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Intake: Energy

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KEY TERMS

activity thermogenesis (AT)
basal energy expenditure (BEE)
basal metabolic rate (BMR)
calorie
direct calorimetry
estimated energy requirement (EER)
excess postexercise oxygen consumption (EPOC)
facultative thermogenesis
fat-free mass (FFM)
high-metabolic-rate organ (HMRO)
indirect calorimetry (IC)
kilocalorie (kcal)
lean body mass (LBM)
metabolic equivalents (METs)
nonexercise activity thermogenesis (NEAT)
obligatory thermogenesis
physical activity level (PAL)
resting energy expenditure (REE)
resting metabolic rate (RMR)
respiratory quotient (RQ)
thermic effect of food (TEF)
total energy expenditure (TEE)

Energy may be defined as "the capacity to do work." The ultimate source of all energy in living organisms is the sun. Through the process of photosynthesis, green plants intercept a portion of the sunlight reaching their leaves and capture it within the chemical bonds of glucose. Proteins, fats, and other carbohydrates are synthesized from this basic carbohydrate to meet the needs of the plant. Animals and humans obtain these nutrients and the energy they contain by consuming plants and the flesh of other animals.

The body makes use of the energy from dietary carbohydrates, proteins, fats, and alcohol; this energy is locked in chemical bonds within food and is released through metabolism. Energy must be supplied regularly to meet needs for the body's survival. Although all energy eventually takes the form of heat, which dissipates into the atmosphere, unique cellular processes first make possible its use for all of the tasks required for life. These processes involve chemical reactions that maintain body tissues, electrical conduction of the nerves, mechanical work of the muscles, and heat production to maintain body temperature.

ENERGY REQUIREMENTS

Energy requirements are defined as the dietary energy intake that is required for growth or maintenance in a person of a defined age, gender, weight, height, and level of physical activity. In children and pregnant or lactating women, energy requirements include the needs associated with the deposition of tissues or the secretion of milk at rates consistent with good health. In ill or injured people, the stressors have an effect by increasing or decreasing energy expenditure.

Body weight is one indicator of energy adequacy or inadequacy. The body has the unique ability to shift the fuel mixture of carbohydrates, proteins, and fats to accommodate energy needs. However, consuming too much or too little energy over time results in body weight changes. Thus body weight reflects adequacy of energy intake, but it is not a reliable indicator of macronutrient or micronutrient adequacy. In addition, because body weight is affected by body composition, a person with a higher lean mass to body fat mass or body fat mass to lean mass may require differing energy intakes compared with the norm or "average" person. Obese individuals have higher energy needs as a result of an increase in body fat mass and lean body mass (Kee et al, 2012).

COMPONENTS OF ENERGY EXPENDITURE

Energy is expended by the human body in the form of **basal energy expenditure (BEE)**, **thermic effect of food (TEF)**, and **activity thermogenesis (AT)**. These three components make up a person's daily **total energy expenditure (TEE)**.

Basal and Resting Energy Expenditure

BEE, or **basal metabolic rate (BMR)**, is the minimum amount of energy expended that is compatible with life. An individual's BEE reflects the amount of energy used during 24 hours while physically and mentally at rest in a thermoneutral environment that prevents the activation of heat-generating processes, such as shivering. Measurements of BEE should be done before an individual has engaged in any physical activity (preferably on awakening from sleep) and 10 to 12 hours after the ingestion of any food, drink, or nicotine. The BEE remains remarkably constant on a daily basis.

Resting energy expenditure (REE), or **resting metabolic rate (RMR)**, is the energy expended in the activities necessary to sustain normal body functions and homeostasis. These activities include respiration and circulation, the synthesis of organic compounds, and the pumping of ions across membranes. REE, or RMR, includes the energy required by the central nervous system and for the maintenance of body temperature. It does not include thermogenesis, activity, or other energy expenditure and is higher than the BEE by 10% to 20% (Ireton-Jones, 2010). The terms *REE* and *RMR* and *BEE* and *BMR* can be used interchangeably, but *REE* and *BEE* are used in this chapter.

Factors Affecting Resting Energy Expenditure

Numerous factors cause the REE to vary among individuals, but body size and composition have the greatest effect. See Chapter 7 for discussion of methods used to determine body composition.

Age. Because REE is highly affected by the proportion of **lean body mass (LBM)**, it is highest during periods of rapid growth, especially the first and second years of life. Growing infants may store as much as 12% to 15% of the energy value of their food in the form of new tissue. As a child becomes older, the energy requirement for growth is reduced to approximately 1% of TEE. After early adulthood there is a decline in REE of 1% to 2% per kilogram of **fat-free mass (FFM)** per decade (Keys et al, 1973). Fortunately, exercise can help maintain a higher LBM and a higher REE. Decreases in REE with increasing age may be partly related to age-associated changes in the relative size of LBM components (Cooper et al, 2013).

Body composition. FFM, or LBM, makes up the majority of metabolically active tissue in the body and is the primary predictor of REE. FFM contributes to approximately 80% of the variations in REE (Bosy-Westphal et al, 2004). Because of their greater FFM, athletes with greater muscular development have an approximately 5% higher resting metabolism than nonathletic individuals. Organs in the body contribute to heat production (Figure 2-1). Approximately 60% of REE can be accounted for by the heat produced by **high-metabolic-rate organs (HMROs)**: the liver, brain, heart, spleen, intestines, and kidneys (McClave and Snider, 2001). Indeed, differences in FFM between ethnic groups may be related to the total mass of these as well as musculature (Gallagher et al, 2006). Relatively small individual variation in the mass of the liver, brain, heart, spleen, and kidneys, collectively or individually, can significantly affect REE (Javed et al, 2010). As a result, estimating the percentage of energy expenditure that appendages (arms and legs) account for in overall daily energy expenditure is difficult, although it is presumably a small amount.

Body size. Larger people generally have higher metabolic rates than smaller people, but tall, thin people have higher metabolic rates than short, stocky people. For example, if two people weigh the same but one person is taller, the taller person has a larger body surface area and a higher metabolic rate. The amount of LBM is highly correlated with total body size. For example, obese children have higher REEs than nonobese children, but, when REE is adjusted for body composition, FFM, and fat mass, no REE differences are found (Byrne et al, 2003). This provides a conundrum for the practitioner when using the BMI to assess health (see Chapter 7).

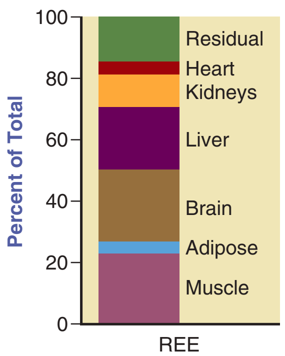

FIGURE 2-1 Proportional contribution of organs and tissues to calculated resting energy expenditure. (Modified and used with permission from Gallagher D et al: Organ-tissue mass measurement allows modeling of REE and metabolically active tissue mass, *Am J Physiol Endocrinol Metab* 275:E249, 1998. Copyright American Physiological Society.)

Climate. The REE is affected by extremes in environmental temperature. People living in tropical climates usually have REEs that are 5% to 20% higher than those living in temperate areas. Exercise in temperatures greater than 86°F imposes a small additional metabolic load of approximately 5% from increased sweat gland activity. The extent to which energy metabolism increases in extremely cold environments depends on the insulation available from body fat and protective clothing (Dobratz et al, 2007).

Gender. Gender differences in metabolic rates are attributable primarily to differences in body size and composition. Women, who generally have more fat in proportion to muscle than men, have metabolic rates that are approximately 5% to 10% lower than men of the same weight and height. However, with aging, this difference becomes less pronounced (Cooper et al, 2013).

Hormonal status. Hormones affect metabolic rate. Endocrine disorders, such as hyperthyroidism and hypothyroidism, increase or decrease energy expenditure, respectively (see Chapter 31). Stimulation of the sympathetic nervous system during periods of emotional excitement or stress causes the release of epinephrine, which promotes glycogenolysis and increased cellular activity. Ghrelin and peptide YY are gut hormones involved in appetite regulation and energy homeostasis (Larson-Meyer et al, 2010). The metabolic rate of women fluctuates with the menstrual cycle. During the luteal phase (i.e., the time between ovulation and the onset of menstruation), metabolic rate increases slightly (Ferraro et al, 1992). During pregnancy, growth in uterine, placental, and fetal tissues, along with the mother's increased cardiac workload, contributes to gradual increases in BEE (Butte et al, 2004).

Temperature. Fevers increase REE by approximately 7% for each degree of increase in body temperature above 98.6° F or 13% for each degree more than 37° C, as noted by classic studies (Hardy and DuBois, 1937).

Other factors. Caffeine, nicotine, and alcohol stimulate metabolic rate. Caffeine intakes of 200 to 350 mg in men or 240 mg in women may increase mean REE by 7% to 11% and 8% to 15%, respectively (Compher et al, 2006). Nicotine use increases REE by approximately 3% to 4% in men and by 6% in women; alcohol consumption increases REE in women by 9% (Compher et al, 2006). Under conditions of stress and disease, energy expenditure may increase or decrease, based on the clinical situation. Energy expenditure may be higher in people who are obese (Dobratz et al, 2007) but depressed during starvation or chronic dieting and in people with bulimia (Sedlet and Ireton-Jones, 1989).

Thermic Effect of Food

The **thermic effect of food (TEF)** is the increase in energy expenditure associated with the consumption, digestion, and absorption of food. The TEF accounts for approximately 10% of TEE (Ireton-Jones, 2010). The TEF may also be called diet-induced thermogenesis, specific dynamic action, or the specific effect of food. TEF can be separated into obligatory and facultative (or adaptive) subcomponents. **Obligatory thermogenesis** is the energy required to digest, absorb, and metabolize nutrients, including the synthesis and storage of protein, fat, and carbohydrate. Adaptive or **facultative thermogenesis** is the "excess" energy expended in addition to the obligatory thermogenesis and is thought to be attributable to the metabolic inefficiency of the system stimulated by sympathetic nervous activity.

The TEF varies with the composition of the diet, with energy expenditure increasing directly after food intake, particularly after consumption of a meal higher in protein compared with a meal higher in fat (Tentolouris et al, 2008). Fat is metabolized efficiently, with only 4% waste, compared with 25% waste when carbohydrate is converted to fat for storage. The macronutrient oxidation rate is not different in lean and obese individuals (Tentolouris et al, 2008). Although the extent of TEF depends on the size and macronutrient content of the meal, TEF decreases after ingestion over 30 to 90 minutes, so effects on TEE are small. For practical purposes, TEF is calculated as no more than an additional 10% of the REE. Spicy foods enhance and prolong the effect of the TEF. Caffeine, capsaicin, and different teas such as green, white, and oolong tea also may increase energy expenditure and fat oxidation and suppress hunger (Hursel and Westerterp-Plantenga, 2010; Reinbach et al, 2009). The role of TEF in weight management is discussed in Chapter 21.

Enteral nutrition (tube feeding) as well as parenteral nutrition exert a thermic effect on energy expenditure, which should be considered in patients receiving nutrition support. Leuck and colleagues found that energy expenditure of patients receiving enteral nutrition intermittently vs. continuously was increased at night and increased in association with each intermittent feeding (Leuck et al, 2013). A case study of a long-term home parenteral nutrition patient showed an increase in energy expenditure when the intravenous nutrition was being infused (Ireton-Jones, 2010). These are important considerations when predicting overall energy needs for patients receiving enteral or parenteral nutrition (see Chapter 13).

Activity Thermogenesis

Beyond REE and TEF, energy is expended in physical activity, either exercise-related or as part of daily work and movement. This is referred to as **activity thermogenesis**. **Activity thermogenesis (AT)** includes **nonexercise activity thermogenesis (NEAT)**, the energy expended during activities of daily living, and the energy expended during sports or fitness exercise. T(Levine and Kotz, 2005).

The contribution of physical activity is the most variable component of TEE, which may be as low as 100 kcal/day in sedentary people or as high as 3000 kcal/day in athletes. **NEAT** represents the energy expended during the workday and during leisure-type activities (e.g., shopping, fidgeting, even gum chewing), which may account for vast differences in energy costs among people (Levine and Kotz, 2005; see Appendix 20). TEE reflects REE, TEF, and energy expended for exercise, as depicted in Figure 2-2.

Individual AT varies considerably, depending on body size and the efficiency of individual habits of motion. The level of fitness also affects the energy expenditure of voluntary activity because of variations in muscle mass. AT tends to decrease with age, a trend that is associated with a decline in FFM and an increase in fat mass. In general, men have greater skeletal muscle than women, which may account for their higher AT. The measurement of physical activity is very difficult whether related to children, adolescents, or adults (Mindell et al, 2014). However, this remains an important component of the overall energy intake recommendation suggesting that low-cost quantitative assessment methods are needed (e.g., heart rate monitoring) along with the typical questionnaire and estimate.

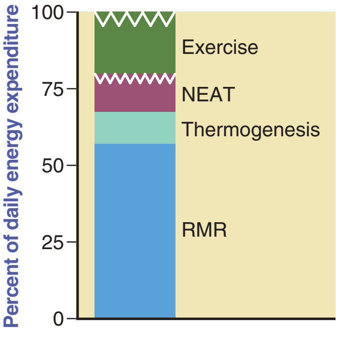

FIGURE 2-2 The components of total energy expenditure: activity, thermic effect of food (TEF), and basal or resting metabolic rate.

Additional Considerations in Energy Expenditure

Excess postexercise oxygen consumption (EPOC) is influenced by the duration and magnitude of physical activity. In a study of high-intensity intermittent exercise, there was an increase in energy expenditure during activity, although the effect on metabolic rate post-activity was minor (Kelly et al, 2013). Habitual exercise does not cause a significantly prolonged increase in metabolic rate unless FM is decreased and FFM is increased, and then this increase in energy expenditure is mostly during the activity itself.

Amputations resulting from trauma, wounds, or disease processes affect body size; presumably then, they would affect activity energy expenditure. However, a study of energy expenditure related to level of amputation (partial foot to transfemoral) at various speeds of walking was done in unilateral amputees, and no differences in energy expenditure were found between levels of amputation or speed when walking (Göktepe et al, 2010).

Measurement of Energy Expenditure

The standard unit for measuring energy is the **calorie**, which is the amount of heat energy required to raise the temperature of 1 ml of water at 15°C by 1°C. Because the amount of energy involved in the metabolism of food is fairly large, the kilocalorie (kcal), 1000 calories, is used to measure it. A popular convention is to designate kilocalorie by Calorie (with a capital C). In this text, however, kilocalorie is abbreviated kcal. The *joule* (J) measures energy in terms of mechanical work and is the amount of energy required to accelerate with a force of 1 Newton (N) for a distance of 1 m; this measurement is widely used in countries other than the United States. One kcal is equivalent to 4.184 kilojoules (kJ).

Because various methods are available to measure human energy expenditure, it is important to gain an understanding of the differences in these methods and how they can be applied in practical and research settings.

Direct Calorimetry

Direct calorimetry is possible only with specialized and expensive equipment. An individual is monitored in a room-type structure (a whole-room calorimeter) that permits a moderate amount of activity. It includes equipment that monitors the amount of heat produced by the individual inside the chamber or room. Direct calorimetry provides a measure of energy expended in the form of heat, but provides no information on the kind of fuel being oxidized. The method also is limited by the confined nature of the testing conditions. Therefore the measurement of TEE using this method is not representative of a free-living (i.e., engaged in normal daily activities) individual in a normal environment, because physical activity within the chamber is limited. High cost, complex engineering, and scarcity of appropriate facilities around the world also limit the use of this method.

Indirect Calorimetry

Indirect calorimetry (IC) is a more commonly used method for measuring energy expenditure. An individual's oxygen consumption and carbon dioxide production are quantified over a given period. The Weir equation (1949) and a constant respiratory quotient value of 0.85 are used to convert oxygen consumption to REE. The equipment varies but usually involves an individual breathing into a mouthpiece (with nose clips), a mask that covers the nose and mouth, or a ventilated hood that captures all expired carbon dioxide (Figure 2-3). Ventilated hoods are useful for short- and long-term measurements.

IC measurements are achieved using equipment called a metabolic measurement cart or an indirect calorimeter. There are various types of metabolic measurement carts, varying from larger equipment that measures oxygen consumption and carbon dioxide production only, to equipment that also has the capability of providing pulmonary function and exercise testing parameters. These larger carts are more expensive because of the expanded capabilities, including measurement interface for IC measurements of hospitalized patients who are ventilator dependent. Metabolic carts often are used at hospitals to assess energy requirements and are found most typically in the intensive care unit (Ireton-Jones, 2010). Individuals and patients who are breathing spontaneously may have their energy expenditure measured with smaller "handheld" indirect calorimeters designed specifically for measuring oxygen consumption while using a static value for carbon dioxide production. These have easy mobility and are relatively low cost (Hipskind et al, 2011).

A strict protocol should be followed before performing IC measurement. For healthy people, a minimum of a 5-hour fast after meals and snacks is recommended. Caffeine should be avoided for at least 4 hours, and alcohol and smoking for at least 2 hours. Testing should occur no sooner than 2 hours after moderate exercise; after vigorous resistance exercise, a 14-hour period is advised (Compher et al, 2006). To achieve a steady-state measurement, there should be a rest period of 10 to 20 minutes before the measurement is taken. An IC measurement duration of 10 minutes, with the first 5 minutes deleted and the remaining 5 minutes having a coefficient of variation less than 10%, indicates a steady-state measurement (Compher et al, 2006). When the measurement conditions listed here are met and a steady state is achieved, energy expenditure can be measured at any time during the day.

Energy expenditure can be measured for ill or injured individuals as well (Cooney and Frankenfield, 2012). Equipment used for the patient who is ventilator dependent may be different from that used for the ambulatory individual; however, a protocol specifying the conditions of measurement should be used for these patients as well (Ireton-Jones, 2010). When these conditions are met, IC can be applied for measuring the energy expenditure of acute or critically ill inpatients, outpatients, or healthy individuals.

Respiratory Quotient

When oxygen consumption and carbon dioxide production are measured, the **respiratory quotient (RQ)** may be calculated as noted in the following equation. The RQ indicates the fuel mixture being metabolized. The RQ for carbohydrate is 1 because the number of carbon dioxide molecules produced is equal to the number of oxygen molecules consumed.

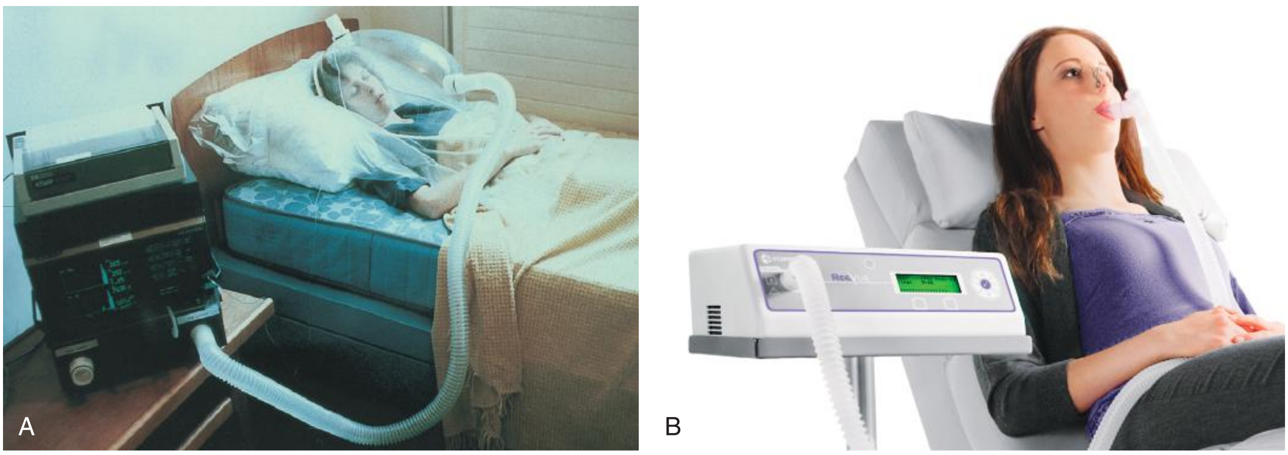

FIGURE 2-3 **A:** Measuring resting energy expenditure using a ventilated hood system. (Courtesy MRC Mitochondrial Biology Unit, Cambridge, England.). **B:** Measuring resting energy expenditure using a handheld system. (Courtesy Korr.)

RQ = volume of CO expired/volume of O_2 consumed (VO_2/VCO_2)

RQ values:
1 = carbohydrate
0.85 = mixed diet
0.82 = protein
0.7 = fat
≤0.65 = ketone production

RQs greater than 1 are associated with net fat synthesis, carbohydrate (glucose) intake, or total caloric intake that is excessive, whereas a very low RQ may be seen under conditions of inadequate nutrient intake (McClave et al, 2003). Although RQ has been used to determine the efficacy of nutrition support regimens for hospitalized patients, McClave found that changes in RQ failed to correlate to percent calories provided or required, indicating low sensitivity and specificity that limits the efficacy of RQ as an indicator of overfeeding or underfeeding. However, use of RQ is appropriate as a marker of test validity (to confirm measured RQ values are in physiologic range) and a marker for respiratory tolerance of the nutrition support regimen.

Other Methods of Measuring Energy Expenditure

Alternative methods of measuring energy expenditure remain in the research setting because of the need for specialized equipment and expertise.

Doubly labeled water. The doubly labeled water (DLW) technique for measuring TEE is considered the gold standard for determining energy requirements and energy balance in humans. The DLW method is based on the principle that carbon dioxide production can be estimated from the difference in the elimination rates of body hydrogen and oxygen. After an oral loading dose of water labeled with deuterium oxide (^2H_2O) and oxygen-18 ($H_2{}^{18}O$)—hence the term doubly labeled water—is administered, the ^2H_2O is eliminated from the body as water, and the $H_2{}^{18}O$ is eliminated as water and carbon dioxide. The elimination rates of the two isotopes are measured for 10 to 14 days by periodic sampling of body water from urine, saliva, or plasma. The difference between the two elimination rates is a measure of carbon dioxide production. Carbon dioxide production then can be equated to TEE using standard IC techniques for the calculation of energy expenditure.

The caloric value of AT can be estimated by using the DLW method in conjunction with IC and also can be used to determine adherence to recommended intake and body composition longitudinally (Wong et al, 2014). The DLW technique is most applicable as a research tool; the stable isotopes are expensive, and expertise is required to operate the highly sophisticated and costly mass spectrometer for the analysis of the isotope enrichments. These disadvantages make the DLW technique impractical for daily use by clinicians.

Measuring Activity-Related Energy Expenditure

Triaxial monitors. A triaxial monitor has also been used to measure energy related to activity. It more efficiently measures multidirectional movement by employing three uniaxial monitors. In a review of numerous articles, Plasqui and Westerterp (2007) found that a triaxial monitor correlated with energy expenditure measured using DLW technique. Application of an easily accessible and useable monitor allows determination of real activity levels, thereby reducing errors related to overreporting or underreporting of actual energy expenditure for weight management.

Physical Activity Questionnaire

Physical activity questionnaires (PAQs) are the simplest and least expensive tools for gaining information about an individual's activity level (Winters-Hart et al, 2004). Reporting errors are common among PAQs, which can lead to discrepancies between calculated energy expenditure and that determined by DLW (Neilson et al, 2008). For healthy individuals, this may account for slowed weight loss or gain and, as such, a need to modify caloric intake.

ESTIMATING ENERGY REQUIREMENTS

Equations for Estimating Resting Energy Expenditure

Over the years several equations have been developed to estimate the REE. Equations are available that allow the estimation of REE as derived from measurement using IC in adults. Until recently, the Harris-Benedict equations were some of the most widely used equations to estimate REE in normal and ill or injured individuals (Harris and Benedict, 1919). The Harris-Benedict formulas have been found to overestimate REE in normal weight and obese individuals by 7% to 27% (Frankenfield et al, 2003). A study comparing measured REE with estimated REE using the Mifflin-St. Jeor equations, Owen equations, and Harris-Benedict equations for males and females found that the Mifflin-St. Jeor equations were most accurate in estimating REE in both normal weight and obese people (Frankenfield et al, 2003). The Mifflin-St Jeor equations were developed from measured REE using IC in 251 males and 247 females; 47% of these individuals had a body mass index (BMI) between 30 and 42 kg/m^2 (Mifflin et al, 1990). Mifflin-St. Jeor equations are used today to estimate energy expenditure of healthy individuals and in some patients and are as follows:

$$\text{Males: kcal/: day} = 10\,(\text{wt}) + 6.25\,(\text{ht}) - 5\,(\text{age}) + 5$$
$$\text{Females: kcal/ day} = 10\,(\text{wt}) + 6.25\,(\text{ht}) - 5\,(\text{age}) - 161$$
$$\text{Weight} = \text{actual body weight in kilograms}$$
$$\text{Height} = \text{centimeters; age} = \text{years}$$

Although the Harris-Benedict equations have been applied to ill and injured people, these equations, as well as those of Mifflin, were developed for use in healthy individuals, and their application to any other population is questionable. In addition, the database from which the Harris-Benedict equations were developed no longer reflects the population, and therefore use of these equations is not recommended.

Energy expenditure of ill or injured patients also can be estimated or measured using IC. For energy requirements for critically ill patients, see Chapter 38.

Determining TEE

The equations for estimating or measuring energy expenditure begin with resting energy expenditure or REE. Additional factors for TEE and activity must be added. As stated previously, the TEF may be considered as an overall additive factor within activity thermogenesis in calculations of TEE. A simplified way of predicting physical activity additions to REE is through the use of estimates of the level of physical activity, which are then multiplied by the measured or predicted REE. To estimate TEE for minimal activity, increase REE by 10% to 20%; for moderate activity, increase REE by 25% to 40%; for strenuous activity, increase REE by 45% to 60%. These levels are ranges used in practice and can be considered "expert opinion" rather than evidence based at this time.

Estimating Energy Requirements from Energy Intake

Traditionally, recommendations for energy requirements were based on self-recorded estimates (e.g., diet records) or self-reported estimates (e.g., 24-hour recalls) of food intake. However, these methods do not provide accurate or unbiased estimates of an individual's energy intake. The percentage of people who underestimate or underreport their food intake ranges from 10% to 45%, depending on the person's age, gender, and body composition. This occurs in the compromised patient population as well (Ribeiro et al, 2014). See Chapter 4.

Many online programs are available in which an individual can enter the food and quantity consumed into a program that estimates the macronutrient and micronutrient content. These programs allow users to enter data and receive a summary report, often with a detailed report provided to the health professional as well. Widely available programs include Food Prodigy and the MyPlate Tracker from the United States Department of Agriculture (see Chapter 4).

Other Prediction Equations

The National Academy of Sciences, Institute of Medicine (IOM), and Food and Nutrition Board, in partnership with Health Canada, developed the estimated energy requirements for men, women, children, and infants and for pregnant and lactating women (IOM, 2005). The **estimated energy requirement (EER)** is the average dietary energy intake predicted to maintain energy balance in a healthy adult of a defined age, gender, weight, height, and level of physical activity consistent with good health. In children and pregnant and lactating women, the EER is taken to include the energy needs associated with the deposition of tissues or the secretion of milk at rates consistent with good health. Table 2-1 lists average dietary reference intake (DRI) values for energy in healthy, active people of reference height, weight, and age for each life-stage group (IOM, 2002; 2005).

Supported by DLW studies, prediction equations have been developed to estimate energy requirements for people according to their life-stage group. Box 2-1 lists the EER prediction equations for people of normal weight. TEE prediction equations also are listed for various overweight and obese groups, as well as for weight maintenance in obese girls and boys. All equations have been developed to maintain current body weight (and promote growth when appropriate) and current levels of physical activity for all subsets of the population; they are not intended to promote weight loss (IOM, 2002; 2005).

The EER incorporates age, weight, height, gender, and level of physical activity for people ages 3 years and older. Although variables such as age, gender, and feeding type (i.e., breast milk, formula) can affect TEE among infants and young children, weight has been determined as the sole predictor of TEE needs (IOM, 2002; 2005). Beyond TEE requirements, additional calories are required for infants, young children, and children ages 3 through 18 to support the deposition of tissues needed for growth, and for pregnant and lactating women. Thus the EER among these subsets of the population is the sum of TEE plus the caloric requirements for energy deposition.

TABLE 2-1 Dietary Reference Intake Values for Energy for Active Individuals

Life-Stage Group	Criterion	ACTIVE PAL EER (kcal/day) Male	Female
Infants			
0-6 mo	Energy expenditure + Energy deposition	570	520 (3 mo)
7-12 mo	Energy expenditure + Energy deposition	743	676 (9 mo)
Children			
1-2 yr	Energy expenditure + Energy deposition	1046	992 (24 mo)
3-8 yr	Energy expenditure + Energy deposition	1742	1642 (6 yr)
9-13 yr	Energy expenditure + Energy deposition	2279	2071 (11 yr)
14-18 yr	Energy expenditure + Energy deposition	3152	2368 (16 yr)
Adults			
>18 yr	Energy expenditure	3067†	2403† (19 yr)
Pregnant Women			
14-18 yr	Adolescent female EER + Change in TEE + Pregnancy energy deposition		
First trimester			2368 (16 yr)
Second trimester			2708 (16 yr)
Third trimester			2820 (16 yr)
19-50 yr	Adult female EER + Change in TEE + Pregnancy energy deposition		
First trimester			2403† (19 yr)
Second trimester			2743† (19 yr)
Third trimester			2855† (19 yr)
Lactating Women			
14-18 yr	Adolescent female EER + Milk energy output − Weight loss		
First 6 mo			2698 (16 yr)
Second 6 mo			2768 (16 yr)
19-50 yr	Adult female EER + Milk energy output − Weight loss		
First 6 mo			2733† (19 yr)
Second 6 mo			2803† (19 yr)

From Institute of Medicine of The National Academies: *Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids.* Washington, DC, 2002/2005, The National Academies Press.

EER, Estimated energy requirement; *PAL,* physical activity level; *TEE,* total energy expenditure.

*For healthy active Americans and Canadians at the reference height and weight.

†Subtract 10 kcal/day for men and 7 kcal/day for women for each year of age above 19 years.

The prediction equations include a physical activity (PA) coefficient for all groups except infants and young children (see Box 2-1). PA coefficients correspond to four **physical activity level (PAL)** lifestyle categories: sedentary, low active, active, and very active. Because PAL is the ratio of TEE to BEE, the energy spent during activities of daily living, the sedentary lifestyle category has a PAL range of 1 to 1.39. PAL categories beyond sedentary are determined according to the energy spent by an adult walking at a set pace (Table 2-2). The walking equivalents that correspond to each PAL category for an average-weight adult walking at 3 to 4 mph are 2, 7, and 17 miles per day, for low active, active and very active (IOM, 2002; 2005). All equations

BOX 2-1 Estimated Energy Expenditure* Prediction Equations at Four Physical Activity Levels†

EER for Infants and Young Children 0 to 2 Years (Within the 3rd to 97th Percentile for Weight-for-Height)

EER = TEE‡ Energy deposition

0-3 months (89 × Weight of infant [kg] − 100) + 175 (kcal for energy deposition)

4-6 months (89 × Weight of infant [kg] − 100) + 56 (kcal for energy deposition)

7-12 months (89 × Weight of infant [kg] −100) + 22 (kcal for energy deposition)

13-35 months (89 × Weight of child [kg] − 100) + 20 (kcal for energy deposition)

EER for Boys 3 to 8 Years (Within the 5th to 85th Percentile for BMI)§

EER = TEE‡ Energy deposition

EER = 88.5 − 61.9 × Age (yr) + PA × (26.7 × Weight [kg] + 903 × Height [m]) + 20 (kcal for energy deposition)

EER for Boys 9 to 18 Years (Within the 5th to 85th Percentile for BMI)

EER = TEE Energy deposition

EER = 88.5 − 61.9 × Age (yr) + PA × (26.7 × Weight [kg] + 903 × Height [m]) + 25 (kcal for energy deposition)

in which

PA = Physical activity coefficient for boys 3-18 years:

PA = 1 if PAL is estimated to be ≥ 1 < 1.4 (Sedentary)

PA = 1.13 if PAL is estimated to be ≥ 1.4 < 1.6 (Low active)

PA = 1.26 if PAL is estimated to be ≥ 1.6 < 1.9 (Active)

PA = 1.42 if PAL is estimated to be ≥ 1.9 < 2.5 (Very active)

EER for Girls 3 to 8 Years (Within the 5th to 85th Percentile for BMI)

EER = TEE Energy deposition

EER = 135.3 − 30.8 × Age (yr) + PA × (10 × Weight [kg] + 934 × Height [m]) + 20 (kcal for energy deposition)

EER for Girls 9 to 18 Years (Within the 5th to 85th Percentile for BMI)

EER = TEE + Energy deposition

EER = 135.3 − 30.8 × Age (yr) + PA × (10 × Weight [kg] + 934 × Height [m]) + 25 (kcal for energy deposition)

in which

PA = Physical activity coefficient for girls 3-18 years:

PA = 1 (Sedentary)

PA = 1.16 (Low active)

PA = 1.31 (Active)

PA = 1.56 (Very active)

EER for Men 19 Years and Older (BMI 18.5 to 25 kg/m²)

EER = TEE

EER = 662 − 9.53 × Age (yr) + PA × (15.91 × Weight [kg] + 539.6 × Height [m])

in which

PA = Physical activity coefficient:

PA = 1 (Sedentary)

PA = 1.11 (Low active)

PA = 1.25 (Active)

PA = 1.48 (Very active)

EER for Women 19 Years and Older (BMI 18.5 to 25 kg/m²)

EER = TEE

EER = 354 − 6.91 × Age (yr) + PA × (9.36 × Weight [kg] + 726 × Height [m])

in which

PA = Physical activity coefficient:

PA = 1 (Sedentary)

PA = 1.12 (Low active)

PA = 1.27 (Active)

PA = 1.45 (Very active)

EER for Pregnant Women

14-18 years: EER = Adolescent EER + Pregnancy energy deposition

First trimester = Adolescent EER + 0 (Pregnancy energy deposition)

Second trimester = Adolescent EER + 160 kcal (8 kcal/wk 1 × 20 wk) + 180 kcal

Third trimester = Adolescent EER + 272 kcal (8 kcal/wk × 34 wk) + 180 kcal

19-50 years: = Adult EER + Pregnancy energy deposition

First trimester = Adult EER + 0 (Pregnancy energy deposition)

Second trimester = Adult EER + 160 kcal (8 kcal/wk × 20 wk) + 180 kcal

Third trimester = Adult EER + 272 kcal (8 kcal/wk × 34 wk) + 180 kcal

EER for Lactating Women

14-18 years: EER = Adolescent EER + Milk energy output − Weight loss

First 6 months = Adolescent EER + 500 − 170 (Milk energy output − Weight loss)

Second 6 months = Adolescent EER + 400 − 0 (Milk energy output − Weight loss)

19-50 years: EAR = Adult EER + Milk energy output − Weight loss

First 6 months = Adult EER + 500 − 70 (Milk energy output − Weight loss)

Second 6 months = Adult EER + 400 − 0 (Milk energy output − Weight loss)

Weight Maintenance TEE for Overweight and At-Risk for Overweight Boys 3 to 18 Years (BMI >85th Percentile for Overweight)

TEE = 114 − 50.9 × Age (yr) + PA × (19.5 × Weight [kg] + 1161.4 × Height [m])

in which

PA = Physical activity coefficient:

PA = 1 if PAL is estimated to be ≥ 1.0 < 1.4 (Sedentary)

PA = 1.12 if PAL is estimated to be ≥ 1.4 < 1.6 (Low active)

PA = 1.24 if PAL is estimated to be ≥ 1.6 < 1.9 (Active)

PA = 1.45 if PAL is estimated to be ≥ 1.9 < 2.5 (Very active)

Weight Maintenance TEE for Overweight and At-Risk for Overweight Girls 3-18 Years (BMI >85th Percentile for Overweight)

TEE = 389 − 41.2 × Age (yr) + PA × (15 × Weight [kg] + 701.6 × Height [m])

in which

PA = Physical activity coefficient:

PA = 1 if PAL is estimated to be ≥ 1 < 1.4 (Sedentary)

PA = 1.18 if PAL is estimated to be ≥ 1.4 < 1.6 (Low active)

PA = 1.35 if PAL is estimated to be ≥ 1.6 < 1.9 (Active)

PA = 1.60 if PAL is estimated to be ≥ 1.9 < 2.5 (Very active)

Continued

BOX 2-1 Estimated Energy Expenditure Prediction Equations at Four Physical Activity Levels—cont'd

Overweight and Obese Men 19 Years and Older (BMI ≥25 kg/m²)

TEE = 1086 − 10.1 × Age (yr) + PA × (13.7 × Weight [kg] + 416 × Height [m])
in which
PA = Physical activity coefficient:
PA = 1 if PAL is estimated to be ≥ 1 < 1.4 (Sedentary)
PA = 1.12 if PAL is estimated to be ≥ 1.4 < 1.6 (Low active)
PA = 1.29 if PAL is estimated to be ≥ 1.6 < 1.9 (Active)
PA = 1.59 if PAL is estimated to be ≥ 1.9 < 2.5 (Very active)

Overweight and Obese Women 19 Years and Older (BMI ≥25 kg/m²)

TEE = 448 − 7.95 × Age (yr) + PA × (11.4 × Weight [kg] + 619 × Height [m])
where
PA = Physical activity coefficient:
PA = 1 if PAL is estimated to be ≥ 1 < 1.4 (Sedentary)
PA = 1.16 if PAL is estimated to be ≥ 1.4 < 1.6 (Low active)
PA = 1.27 if PAL is estimated to be ≥ 1.6 < 1.9 (Active)
PA = 1.44 if PAL is estimated to be ≥ 1.9 < 2.5 (Very active)

Normal and Overweight or Obese Men 19 Years and Older (BMI ≥18.5 kg/m²)

TEE = 864 − 9.72 × Age (yr) + PA × (14.2 × Weight [kg] + 503 × Height [m])
in which
PA = Physical activity coefficient:
PA = 1 if PAL is estimated to be ≥ 1 < 1.4 (Sedentary)
PA = 1.12 if PAL is estimated to be ≥ 1.4 < 1.6 (Low active)
PA = 1.27 if PAL is estimated to be ≥ 1.6 < 1.9 (Active)
PA = 1.54 if PAL is estimated to be ≥ 1.9 < 2.5 (Very active)

Normal and Overweight or Obese Women 19 Years and Older (BMI ≥18.5 kg/m²)

TEE = 387 − 7.31 × Age (yr) + PA × (10.9 × Weight [kg] + 660.7 × Height [m])
in which
PA = Physical activity coefficient:
PA = 1 if PAL is estimated to be ≥ 1 < 1.4 (Sedentary)
PA = 1.14 if PAL is estimated to be ≥ 1.4 < 1.6 (Low active)
PA = 1.27 if PAL is estimated to be ≥ 1.6 < 1.9 (Active)
PA = 1.45 if PAL is estimated to be ≥ 1.9 < 2.5 (Very active)

From Institute of Medicine, Food and Nutrition Board: *Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids,* Washington, DC, 2002, The National Academies Press, www.nap.edu.
BMI, Body mass index; *EER,* estimated energy requirement; *PA,* physical activity; *PAL,* physical activity level; *TEE,* total energy expenditure.
EER is the average dietary energy intake that is predicted to maintain energy balance in a healthy adult of a defined age, gender, weight, height, and level of physical activity consistent with good health. In children and pregnant and lactating women, the EER includes the needs associated with the deposition of tissues or the secretion of milk at rates consistent with good health.
†PAL is the physical activity level that is the ratio of the total energy expenditure to the basal energy expenditure.
‡TEE is the sum of the resting energy expenditure, energy expended in physical activity, and the thermic effect of food.
§BMI is determined by dividing the weight (in kilograms) by the square of the height (in meters).

TABLE 2-2 Physical Activity Level Categories and Walking Equivalence*

PAL Category	PAL Values	Walking Equivalence (Miles/Day at 3-4 mph)
Sedentary	1-1.39	
Low active	1.4-1.59	1.5, 2.2, 2.9 for PAL = 1.5
Active	1.6-1.89	3, 4.4, 5.8 for PAL = 1.6
		5.3, 7.3, 9.9 for PAL = 1.75
Very active	1.9-2.5	7.5, 10.3, 14 for PAL = 1.9
		12.3, 16.7, 22.5 for PAL = 2.2
		17, 23, 31 for PAL = 2.5

From Institute of Medicine, The National Academies: Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids, Washington, DC, 2002/2005, The National Academies Press.
PAL, Physical activity level.
*In addition to energy spent for the generally unscheduled activities that are part of a normal daily life. The low, middle, and high miles/day values apply to relatively heavy-weight (120-kg), midweight (70-kg), and lightweight (44-kg) individuals, respectively.

are only estimates and individual variations may be wide and unexpected (O'Riordan et al, 2010).

Estimated Energy Expended in Physical Activity

Energy expenditure in physical activity can be estimated using either the method shown in Appendix 20, which represents energy spent during common activities and incorporates body weight and the duration of time for each activity as variables, or using information in Figure 2-3, which represents energy spent by adults during various intensities of physical activity—energy that is expressed as **metabolic equivalents (METs)** (IOM, 2002; 2005).

Estimating Energy Expenditure of Selected Activities Using Metabolic Equivalents

METs are units of measure that correspond with a person's metabolic rate during selected physical activities of varying intensities and are expressed as multiples of REE. A MET value of 1 is the oxygen metabolized at rest (3.5 ml of oxygen per kilogram of body weight per minute in adults) and can be expressed as 1 kcal/kg of body weight per hour. Thus the energy expenditure of adults can be estimated using MET values (1 MET = 1 kcal/kg/hr). For example, an adult who weighs 65 kg and is walking moderately at a pace of 4 mph (which is a MET value of 4.5) would expend 293 calories in 1 hour (4.5 kcal × 65 kg × 1 = 293) (Table 2-3).

Estimating a person's energy requirements using the Institute of Medicine's EER equations requires identifying a PAL value for that person. A person's PAL value can be affected by various activities performed throughout the day and is referred to as the change in physical activity level (Δ PAL). To determine Δ PAL, take the sum of the Δ PALs for each activity performed for 1 day from the DRI tables (IOM, 2002; 2005). To calculate the PAL value for 1 day, take the sum of activities and add the BEE (1) plus 10% to account for the TEF (1 + 0.1 = 1.1). For example, to calculate an adult woman's PAL value, take the sum of the Δ PAL values for activities of daily living, such as walking the dog (0.11) and vacuuming (0.14) for 1 hour each, sitting for 4 hours doing light activity (0.12), and then performing moderate to vigorous activities such as

TABLE 2-3 Intensity and Effect of Various Activities on Physical Activity Level in Adults*

Physical Activity	METs*	Δ PAL/10 min†	Δ PAL/hr‡
Daily Activities			
Lying quietly	1	0	0
Riding in a car	1	0	0
Light activity while sitting	1.5	0.005	0.03
Watering plants	2.5	0.014	0.09
Walking the dog	3	0.019	0.11
Vacuuming	3.5	0.024	0.14
Doing household tasks (moderate effort)	3.5	0.024	0.14
Gardening (no lifting)	4.4	0.032	0.19
Mowing lawn (power mower)	4.5	0.033	0.20
Leisure Activities: Mild			
Walking (2 mph)	2.5	0.014	0.09
Canoeing (leisurely)	2.5	0.014	0.09
Golfing (with cart)	2.5	0.014	0.09
Dancing (ballroom)	2.9	0.018	0.11
Leisure Activities: Moderate			
Walking (3 mph)	3.3	0.022	0.13
Cycling (leisurely)	3.5	0.024	0.14
Performing calisthenics (no weight)	4	0.029	0.17
Walking (4 mph)	4.5	0.033	0.20
Leisure Activities: Vigorous			
Chopping wood	4.9	0.037	0.22
Playing tennis (doubles)	5	0.038	0.23
Ice skating	5.5	0.043	0.26
Cycling (moderate)	5.7	0.045	0.27
Skiing (downhill or water)	6.8	0.055	0.33
Swimming	7	0.057	0.34
Climbing hills (5-kg load)	7.4	0.061	0.37
Walking (5 mph)	8	0.067	0.40
Jogging (10-min mile)	10.2	0.088	0.53
Skipping rope	12	0.105	0.63

Modified from Institute of Medicine of The National Academies: *Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, protein, and amino acids*, Washington, DC, 2002, The National Academies Press.
MET, Metabolic equivalent; *PAL*, physical activity level.
*PAL is the physical activity level that is the ratio of the total energy expenditure to the basal energy expenditure.
†METs are multiples of an individual's resting oxygen uptakes, defined as the rate of oxygen (O_2) consumption of 3.5 ml of O_2/min/kg body weight in adults.
‡The Δ PAL is the allowance made to include the delayed effect of physical activity in causing excess postexercise oxygen consumption and the dissipation of some of the food energy consumed through the thermic effect of food.

walking for 1 hour at 4 mph (0.20) and ice skating for 30 minutes (0.13) for a total of 0.7. To that value add the BEE adjusted for the 10% TEF (1.1) for the final calculation:

$$0.7 + 1.1 = 1.8$$

For this woman, the PAL value (1.8) falls within an active range. The PA coefficient that correlates with an active lifestyle for this woman is 1.27.

To calculate the EER for this adult woman, age 30, use the EER equation for women 19 years and older (BMI 18.5-25 kg/m^2); see Box 2-1. The following calculation estimates the EER for a 30-year-old active woman who weighs 65 kg, is 1.77 m tall, with a PA coefficient (1.27):

$$\text{EER} = 354 - 6.91 \times \text{Age (yr)} + \text{PA} \times (9.36 \times \text{Weight [kg]} + 726 \times \text{Height [m]})$$

$$\text{EER} = 354 - (6.91 \times 30) + 1.27 \times ([9.36 \times 65] + [726 \times 1.77])$$

$$\text{EER} = 2551 \text{ kcal}$$

Energy spent during various activities and the intensity and impact of selected activities also can be determined for children and teens (see Box 2-1).

Physical Activity in Children

CALCULATING FOOD ENERGY

The total energy available from a food is measured with a bomb calorimeter. This device consists of a closed container in which a weighed food sample, ignited with an electric spark, is burned in an oxygenated atmosphere. The container is immersed in a known volume of water, and the rise in the temperature of the water after igniting the food is used to calculate the heat energy generated.

Not all of the energy in foods and alcohol is available to the body's cells, because the processes of digestion and absorption are not completely efficient. In addition, the nitrogenous portion of amino acids is not oxidized but is excreted in the form of urea. Therefore, the biologically available energy from foods and alcohol is expressed in values rounded off slightly below those obtained using the calorimeter. These values for protein, fat, carbohydrate, and alcohol (Figure 2-4) are 4, 9, 4, and 7 kcal/g, respectively. Fiber is an "unavailable carbohydrate" that resists digestion and absorption; its energy contribution is minimal.

Although the energy value of each nutrient is known precisely, only a few foods, such as oils and sugars, are made up of a single nutrient. More commonly, foods contain a mixture of protein, fat, and carbohydrate. For example, the energy value of one medium (50 g) egg calculated in terms of weight is derived from protein (13%), fat (12%), and carbohydrate (1%) as follows:

Protein: 13% × 50 g = 6.5 g × 4 kcal/g = 26 kcal

Fat: 12% × 50 g = 6 g × 9 kcal/g = 54 kcal

Carbohydrate: 1% × 50 g = 0.05g × 4 kcal/g = 2 kcal

Total = 82 kcal

The energy value of alcoholic beverages can be determined using the following equation:

Alcohol kcal = amount of beverage (oz) x proof x .8 kcal/proof/oz.

Proof is the proportion of alcohol to water or other liquids in an alcoholic beverage. The standard in the United States defines 100-proof as equal to 50% of ethyl alcohol by volume. To determine the percentage of ethyl alcohol in a beverage, divide the proof value by 2. For example, 86-proof whiskey contains 43% ethyl alcohol. The latter part of the equation—0.8 kcal/proof/1 oz—is the factor that accounts