Science of Strength and Conditioning Series

NSCA's Guide to TESTS AND ASSESSMENTS

NSCA™
National Strength and Conditioning Association

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EDITOR

NSCA's Guide to Tests and Assessments

National Strength and Conditioning Association

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Metabolic Rate

Wayne C. Miller, PhD, EMT

The capacity of the body to exercise or do physical work depends on its ability to produce, use, and regulate energy. *Metabolism* is the term used to describe this all-encompassing use of energy in the body. Although metabolism includes both the building up and the breaking down of biological compounds, or the sum of the balance between food intake and energy expenditure, we generally refer to the metabolic rate as the rate of energy expenditure. The rate of energy expenditure (metabolism) required by the body or any one of its cells can vary from high-power output to low-power output. Exercise scientists classify the biochemical processes used to expend energy during exercise into categories, depending on the power output demand. Terms such as *fast glycolysis, slow glycolysis, aerobic metabolism, anaerobics*, and others, are used to describe rates of metabolism.

Other chapters in this book describe how the capacity for energy expenditure in the various biochemical pathways affects exercise performance. The focus of the current chapter, however, is on the body's total metabolic rate at rest, during exercise, and throughout the day. This chapter addresses what constitutes the 24-hour energy expenditure, how energy expenditure is measured, how physical activity is monitored, and how energy expenditure can be predicted.

Knowledge about energy expenditure and how it is measured can be helpful to both the practitioner and the client. For example, knowing the 24-hour energy expenditure of a client can help the practitioner structure a diet plan that can help the client lose weight, gain weight, or maintain weight. This knowledge of metabolic rate would be particularly important for the overweight client attempting weight loss or the ultra-endurance athlete trying to maintain weight during a competitive season. Knowledge about metabolic rate may also be helpful as a diagnostic tool to identify possible reasons for decrements or improvements in exercise performance.

Staleness or decrements in athletic performance can often be traced to a chronic energy imbalance, particularly in sports such as gymnastics, wrestling, and cycling.

Components of Energy Expenditure

The body's 24-hour energy expenditure can be broken down into three components: the thermal effect of food, the resting metabolic rate, and the energy cost of physical activity.

Thermal Effect of Food

The thermal effect of food (TEF) is defined as the amount of energy required to digest, absorb, and further process the energy-yielding nutrients in food (i.e., fat, protein, carbohydrate). These energy-expending processes for preparing food prior to its use in the body are collectively called the thermal effect of food, or alternatively, dietary-induced thermogenesis. The contribution of the TEF to the total 24-hour energy expenditure is 5 to 10% (Miller 2006). From a practical or intervention standpoint, the TEF is rather insignificant—individual variance in the TEF does not seem to make a difference in body composition among people; and changes in diet composition do not alter the TEF appreciably (Miller 2006).

Resting Metabolic Rate

The amount of energy expended to sustain the basic body functions is called the resting metabolic rate (RMR) and is generally expressed as kilocalories (kcal). The RMR amounts to about 1 kcal · kg^{-1} of body weight per hour, or roughly 1,800 kcal per day for the average 75-kilogram (165 lb) man. The RMR accounts for approximately 60 to 75% of the total daily energy expenditure, and therefore, anything that alters the RMR has the potential to significantly affect the body's energy balance. Factors that have been implicated in the variance found for RMR within and among people are body composition, gender, race, restrictive dieting, and exercise. Some of these factors are interrelated, some are subject to behavior modification, and some are nonmodifiable (e.g., race).

Individual differences in body composition, particularly in lean body mass, account for most of the 25 to 30% variation in RMR among people. Muscles, organs, bone, and fluids make up most of the lean body mass. The tissues and organs that contribute most to the RMR are the liver, skeletal muscles, brain, heart, and kidneys. The size of each of these is directly related to body size. The size of the skeletal muscle mass is also related to body type, muscle development, and age. People with greater amounts of lean body mass generally have higher RMRs than those with less lean body mass (Cunningham 1982). Although the metabolic rate of fat mass contributes only 2% to the total RMR, obese people generally have a higher absolute RMR than lean people. The proportionately larger tissue and organ size of obese people gives them a greater total lean body mass than lean people. Similarly, the generally larger body size and greater muscularity in men gives them a greater total lean body mass than women. The salient point to remember, then, is that the RMR for people of all sizes and shapes is strongly related to their lean body mass, because lean body mass is positively related to body size or body surface area.

Variation in RMR within a person is predominantly attributed to fluctuations in lean body mass. When an overweight or obese person loses weight, the RMR decreases in proportion to the amount of lean body mass that is lost, not the amount of fat lost. People who gain muscle mass (and other lean tissue) through athletic training experience an increase in RMR in proportion to the lean mass gained.

The fact that RMR is largely determined by lean body mass has led many professionals (and unfortunately, some quacks) to heavily promote unproven products, programs, supplements, and aids that are purported to boost metabolism by increasing lean body mass. Even well-intentioned professionals often get caught up in the notion that exercise is going to make a huge difference in RMR by dramatically increasing lean body mass. It is true that exercise will increase lean body mass, which will ultimately elevate RMR, but the resultant changes in RMR are modest and will not overshadow the effects of poor health behaviors.

For instance, the metabolic rate of 1 kilogram (2.2 lb) of lean body mass is approximately 20 kcal/d (McArdle, Katch, and Katch 2001). Therefore, exercise would have to induce an increase in lean body mass of 5 kilograms (11 lb) to elevate RMR by 100 kcal/d. Although an elevation in RMR of 100 kcal/d may have a significant effect on body composition over a long period of time, a person can easily overcompensate for that 100 kcal by consuming half of a chocolate chip cookie or 8 ounces (240 ml) of soda.

Exercise physiologists have contended for years that aerobic, or endurance, exercise training increases RMR. The research, however, suggests that aerobic exercise training does not necessarily increase RMR significantly. For example, Wilmore and associates (1998) showed that RMR remained unchanged following 20 weeks of aerobic exercise training in men and women of all ages, in spite of an 18% increase in maximal aerobic capacity. Because it is well accepted that strength training can increase muscle mass, and that muscle mass is very active metabolically, Byrne and Wilmore (2001) investigated how strength training may differentially affect RMR in comparison to aerobic, or endurance, exercise training. This cross-sectional study revealed no significant difference in RMR among strength-trained, endurance-trained, and untrained women. Thus, it appears that neither aerobic nor strength training increases RMR significantly.

In spite of the research, many professionals insist and continue to promote the notion that exercise training, particularly resistance training, will greatly increase lean body mass and consequently RMR substantially. This viewpoint is frequently endorsed by professionals working with overweight clients desiring to lose weight. The weakness in this line of thinking lies in the fact that a decrease in lean body mass almost always accompanies a significant drop in body weight (Stiegler and Cunliff 2006). Nonetheless, the loss in lean body mass can be minimized by including exercise in a weight loss program (Hunter et al. 2008).

Even if a person were able to gain lean body mass through an exercise program, how much would this affect RMR? The average amount of lean body mass gained during several weeks of resistance training is variable. However, the obesity research suggests that the increase in lean body mass during exercise training with obese people amounts to only about 2 to 3 kilograms (4.4 to 6.6 lb). Similarly, the resting metabolic rate of muscle tissue is variable, but several reports suggest that the value ranges from 20 to 30 kcal · kg^{-1} · day^{-1}. Taking the average of these estimates, the energy expenditure of an additional 2.5 kilograms of muscle, at 25 kcal · kg^{-1} · day^{-1}, would be 63 kcal · day^{-1}. This would be the equivalent in energy value to about 3 kilograms (6.6 lb) of body fat in one year. The obese person who may need to lose 10 times this amount of fat to become normal weight will need more motivation to resistance exercise train than the promise that resistance exercise training will increase the lean body mass and RMR enough to appreciably alter body fat content. On the other hand, resistance training for the obese person will help maintain the observed decrease in lean body mass and RMR seen with restrictive dieting.

Bray (1983) was the first to demonstrate that a reduction in energy intake results in a decline in RMR. He found that this decrease in RMR was about 15% when subjects were removed from a maintenance diet of 3,500 kcal · day^{-1} and placed on a very-low-calorie diet of 450 kcal · day^{-1}. Although RMR drops while a person is on a very-low-calorie diet, most scientists agree that when energy intake is restored to predieting levels, the RMR also returns to predieting levels, unless there is a decrease in lean body mass. In this case, the postdiet RMR-per-lean-body-mass ratio (RMR:LBM) would be equivalent to predieting levels. However, an early research paper revealed that severe energy restriction lowers RMR:LBM significantly (Fricker et al. 1991). During this study, obese women were placed on a very-low-calorie diet for three weeks. RMR:LBM declined to 94%, 91%, and 82% of the original value on days 3, 5, and 21 of the diet, respectively.

In a randomized controlled clinical trial, moderately obese men and women were assigned to one of three groups: diet plus strength training, diet plus endurance training, or diet only (Geliebter et al. 1997). The exercise protocols were designed to be isoenergetic, meaning that the energy expenditures for the two types of exercise training were equivalent. The average weight loss among the three groups did not differ significantly after eight weeks, but those in the strength-trained group lost less lean body mass than those in the other two groups did. The RMR declined significantly in each group, with no difference among groups. These data indicate that neither strength training nor endurance exercise training prevent the decline in RMR caused by restrictive dieting.

These studies on the effects of restrictive dieting and RMR suggest that the metabolic activity of the lean tissues themselves may be reduced with restrictive dieting. The consequence of such an adaptation would be a greater weight gain when energy consumption returns to predieting levels, greater difficulty maintaining a reduced weight postdiet, or both. More research needs to be done to determine whether this reduction in metabolic rate due to severe dieting is permanent. For now, maintaining exercise training while attempting weight loss, and avoiding periods of extensive and extreme dieting, are recommended.

African Americans have a lower RMR than Caucasians, and the magnitude of difference between the races is similar for both men and women. Investigators have measured the RMR for African Americans to be anywhere from 5 to 20% below that of Caucasians (Forman et al. 1998; Sharp et al. 2002). The range of difference in the RMR over a 24-hour period amounts to 80 to 200 kcal. This metabolic discrepancy cannot be attributed to differences in age, body mass index (BMI), body composition, daily activity levels, menstrual cycle phase, or fitness level. The mechanism underlying this metabolic discrepancy has not yet been identified, and it is still controversial as to whether this difference in RMR between races is the cause of the higher prevalence of obesity in African Americans. Nonetheless, research has also shown that African Americans respond the same physiologically to weight loss intervention as do Caucasians (Glass et al. 2002).

One promising finding is that aerobic exercise may prevent the common age-related decline in RMR. Endurance-trained middle-aged and older women presented a 10% higher RMR than sedentary women, when RMR was adjusted for body composition (Van Pelt et al. 1997). Although descriptive in nature, these data suggest that exercise may help prevent the age-related weight gain seen in sedentary women, and that the protective mechanism may be an altered RMR.

TEF and RMR are not subject to voluntary perturbations that would cause changes in the 24-hour energy expenditure considerably enough to affect body energy balance in the short term (weeks to months). Therefore, it must be concluded that these two components of metabolism are relatively fixed, and that we cannot voluntarily do much to change them. At best, a healthy diet and exercise regimen can help maintain a normal RMR and possibly prevent the slow decrease in RMR seen with aging. On the other hand, the energy expenditure associated with physical activity, whether in the form of structured exercise or not, is quite variable and under voluntary control.

Energy of Physical Activity

Even though skeletal muscle contributes less than 20% to the RMR, skeletal muscle can cause the most dramatic increase in metabolic rate. During strenuous exercise, the total energy expenditure of the body may increase to over 20 times the resting levels. This enormous elevation in the body's metabolic rate is the result of a 200-fold increase in the energy requirement of exercising muscles. In terms of comparison, the RMR of a 70-kilogram (154 lb) person is approximately 1.2 kcal per minute, whereas the energy cost during strenuous exercise can be up to 25 kcal per minute.

A 30-minute exercise bout at moderate intensity may account for 10% or more of daily energy expenditure. This amount of energy expended during exercise can easily offset the energy balance of the body. A 10% or more increase in daily energy expenditure may be desirable for an overweight person, but may be detrimental to performance for an athlete who is not taking in adequate energy. Furthermore, exercise may have a metabolic effect beyond what is accounted for during the exercise session itself.

It is well established that metabolic rate remains elevated for some time following exercise. This phenomenon has been termed excess postexercise oxygen consumption (EPOC). Studies have shown that the magnitude of EPOC is linearly related to the duration and intensity of exercise, and that EPOC following a moderate-intensity exercise bout accounts for about 15% of the total energy cost of the exercise (Gaesser and Brooks 1984). The time for metabolism to return to baseline following an acute exercise session can vary from as little as 20 minutes to more than 10 hours, depending on the duration and intensity of the exercise. Increments of EPOC may play a significant role in the energy balance of the body. Unfortunately, EPOC is insufficiently predictable as a measurable variable in exercise prescription.

The 24-hour energy expenditure, therefore, consists of TEF, RMR, and the energy of physical activity. TEF cannot be easily manipulated and therefore is not considered a viable mechanism to voluntarily affect change in body composition. RMR is strongly related to lean body mass and is depressed during restrictive dieting, while being elevated in response to exercise training that increases lean body mass. The changes in RMR that are seen with either dieting or exercise training are relatively small, but they can affect body composition over an extended period of time. The changes in RMR due to diet and exercise can either augment or hinder weight loss attempts by obese people. An acute exercise bout can increase metabolism by as much as 20-fold, and can contribute as much as 20% or more to the 24-hour energy expenditure. Exercise is the only voluntary behavior that positively affects metabolic rate.

Sport Performance and Metabolic Rate

Knowledge of metabolic rate can help athletes as well as health-conscious people improve their exercise performance or obtain the fat-to-lean-mass ratio optimal for their personal situations. Metabolic knowledge can be used to create a personal training plan, to design an eating schedule for an ultra-endurance event, to monitor body composition during the off-season, and to lose weight to improve health status; it can also be applied to other needs. Two examples of how this works follow.

A personal trainer, who is also a dietitian, is working with an athlete who wants to increase lean body mass during the off-season. The professional obviously knows how to structure the off-season training regimen and how to design a diet to meet specific nutritional needs. What the professional will need to know to make this program most effective is the client's metabolic rate—specifically, the client's 24-hour energy expenditure. Because this client is an athlete who expends a great deal of energy when training, the professional will need to determine the athlete's exercise energy expenditure as well as the resting energy expenditure to calculate the athlete's 24-hour energy expenditure. If the athlete's RMR is 2,300 kcal per day, and the athlete will expend an additional 700 kcal a day in exercise, the athlete's 24-hour energy expenditure would be 3,000 kcal per day. The personal trainer would then have to design a nutritional plan for the athlete that surpasses 3,000 kcal per day for the athlete to increase lean body mass.

A second example is of a competitive cyclist planning to compete in an ultra-endurance event lasting several days (e.g., the Tour de France). The goal for the dietary prescription during the event is to ensure adequate energy intake to meet the metabolic demands of the competition. Otherwise, the athlete will become fatigued prematurely. Again, knowing the athlete's 24-hour energy expenditure is critical to the design of the diet plan. If the athlete's RMR is 2,000 kcal per day, and the athlete expends an additional 6,000 kcal per day in activity, the goal would be to consume 8,000 kcal per day during the event. Knowing this, the professional can now structure the composition of the diet and the timing of dietary intake to match the exercise needs and meet the 8,000-kcal-per-day requirement.

In the two preceding examples, accurate measures of RMR and exercise energy expenditure were necessary prior to the design and implementation of a diet and exercise regimen. There are several ways to measure energy expenditure. The method of choice will depend on equipment availability, cost, and desired accuracy.

Measurement of Energy Expenditure

Heat is released as a by-product in cellular metabolism. Because the rate of heat release is directly proportional to the rate of metabolism, metabolic rate can be determined by measuring heat release. The process of measuring this metabolic heat release is termed direct calorimetry.

Direct Calorimetry

Direct calorimetry can be used to measure the heat emission from a person enclosed in an insulated chamber. The change in chamber temperature as a result of the heat released from the body is measured in units with which we are all familiar, kilocalories (or kcal). The machines for measuring body heat loss are called calorimeters.

Several types of direct calorimeters have been used in studying human metabolism: room-sized, booth- or closet-sized, and body suit calorimeters. Room-sized direct calorimeters allow for the study of energy expenditure in "freely living" subjects. However, the room measurements are that of a small bedroom (3 by 3 meters, or yards), and it is debatable whether a person is truly "freely living" in a room this confined. Closet-sized and body suit calorimeters further confine the movement of a person and therefore can be used only to estimate the person's 24-hour resting energy expenditure.

Direct calorimeters are usually not available in health clubs or sport settings because of their high cost. A body suit may cost several thousand dollars, and a room calorimeter may cost several hundred thousand dollars. However, professionals who work in conjunction with hospitals, clinics, or university research labs may have access to direct calorimeters.

Indirect Calorimetry

The heat liberated from the body is the result of the metabolism of food. The metabolism of food can be simplified into the biochemical equation:

$$\text{food} + O_2 \rightarrow \text{usable energy} + \text{heat} + CO_2 + H_2O$$

This equation indicates that oxygen use and heat release are directly related. That is, as more food is metabolized and heat release increases, oxygen use increases as well. Most clinics and laboratories do not measure energy expenditure (heat production) directly, because direct calorimetry equipment is not universally available and is very expensive. Therefore, a technique called indirect respiratory calorimetry is more commonly employed in clinics and laboratories to measure metabolic rate. This form of calorimetry directly measures the oxygen consumption ($\dot{V}O_2$) in metabolism through the measurement of respiratory gases. The $\dot{V}O_2$ data are then converted to an equivalent energy cost in kcal.

Metabolic rate is derived indirectly in respiratory calorimetry by first measuring the $\dot{V}O_2$ and converting this value to a calorie value. This is possible because $\dot{V}O_2$ can be converted to heat equivalents when the type of nutrients undergoing metabolism is known. The energy liberated when only fat is metabolized is 4.7 kcal · L^{-1} oxygen consumed, and 5.05 kcal · L^{-1} oxygen when only carbohydrate is metabolized. Because the energy source for metabolism in the body is generally a combination of fat and carbohydrate, an average caloric expenditure is usually estimated as 5 kcal · L^{-1} of oxygen consumed. For example, if a person exercises at a $\dot{V}O_2$ cost of 1.0 L · min^{-1} of oxygen, the approximate energy expenditure equals 5 kcal · min^{-1}.

Indirect respiratory calorimetry may be performed by either closed-circuit spirometry or open-circuit spirometry. With closed-circuit spirometry systems, the person breathes 100% oxygen from a prefilled cylinder connected to a recording apparatus to account for the oxygen removed from the cylinder and the carbon dioxide produced and collected by an absorbing material. By calculating the ratio of the volume of oxygen consumed to the carbon dioxide produced, a more exact calorie value for $\dot{V}O_2$ can be determined, rather than using the average value of 5 kcal · L^{-1} of oxygen.

The ratio of oxygen consumed to carbon dioxide produced is called the respiratory exchange ratio (RER). The RER will be 0.70 when the food metabolized is 100% fat and 1.00 when the food metabolized is 100% carbohydrate. A mixture of half fat and half carbohydrate yields an RER of 0.85. The biochemical formula for protein metabolism is not as simple as that for carbohydrate and fat, so indirect respiratory calorimetry methods ignore protein's contribution to the metabolic rate. Ignoring protein's metabolic contribution presents some inaccuracy of measurement, but it is well known that protein contributes almost nothing to resting metabolism and very little to exercise metabolism (Brown, Miller, and Eason 2006).

The closed-circuit method of indirect respiratory calorimetry is most commonly used to measure energy expenditure in clinical laboratories. Its usefulness during exercise conditions is limited because of the resistance to breathing offered by the closed circuit and the large volumes of oxygen consumed during exercise.

To accommodate the exercising subject, the open-circuit technique is most commonly used. In this method, the patient inspires air directly from the atmosphere, and measurements of the fractional amounts of oxygen inspired and oxygen expired are made. The respiratory volume is also measured. By calculating the difference between the percentage of oxygen that comprises both inspired and expired air, as well as the respiratory volume, the $\dot{V}O_2$ can be determined. For example, at a respiratory volume of 80 L · min^{-1}, an inspiratory oxygen concentration of 20.93% (0.2093), and an expiratory oxygen concentration of 18.73% (0.1873), the difference in oxygen concentration for the respiratory gas is 2.2%, or 0.022. The corresponding $\dot{V}O_2$ is 1.76 L · min^{-1} ($\dot{V}O_2$ = 80 L · min^{-1} × 0.022, or 1.76 L · min^{-1}). At an average calorie value of 5 kcal · L^{-1} of oxygen, the exercise energy expenditure would be 8.8 kcal · min^{-1} (1.76 × 5 = 8.8).

The costs of open-circuit spirometry and closed-circuit spirometry are about the same; they range from around $15,000 to $40,000, depending on the peripherals and added features that come with the system. The fact that RER can be determined with indirect calorimetry makes this type of metabolic measurement particularly useful for exercise tests and prescriptions. For example, it is well known that muscle glycogen (carbohydrate) depletion is a major cause of fatigue during endurance events. Indirect calorimetry can be used to determine how much fat versus how much carbohydrate is being burned during exercise (the event). Then, after a dietary intervention or change in training routine is implemented, indirect calorimetry can be used to determine whether the manipulation slowed the rate of carbohydrate use for energy, which would theoretically prolong the onset of fatigue.

Doubly Labeled Water

Another method for measuring metabolic rate through gas exchange is through the use of doubly labeled water. The doubly labeled water method of indirect calorimetry works on a similar principle as indirect respiratory calorimetry—gas exchange. However, with doubly labeled water, carbon dioxide (CO_2) production is calculated rather than oxygen consumption. An oral dose of the stable isotopes of ^2H and ^{18}O is taken. The ^2H labels the body water pool, and the ^{18}O labels both the body water pool and the bicarbonate pool. The disappearance rates of the two isotopes measure the turnover of water and the turnover of water plus CO_2. The CO_2 production is calculated by the difference. Because CO_2 production and oxygen consumption are directly related (food + O_2 → usable energy + heat + CO_2 + H_2O), oxygen consumption becomes known once CO_2 is determined. Once CO_2 and the corresponding oxygen consumption are known, energy expenditure can be calculated by the same calorimetric equations that are used for indirect respiratory calorimetry.

The doubly labeled water technique is a clinical method for determining energy expenditure over prolonged periods of time. The advantage of this method is that the client can live freely for days and weeks without any perception that a metabolic measurement is being taken. However, the calculated result is the average energy expenditure over the entire measurement period (days to weeks). Thus, this method is not suitable for measuring energy expenditure during a single exercise bout. Doubly labeled water is almost exclusively used to assess metabolism in hospital and clinical settings in which the focus is on obesity research and treatment.

TABLE 4.1 Common Prediction Equations for RMR

Name	Equation
Harris and Benedict equations	$RMR\ (men) = 13.75 \times BM + 500.3 \times H - 6.78 \times Age + 66.5$ $RMR\ (women) = 9.56 \times BM + 185.0 \times H - 4.68 \times Age + 655.1$
Kleiber equation	$RMR = 73.3 \times BM^{0.74}$
Livingston and Kohlstadt equations	$RMR\ (men) = 293 \times BM^{0.4330} - 5.92 \times Age$ $RMR\ (women) = 248 \times BM^{0.4356} - 5.09 \times Age$
Mifflin equations	$RMR\ (men) = (10 \times BM) + (625 \times H) - (5 \times Age) + 5$ $RMR\ (women) = (10 \times BM) + (625 \times H) - (5 \times Age) - 161$

RMR = $kcal \cdot day^{-1}$; BM = body mass in kg; H = height in meters; Age = age in years.

Harris and Benedict 1919; Kleiber 1932; Livingston and Kohlstadt 2005; Mifflin et al. 1990.

Prediction of Energy Expenditure

Direct and indirect calorimetry methods for measuring energy expenditure are too complex, time consuming, and costly for most settings. Therefore, major efforts have been made to derive equations for predicting energy expenditure. The most common prediction equations for RMR are those of Kleiber (1932) and Harris and Benedict (1919). Both of these prediction models are based on the relationship between body mass and metabolic rate. Kleiber (1932) demonstrated that RMR, relative to body mass raised to the exponent of 0.74, was consistent for mature mammals, ranging in size from rats to steers (see table 4.1). Harris and Benedict (1919) included variables other than body mass in their equation; namely, height and age (table 4.1). These two equations are less predictive for the obese, because obese people were not included in the original data sets.

Mifflin and coworkers (1990) included men and women of varying body sizes and body compositions in their data set, and derived valid RMR prediction equations based on weight, height, and age. More recently, Livingston and Kohlstadt (2005) derived RMR prediction equations from a large data set containing both normal weight and obese people (table 4.1). These two newer prediction equations are best suited for clients who are overweight, whereas any of the equations presented are viable for normal weight people.

During the middle of the 20th century, much research was performed to determine the energy cost of various physical activities. Tables and charts were published that gave energy expenditure values (kcal) for activities of daily living, work activities, recreational activities, and sport activities. The accuracy of these predictors of physical activity energy expenditure is similar to that of predicting RMR. The American College of Sports Medicine (2010) published metabolic equations for predicting energy expenditure in

TABLE 4.2 Common Prediction Equations for Exercise Energy Expenditure

Activity	Equation
Walking	$kcal \cdot min^{-1} = [(0.1 \times S) + (1.8 \times S \times G) + 3.5] \times BM \times 0.005$
Running	$kcal \cdot day^{-1} = [(0.2 \times S) + (0.9 \times S \times G) + 3.5] \times BM \times 0.005$
Leg cycle ergometer	$kcal \cdot day^{-1} = [(10.8 \times W \times BM^{-1}) + 3.5] \times BM \times 0.005$
Arm cycle ergometer	$kcal \cdot day^{-1} = [(18 \times W \times BM^{-1}) + 3.5] \times BM \times 0.005$
Stepping	$kcal \cdot day^{-1} = [(0.2 \times F) + (1.33 \times 1.8 \times H \times F) + 3.5] \times BM \times 0.005$

Speed = meters · minute^{-1}; G = percent grade expressed as a decimal; BM = body mass in kg; W = watts; F = stepping frequency per minute; H = step height in meters.

Data from ACSM 2010.

clinical settings (table 4.2). These equations were derived from metabolic measurements taken during ergometer work while subjects were walking, running, leg cycling, arm cycling, and stepping; and therefore would be the preferred calculations for people exercising on any one of these ergometers.

Estimation of 24-Hour and Physical Activity Energy Expenditure

It is very costly, and in most cases impractical, to measure 24-hour energy expenditure or to monitor physical activity energy expenditure through either direct or indirect calorimetry. These two methods of measurement are used only for research and clinical applications. Therefore, most professionals use energy expenditure prediction equations, movement analysis devices, or both, to estimate the energy cost of physical activity and the 24-hour energy expenditure for their clients. Tools used to monitor physical activity and estimate energy expenditure range from expensive and sophisticated machines, which are found only in health centers, to inexpensive gadgets and activity diaries, which can be found in almost any setting.

Activity Monitors

The most plausible tools for measuring either 24-hour energy expenditure or physical activity energy expenditure in the field are pedometers, accelerometers, and heart rate monitors. Pedometers are more suited for monitoring physical activity than 24-hour energy expenditure, whereas accelerometers and heart rate monitors are well suited for both.

Pedometers

Pedometers have been around for several decades. The pedometer itself measures the number of steps taken during the day. The summation of these steps is converted to a distance, and energy expenditure is estimated based on the distance traveled. Pedometer estimates for physical activity energy expenditure correlate moderately well with indirect calorimetry measures (Brown, Miller, and Eason 2006). However, only the total distance traveled is recorded on the pedometer, and there is no indication of the intensity of the physical activity. Therefore, pedometers are useful for gaining insight into 24-hour energy expenditure, but do not offer any reference to exercise intensity or activity patterns throughout the day. An advantage of pedometers is that they are relatively inexpensive; even children can learn how to use them.

Accelerometers

Accelerometers work on a principle that is different from that of pedometers. Accelerometers contain tiny force transducers that continuously measure the intensity, frequency, and duration of movement for extended periods of time. The forces measured by the accelerometer are summed and recorded as counts per time frame. There is no consensus about the accelerometer count thresholds for defining mild, moderate, and high exercise intensities. Nonetheless, accelerometers are valid and reliable for monitoring physical activity counts in both children and adults. Correlation coefficients between accelerometer counts and indirect calorimetry measures range from about 0.60 to 0.85, which represent fairly high correlations (Brown, Miller, and Eason 2006).

The advantage of accelerometers over pedometers is that accelerometers can measure the intensity of energy expenditure throughout the day, and this information can be downloaded to a computer. The computer then generates the data and pinpoints the fluctuations in energy expenditure at any time of day. The computer also uses regression equations to calculate the actual energy expenditure from recorded activity counts.

Heart Rate Monitors

Heart rate is strongly related to respiratory rate and energy expenditure across a wide range of values. Heart rate monitors are similar to accelerometers in that they can accumulate data from short or long bouts of activity throughout the day. Heart rate data can also be downloaded to a computer, and the magnitude of fluctuations in heart rate during the day can be pinpointed. Regression equations are used to convert heart rate measures to energy expenditure.

Activity Surveys and Diaries

Activity diaries necessitate that the participant (or an adult observer in the case of young children) make a record of every activity undertaken throughout the day. The person describes the nature of the activity and the time spent participating. This record includes activities that are sedentary as well as those that require physical exertion. Predetermined values for the energy expenditure of each activity noted in the diary are applied, and the energy expenditure is summed across time and throughout the day.

Activity surveys are similar to activity diaries, but rather than record the actual events at the time they occur (or shortly thereafter), recorders estimate the activity of an average day or an average week or month. In other words, people describe their usual routines over a period of many days, rather than recording actual events over a period of a few days. Calculations for energy expenditure are performed as with activity diaries to get the estimated energy expenditure.

The accuracy of physical activity surveys and diaries is variable; they range from being rather poor indicators of actual physical activity to being relatively good measures of physical activity. Activity surveys and diaries for children tend to be less accurate than those intended for adults. Nonetheless, physical activity surveys and diaries are commonly used to determine physical activity levels in both children and adults, because they are inexpensive, unobtrusive, and easily administered.

Many physical activity surveys have been designed for adults. Some of these have been intended for specific populations, or constructed specifically for independent research studies. The reliability and validity of these surveys is variable. The most popular of these surveys were collected and published by the American College of Sports Medicine (1997) several years ago.

One of the most popular physical activity surveys is the International Physical Activity Questionnaire (Craig et al. 2002; IPAQ 2011). The IPAQ comes in a long and short version, and in several languages, and can be downloaded (IPAQ 2011). Both versions ask respondents to record their health-related physical activity for the past seven days. Both versions can be either administered by a professional (in person), or self-administered. The long version consists of 27 questions that focus on job-related physical activity, transportation-related physical activity, housework, recreation and sport activity, and sedentary or sitting time. The short version of the form asks only seven questions about time spent in vigorous physical activity, moderate intensity activity, walking, and sitting.

A popular physical activity diary for older children and adolescents is the Previous Day Physical Activity Recall (PDPAR; Children's Physical Activity Research Group 2011). The PDPAR was designed to provide accurate data on the type, frequency, intensity, and duration of physical activities; these are then used to estimate physical activity energy expenditure (Weston, Petosa, and Pate 1997). The PDPAR is an activity diary that is segmented into seventeen 30-minute intervals. Participants are given a list of 35 numbered activities in which youth normally engage. They record the number of the activity in which they participated for any given 30-minute interval of the previous day. For the selected activity, they also record the intensity as being very light (slow breathing and little or no movement), light (normal breathing and movement), medium (increased breathing and moderate movement), and hard (hard breathing and quick movement). An estimated energy expenditure value is then calculated for each activity within the given time frame.

Relevance of and Applications for Metabolic Testing

Once a client's metabolic data are available, the fitness professional can use them to prescribe a diet intervention, an exercise intervention, or both, or to monitor energy balance. The metabolic data from indirect calorimetry measurements taken during a graded exercise test can also be used to set a safe and appropriate exercise intensity.

Resting Metabolic Rate (RMR) Testing

The measurement of RMR is most valuable in clinical practice, but it also has applications to athletic performance. The clinical application for RMR testing usually lies on two extremes of the spectrum—obesity and malnutrition or anorexia. The obvious use for RMR in obesity treatment is to determine the client's metabolic rate so that dietary interventions, exercise interventions, or both, can be implemented to create an energy deficit that will favor weight loss. The opposite is true for malnutrition or anorexia. In this case, the RMR helps in the design of dietary practices that will create a positive energy balance favoring weight gain.

The RMR test can also be used as a diagnostic tool. Because the average RMR for adults is 3.5 milliliters of oxygen consumed per kilogram of body weight per minute (American College of Sports Medicine 2010; $3.5\ ml \cdot kg^{-1} \cdot min^{-1}$), an RMR measure that varies significantly from this average can be seen as abnormal. If an abnormal RMR is discovered, further medical testing, psychological testing, or both, can be done to determine whether the aberrant RMR is to the result of a physical condition, such as hypothyroidism, or an eating disorder. A client with an abnormal RMR should be referred to the appropriate health care professional for follow-up testing and diagnosis. The predominant use for nonclinical RMR testing in athletics is to ensure that adequate nutrition is maintained for the energy demands of athletic competition.

The procedures for measuring RMR are fairly standardized and consistent from one facility to the next, although testing centers do not use the same time frames for taking metabolic measurements. Whether the time frame of metabolic measurement is several minutes or several hours, the estimated RMR is calculated by averaging the minute-by-minute metabolic rate measurements across the time of measurement.

FIGURE 4.1 RMR testing using indirect respiratory calorimetry.

RMR testing is almost exclusively performed by indirect calorimetry. The general procedure is that the client reports to the laboratory in the morning as soon as possible after waking and after fasting for 8 to 12 hours. The subject is not to have taken any stimulants, such as coffee, or been agitated emotionally. The test begins with a run-in period of 30 to 60 minutes of supine rest in a dimly lit room; no metabolic measurements are recorded. This run-in period allows the person to adjust to the testing environment and for metabolism to return to the resting level following any possible stimulating effects incurred by coming to the testing facility. Following the run-in period, metabolic rate is measured using indirect calorimetry. Respiratory gasses are collected using a respiratory gas mask or respiratory hood that is draped over the client (see figure 4.1). Minute-by-minute measures are summed and averaged to derive the RMR.

Theoretically, if the RMR of an obese person were measured at 1,700 kcal · day^{-1}, and the person wanted to lose weight at a rate of 0.5 kilogram (1 lb) per week; an energy intake of 1,200 kcal · day^{-1} would be prescribed (1 lb fat = 3,500 kcal). If the client were to exercise, the rate of weight loss would be increased by the energy cost of the exercise. Alternatively, the dietary intake could be increased above 1,200 kcal · day^{-1} by the energy cost of the exercise to keep the predicted weight loss consistent with 0.5 kilogram (1 lb) per week.

Metabolic Prediction Equations

Quite often, fitness professionals do not have access to the equipment needed for measuring metabolic rate through indirect respiratory calorimetry. In these cases, prediction equations are used to estimate the RMR or the energy cost of exercise. Once an estimate of metabolic rate is derived, the application is the same as described. An example of how this is done is given next.

The client is a 50-year-old obese woman who weighs 100 kilograms (220 lb) and is 169 centimeters (5 feet 6.5 inches) tall. The woman desires to lose weight at a rate of 0.5 kilogram (1 lb) a week. Using the Harris and Benedict equation (see table 4.1), her RMR is estimated at 1,700 kcal · day^{-1} [RMR (kcal · day^{-1}) = 9.56 × 100 + 185 × 1.68 – 4.68 × 50 + 665.1]. Comparatively, her predicted RMR using the equation of Livingston and Kohlstadt (table 4.1) is estimated at 1,588 kcal · day^{-1} [RMR (kcal · day^{-1}) = 248 × 100$^{0.4356}$ – (5.09 × 50)]. The slight discrepancy between the values derived from the two equations demonstrates that prediction equations are less accurate than real metabolic measurements. Nonetheless, for this woman to lose weight at a rate of 0.5 kilogram (1 lb) a week, she should consume only 1,088 to 1,200 kcal · day^{-1}. Such a low energy intake may seem too restrictive for this woman. Alternatively, she could consume between 1,338 and 1,450 kcal · day^{-1} and expend 250 kcal · day^{-1} in exercise to meet her goal.

If the woman decides to exercise, the question becomes how much exercise must she perform daily to meet her exercise energy expenditure goal? The answer is found by using the exercise metabolic calculations provided in table 4.2. If the woman selects walking for her physical activity, at a rate of 3 miles per hour (80.5 m · min^{-1}), then she should walk for 43 min · day^{-1} to meet her goal of 250 kcal · day^{-1} spent in exercise [(kcal · min^{-1}) = (0.1 × 80.5) + (1.8 × 80.5 × 0) + 3.5) × 100 kg body weight × 0.005 kcal · ml^{-1} oxygen, yields 5.77 kcal · min^{-1}]. If the woman chooses to ride a cycle ergometer for exercise, at a rate of 50 watts, she would need to ride for 56 min · day^{-1} to meet her goal of 250 kcal · day^{-1} spent in exercise [(kcal · min^{-1}) = 10.8 × 50 × 100^{-1} + 3.5 × 100 kg body weight × 0.005 kcal · ml^{-1} oxygen, yields 4.45 kcal · min^{-1}].

Pedometers

Pedometers estimate energy expenditure similar to the way metabolic prediction equations do. However, the metabolic prediction equations in pedometers are based on distance traveled rather than the speed and grade of travel. Therefore, the pedometer output is usually expressed as kcal per mile (or kilometer), rather than kcal per minute. The metabolic calculations used in pedometers are based on the energy cost of walking 1 mile (or kilometer). Sophisticated pedometers allow the user to enter body weight and stride length into the device, whereas inexpensive pedometers use a predetermined average value for these variables. Pedometers are more accurate estimating energy expenditure when the person is walking on level ground with a consistent stride length, than when the person is walking on a grade, has an intermittent stride length, or both. Therefore, pedometers are more accurate at estimating energy expenditure during a formal exercise bout than over a 24-hour period. Although pedometers may not be that accurate at determining actual energy expenditure, they are very useful for making relative comparisons for the same person (e.g., day-to-day step counts; Harris et al. 2009).

Accelerometers

Accelerometers are electronic motion sensors that quantify the volume and intensity of movement over time. The raw acceleration signal of an accelerometer is specific to the brand name or model of the device, meaning that counts from one brand or model accelerometer cannot be directly compared to counts from another brand or model. Consequently, the raw acceleration signal of an accelerometer is usually translated into a variable that has some common meaning (e.g., kcal). Because accelerometer technology is based on biomechanical principles and metabolic rate is based on biological measures, it is difficult to accurately translate accelerometer signals to metabolic rates. The process is further complicated when individual differences in body mass and biomechanical efficiency are taken into consideration.

Indirect calorimetry is used to calibrate each brand or model of accelerometer for determining the metabolic rates of children, adolescents, and adults. The manufacturers provide software programs that default to metabolic calculations for adults; however, because the metabolic cost of movement in children changes as they grow, a common metabolic parameter for children has not been agreed on. Therefore, accelerometer users either use the software default calculations for children and adolescents or construct their own conversion programs using the data they find for children in the scientific literature.

The accelerometer can be worn at the hip, wrist, or ankle. However, most users find that measurements are the least variable when the unit is worn on the hip (Heil 2006; Respironics 2008). Before using the accelerometer, the user or clinician programs the device to take measurements in epoch lengths ranging from a few seconds to several minutes. The gender, age, height, and weight of the wearer are also programmed into the accelerometer at this time. Most accelerometers are waterproof and can record data 24 hours a day for a few weeks at a time. At the end of the trial period, the data are downloaded to a computer and analyzed with the manufacturer-provided software. As mentioned earlier, the benefit of accelerometers is that they can register the intensity of exercise within a given time frame. Furthermore, accelerometers can be used to estimate 24-hour expenditure as well as the energy expenditure of physical activity.

Heart Rate Monitors

Sophisticated heart rate monitors (figure 4.2) collect data in time epochs similar to the way accelerometers do. Rather than accumulate accelerations, though, heart rate monitors record heartbeats. Generally, the more heartbeats in a time epoch, the higher the metabolic rate. Heart rates are converted into metabolic measures in the same way that they would be correlated to energy expenditure during a graded exercise test using indirect respiratory calorimetry (see chapter 5). In other words, metabolic rate is determined by knowing the relationship between heart rate and aerobic metabolism. Data from sophisticated heart rate monitors can be downloaded to computers, as with accelerometers.

FIGURE 4.2 Training with a heart rate monitor can be useful for making relative energy expenditure comparisons from day to day.

Less expensive heart rate monitors do not interface with computers and cannot be programmed. The usefulness of these monitors, therefore, is limited to immediate observation or manual recording of heart rate at various time points. Many people use low-cost heart rate monitors to help them maintain their heart rate in a predetermined range during an exercise bout. Observations and recordings of personal heart rates during exercise can be used later to calculate whether the desired exercise intensity was met to achieve the prescribed metabolic rate. On the other hand, the person can determine ahead of time the target heart rate necessary for meeting any desired metabolic rate during exercise, and then during the exercise bout bring the heart rate to the predetermined level for the desired time frame. Regardless of how heart rate monitors are used to estimate metabolic rate, it must be remembered that they are not accurate in estimating the energy cost of anaerobic exercise.

International Physical Activity Questionnaire (IPAQ)

As mentioned earlier, the IPAQ comes in a long and short version (IPAQ 2011). Both versions ask respondents to record their health-related physical activity for the past seven days. Both versions ask about physical activity undertaken across four domains:

- Leisure time physical activity
- Domestic and yard physical activity
- Work-related physical activity
- Transport-related physical activity

The IPAQ short version asks for three specific types of activity within these four domains: walking, moderate-intensity activity, and vigorous activity. The IPAQ long version asks for details on activities within the four domains. Both versions of the IPAQ can be scored as continuous measures of physical activity. The calculations are made by multiplying the energy cost of each activity in METs (metabolic equivalents or multiples of the RMR) by the minutes the activity is performed. For example, an activity with an energy cost of 3.0 METs performed for 25 minutes has a MET-minute value of 75. Alternatively, the energy cost of the activity (MET) can be multiplied by the quotient of the body weight (kg) divided by 60 to yield an energy cost in kcal per minute.

The usefulness of the IPAQ is to determine the energy cost of physical activity in various settings, and not to determine RMR or 24-hour energy expenditure. However, by combining the values for the energy cost of physical activity obtained from the IPAQ with a value for the RMR obtained from one of the prediction equations detailed earlier, a person can derive an estimate of the 24-hour energy expenditure. Guidelines for scoring and comparing IPAQ scores among individuals and populations are provided with the questionnaires (IPAQ 2011).

Previous Day Physical Activity Recall (PDPAR)

The PDPAR captures the habitual physical activity of older children and adolescents. The PDPAR uses a time-based recall approach to record and measure physical activity levels. Each day is divided into 34 time blocks of 30 minutes going from 7:00 a.m. to midnight. Adolescents are asked to record their specific activity (35 common activities are listed for them to select from, each with a numeric code) and the intensity of the activity for each block of time. The energy cost of physical activity is then determined using the metabolic equivalent (MET) value for each activity. MET values can be converted to kcal using standard conversion factors.

Comparing Metabolic Rate Measurement Methods

Although accelerometers, pedometers, heart rate monitors, and questionnaires are not as accurate as direct and indirect calorimetry in determining metabolic rate, these less expensive tools can be used to create exercise plans, particularly those focused on health promotion and fitness. For example, if a person wants to increase her fitness level by doing aerobic exercise four times a week at a predetermined intensity, a heart rate monitor would be an excellent tool to use for monitoring intensity. The fitness professional could help the client determine the appropriate target heart rate, and then show the client how to use the heart rate monitor safely to achieve the

Professional Applications

As shown throughout this chapter, fitness professionals can use information about clients' metabolic rates to help them achieve their performance or health-related goals. Problems can arise, however, when the metabolic data generated do not seem to coincide with what would be expected from the client's demographics, behavior or training patterns, or predicted physiological outcome(s). Under these situations, the professional needs to know how to interpret metabolic data and how to determine whether metabolic data and predictions are valid for that particular client. The two case studies that follow demonstrate how the professional can overcome what initially seem to be unsolvable inconsistencies.

Case Study 1: John's Inability to Lose Weight

John is a client requesting an exercise program to help him lose weight. He is an accountant, is 40 years old, and has not exercised since college. He is 6 feet 0 inches tall (183 cm) and weighs 220 pounds (100 kg). You calculate John's BMI to be 29.9, which is borderline obesity. You also perform a body composition assessment on John and find him to be 31.0% body fat. John does not have any health risk factors, except his weight. John selects walking as his mode of exercise, and agrees to exercise for 30 minutes a day. You complete your exercise prescription for John by teaching him how to safely monitor himself while walking.

Your facility does not have equipment for measuring metabolic rate, so you decide to use prediction equations to estimate John's 24-hour energy expenditure. You will subsequently use that predictive data to design a modest restriction in John's energy intake that will allow him to feel satisfied when eating, but still lose weight (because he is not really interested in dieting). You decide to use the Mifflin equation (see table 4.1) to predict John's 24-hour resting metabolism, because John is overweight. The results calculate to be 1,948 kcal per day. You next use the prediction equation in table 4.2 to calculate John's walking energy expenditure. At John's selected speed of 3.0 miles per hour (4.8 km/h), he should expend 5.98 kcal per minute or 179 kcal per exercise bout. John's total energy expenditure each day is predicted to be 2,127 kcal.

You and John next sit down with your coworker, who is a dietitian, to design John's eating plan. Because John does not want a restrictive diet, the dietitian prescribes a healthy diet containing 1,800 kcal per day. This means that John's energy deficit should be 327 kcal per day, causing a predicted weight loss of 1 pound (0.45 kg) every 11 days.

You track John's progress, and at the end of two months, John is feeling discouraged because he has lost only 3 pounds (1.4 kg). His predicted weight loss should be 5.5 pounds (2.5 kg). Your initial instinct is that John has lost 5.5 pounds (2.5 kg) of fat, but gained 2.5 pounds (1.1 kg) of lean mass from the exercise. You repeat the body composition assessment and find that John is still 31.0 % body fat. Your next speculation is that John has not kept his diet.

However, John is an accountant and very particular about numbers. He has not only adhered to his diet, but also actually weighed his food and calculated the energy content of everything he ate. He provides dietary diaries that show he averaged 1,800 kcal a day for the past 60 days. The dietitian concurs that John's records are correct. The only conclusion you can make is that the prediction equations for metabolic rate were not accurate for John.

Fortunately, you have access to an accelerometer. John agrees to wear an accelerometer 24 hours a day for the next week. The results from the accelerometer reveal that John's average 24-hour energy expenditure is 1,981 kcal. This means that the prediction equations underestimated John's daily energy expenditure by 146 kcal per day (7% discrepancy). Multiplied by 60 days, this error is equivalent to the caloric value of 2 pounds (0.9 kg) of fat. The discrepancy, or apparent inconsistency, has been resolved. You can now adjust John's regimen to meet his weight loss goal.

Case Study 2: Jill's Deteriorating Gymnastics Performance

Jill is a competitive gymnast. Her coach is very adamant about the team's maintaining a rigid training schedule. The end of the season is approaching, and Jill's performance has deteriorated over the season. Moreover, Jill has been plagued with minor injuries and constant aches and pains all season. Jill's coach has sent her to you, the strength and conditioning coach for the team. Your job is to find out why Jill's performance has deteriorated, and to fix the problem.

Your initial interview with Jill reveals that she has interpreted her coach's strict training schedule to mean that she is too fat and needs to lose weight. Jill's reaction to this perceived message was to diet throughout the season. She has been seeing a clinical psychologist this year because of some emotional problems she is having. She gives you permission to speak with her psychologist. The psychologist assures you that Jill does not have an eating disorder, but that Jill does have a long history of dieting. The psychologist has been working on Jill's body perception, and asks if you have any objective information that may help change Jill's perception.

Your plan is to perform a diet analysis, measure resting metabolic rate, and determine Jill's percent body fat. The clinical psychologist refers Jill to a dietitian, and you perform the tests for body fat content and metabolism. Jill's body fat content is 15.2%, which is lean for a female athlete. Jill's measured RMR comes out to be 1,600 kcal per day. Using the Harris and Benedict equation (table 4.1), you get a similar prediction. So, you assume that the RMR measure is a valid metabolic measure for Jill's small body size.

Jill's diet analysis reveals that she is consuming only 1,250 kcal a day. Thus, there is an energy deficit of 350 kcal a day between Jill's intake and her 24-hour RMR, and you have not yet accounted for her daily exercise energy expenditure.

(continued)

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It is also enlightening to see that when you calculate Jill's metabolic rate in relation to her lean body mass, you find that the value is 18 kcal · kg LBM^{-1} · day^{-1}. Given that the normal value is about 25 kcal · kg LBM^{-1} · day^{-1}, with a range of 20 to 30 kcal · kg LBM^{-1} · day^{-1}, you conclude that Jill's history of dieting may have reduced her metabolic rate.

You bring all of this information to Jill's psychologist and explain the following:

- Jill is consuming several hundred kcal below what she needs to maintain her health.
- Jill's history of restrictive dieting may have reduced the metabolic rate of her lean tissues.
- Jill's body fat content is low, but not dangerously low for a female athlete. Nonetheless, Jill does not need to lose weight.

Rather than prescribe a rigid diet plan for Jill, the psychologist decides to work with the dietitian to help Jill learn to eat intuitively. This means helping Jill learn to eat with intention while paying attention to body cues of hunger and satiety. The metabolic information you provided to Jill's psychologist will help both the psychologist and Jill to view Jill's problematic behaviors more objectively. You now need to report back to Jill's coach that the problem has been identified and that Jill is on the road to recovery; however, the recovery will not be completed before the end of the season.

SUMMARY

- *Metabolism* is the term used to describe the body's ability to produce, use, and regulate energy.
- The overall energy expenditure of the body is a summation of TEF, RMR, and the energy cost of physical activity. RMR contributes from 60 to 75% of the 24-hour energy expenditure. RMR is almost exclusively a reflection of the lean body mass (Cunningham 1982). Severe restrictions in energy intake reduce RMR significantly, and can even reduce the RMR:LBM ratio. Increases in lean body mass raise the RMR slightly, but most people do not gain enough lean body mass through exercise training to appreciably affect the RMR or overall energy balance in the body.
- The energy cost of physical activity or exercise energy expenditure is the only component of the 24-hour energy expenditure that can be voluntarily controlled.
- Energy expenditure, or metabolic rate, can be measured through direct calorimetry and indirect respiratory calorimetry; or estimated by using activity monitors, prediction equations, and surveys. Once a

client's metabolic rate is known, the fitness professional can use the information to prescribe diet interventions, exercise interventions, or both, or monitor the energy balance of the client.

- Knowledge about exercise energy expenditure can be used to prescribe the proper intensity and duration of exercise to meet the preventive, therapeutic, or performance goals of the client.

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

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

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

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

SUMMARY

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