition methods considering accuracy, cost, availability, portability, and ease of use. Which may be useful in a research setting? A high school? A university? A health and fitness club?
8. In what ways may body composition estimates be useful to athletes and those who work with athletes?
9. Body weight does not give information about body composition, so why is the measurement of body weight useful?
10. Describe a situation in which calculating a minimum body weight might be beneficial.
11. Name the two dietary factors that are critical to increasing muscle mass. Explain why each is important.
12. What effect does weight cycling have on performance? On mental health? On physical health?
13. Name some of the side effects of anabolic steroids and androstenedione.
14. Develop a point/counterpoint discussion for a ban on all ephedrine-containing dietary supplements.

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