

CHAPTER 6

Energy Balance

KEY CONCEPTS

- Food energy is changed into body energy to do work.
- The body uses most of its energy supply for basal metabolic needs.
- A balance between the intake of food energy and the output of body work maintains life and health.
- States of being underweight and overweight reflect degrees of energy imbalance.

Efficient human bodies constantly convert energy from food into the energy that is used for work and activity. Fuel is used and stored as necessary according to intake and output demands.

This chapter looks at the big picture of energy balance among all of the energy-yielding nutrients and shows how energy intake is measured, cycled, and used to meet all of the body's energy demands.

HUMAN ENERGY SYSTEM

Basic Energy Needs

The body needs constant energy to do the work that is necessary for maintenance of life and health. Both voluntary and involuntary actions require energy.

Voluntary Work and Exercise

Voluntary work includes all of the actions related to a person's conscious activities of daily living and physical exercise. Although these intentional actions seem to use most of the energy output, that usually is not the case.

Involuntary Body Work

The greatest energy output is the result of involuntary work, which includes all of the activities in the body that are not consciously performed. These activities include such vital processes as circulation, respiration, digestion, and absorption (this is referred to as the *thermic effect of food*) as well as many other internal activities that maintain life. Involuntary body functions require energy in various forms, such as chemical energy (in many metabolic products), electrical energy (in brain and nerve activities), mechanical energy (in muscle contraction), and thermal (i.e., heat) energy to maintain body temperature.

Sources of Fuel

Energy that is needed for voluntary and involuntary body work requires fuel, which is provided in the form of adenosine triphosphate. As explained earlier in this book, the only three energy-yielding nutrients are the macronutrients carbohydrate, fat, and protein. Carbohydrates are the body's primary fuel, with fat assisting as a storage fuel. Protein is used for energy only when other fuel sources are not available. The body must have an adequate supply of fuel to balance energy demands for healthy weight maintenance.

Measurement of Energy

Unit of Measure: Kilocalorie

In common usage, the word *calorie* refers to the amount of energy in food or the amount that is expended in physical actions. However, in human nutrition, the term kilocalorie (i.e., 1000 calories) is used to designate the large calorie unit that is used in nutrition science to avoid dealing with such large numbers. A kilocalorie, which is abbreviated as *kcalorie* or *kcal*, is the amount of heat that is necessary to raise 1 kg of water 1° C. The international unit of measure for energy is the joule (J). To convert kilocalories (kcal) into kilojoules (kJ), multiply

the number of kilocalories by 4.184 (e.g., $200 \text{ kcal} \times 4.184 = 836.8 \text{ kJ}$).

Food Energy: Fuel Factors

As discussed previously, the macronutrients have basic fuel factors. Ethanol (i.e., beverage alcohol from fermented grains and fruits) also supplies fuel. These factors reflect their relative fuel densities: carbohydrate, 4 kcal/g; fat, 9 kcal/g; protein, 4 kcal/g; and alcohol, 7 kcal/g.

Caloric and Nutrient Density

The term *density* refers to the degree of concentrated material in a given substance. More material in a smaller amount of substance increases the density. Thus, the concept of *caloric density* refers to a high concentration of energy (i.e., kilocalories) in a small amount of food. Of the three energy nutrients, fat or foods that are high in fat have the highest caloric density. Similarly, foods may be evaluated in terms of their relative nutrient density. A food with a high nutrient density has a relatively high concentration of all nutrients, including vitamins and minerals, in smaller amounts of a given food. Food guides such as MyPlate (www.choosemyplate.gov/guidelines; see Figure 1-3) recommend foods that are nutrient dense as opposed to only calorie dense. Some foods are both calorie and nutrient dense, which means that they provide a lot of both kilocalories and nutrients.

ENERGY BALANCE

Energy—like matter—is neither created nor destroyed. When energy is referred to as “being produced,” it really means that it is transformed (i.e., changed in form and cycled through a system). Consider the human energy system as part of the total energy system on Earth. In this sense, two energy systems support human life—one within the body and the much larger one surrounding us—as follows:

1. **External energy cycle:** In the environment, the ultimate source of energy is the sun and its vast nuclear reactions. With the use of water and carbon dioxide as raw materials, plants transform the sun’s radiation into stored chemical energy that is mainly carbohydrate with some fat and protein. The food chain continues as animals, including humans, eat plants and the products of other animals (e.g., meat, milk, eggs).
2. **Internal energy cycle:** When people eat plant and animal foods, the stored energy changes into body fuels (i.e., glucose and fatty acids) and cycles into various other energy forms to serve body

needs. These forms include the involuntary actions mentioned previously: chemical, electrical, mechanical, and thermal energy. As this internal energy cycle continues, water is excreted, carbon dioxide is exhaled, and heat is radiated, thereby returning these end products to the external environment. The overall energy cycle continually repeats itself to sustain life.

Energy Intake

The total overall energy balance within the body depends on the energy intake in relation to the energy output. The main source of energy for all body work is food, and this is supplemented with stored energy in the body tissues.

Sources of Food Energy

The three energy-yielding nutrients in food keep human bodies supplied with fuel. Personal energy intake can easily be estimated by recording a day’s actual food consumption and calculating its energy value. Nutritrac, which is the nutrition analysis program that is available on the Evolve Web site for this book (see the front matter for instructions and details on page 000), is an excellent tool for evaluating energy intake as well as several other components of an individual’s diet (e.g., vitamins, minerals, fat, carbohydrates, sugar, protein). The MyPlate Tracker (www.choosemyplate.gov) is another free software tool that is available through the Internet and that can be used to assess total energy intake.

Sources of Stored Energy

When food is not available, such as during sleep, longer periods of fasting, or the extreme stress of starvation, the body draws from its stored energy.

thermic effect of food an increase in energy expenditure caused by the activities of digestion, absorption, transport, and storage of ingested food; a meal that consists of a usual mixture of carbohydrates, protein, and fat increases the energy expenditure equivalent to approximately 10% of the food’s energy content (e.g., a 300-kcal piece of pizza would elicit an energy expenditure of 30 kcal to digest the food).

calorie a measure of heat; the energy necessary to do work is measured as the amount of heat produced by the body’s work; the energy value of a food is expressed as the number of kilocalories that a specified portion of the food will yield when it is oxidized in the body.

Glycogen. A 12- to 48-hour reserve of glycogen exists in the liver and in the body's muscles, and it is quickly depleted if it is not replenished by daily food intake. For example, glycogen stores maintain normal blood glucose levels for body functions during the hours of sleep. The first meal, breakfast (which is so named because it “breaks the fast”), has a significant function for energy intake.

Adipose Tissue. Although the amount of fat storage is larger than that of glycogen storage, the supply varies from person to person. As an additional energy resource, stored fat provides more kilocalories per gram than any other fuel source.

Muscle Mass. Energy in the form of protein may be elicited from muscle mass. However, this lean tissue serves important structural functions, and it is ideally not sacrificed for energy use. Only during longer periods of fasting or starvation does the body turn to this tissue for energy.

Energy Output

The necessary activities to sustain life—normal body functions, the regulation of body temperature, and the processes of tissue growth and repair—use energy from food and body reserves. The sum of the total chemical changes that occur during all of these activities is called *metabolism*. The following three demands for energy determine the body's total energy requirements: (1) resting energy expenditure; (2) physical activity; and (3) the thermic effect of food.

Resting Energy Expenditure and Basal Energy Expenditure

The term *resting energy expenditure (REE)* or *resting metabolic rate (RMR)* refers to the sum of all internal working activities of the body at rest; it is expressed in kilocalories per day. For example, if an individual's REE is 1500 kcal, that would represent the amount of energy that this particular person would need to consume, on average, over a 24-hour period to maintain his or her current weight while at complete rest. In general use, the terms *REE*, *RMR*, and *basal energy expenditure (BEE)* are used interchangeably to describe a vast amount of physiologic work. However, a technical difference exists between BEE and REE. BEE must be measured when an individual is at complete digestive, physical, mental, thermal, and emotional rest. Maintaining the stringent conditions required to measure a true BEE is rather difficult; therefore, measurements are most often expressed as REE. The REE is slightly higher than a true BEE measurement.¹



Figure 6-1 Measuring resting metabolic rate with a metabolic cart.

Most of the body's total energy expenditure (i.e., 60% to 75%) is spent maintaining necessary bodily functions in the form of REE. The majority of that energy is used by small but highly active tissues (e.g., liver, brain, heart, kidney) that only amount to 5% to 6% of the total body weight. A recent study of healthy adults found that the relative size of skeletal muscle mass and liver mass accounted for 81% of individual variability with regard to REE.²

Measuring Basal Metabolic Rate or Resting Metabolic Rate. A measure of basal metabolic rate (BMR) or RMR is sometimes made in clinical practice (e.g., on metabolic wards or in research laboratories) with the use of indirect calorimetry. This method measures the amount of energy that a person uses while at rest. A portable metabolic cart allows the person to breathe into an attached mouthpiece or ventilated hood system while lying down, and the normal exchange of oxygen and carbon dioxide is measured (Figure 6-1). The metabolic rate can be calculated with a high degree of accuracy from the rate of oxygen use.

resting energy expenditure (REE) the amount of energy (in kcal) needed by the body for the maintenance of life at rest over a 24-hour period; this is often used interchangeably with the term *basal energy expenditure*, but in actuality it is slightly higher.

basal energy expenditure (BEE) the amount of energy (in kcal) needed by the body for the maintenance of life when a person is at complete digestive, physical, mental, thermal, and emotional rest (i.e., 10 to 12 hours after eating and 12 to 18 hours after physical activity; measured immediately upon waking).

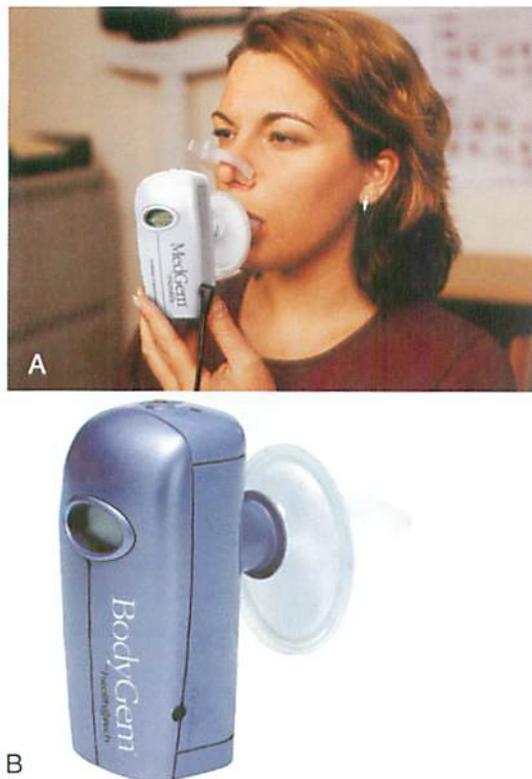


Figure 6-2 A, MedGem and B, BodyGem devices, which are used to determine the resting metabolic rate. (Courtesy Microlife USA, Dunedin, Fla.)

The MedGem and BodyGem (Microlife USA, Dunedin, Fla) are alternative methods for determining RMR with fast and portable devices (Figure 6-2). Both devices are handheld and come with disposable mouthpieces and nose clips. The individual being tested holds the device while breathing exclusively into the mouthpiece. The MedGem and BodyGem measure oxygen consumption to determine an individual's RMR by using a modified Weir equation with a constant respiratory quotient of 0.85 ($RMR = 6.931 \times \text{Maximal oxygen consumption [i.e., } VO_2\text{max}]$).

Predicting Basal Metabolic Rate or Resting Metabolic Rate. A general formula for calculating basal energy needs is to multiply 0.9 or 1 kcal/kg body weight by the number of hours in a day. Thus, the daily basal metabolic needs (in kilocalories) are calculated as follows:

For a 154-lb man:

$$1 \text{ kcal} \times \text{kg body weight} \times 24 \text{ hours}$$

$$(1) \text{ Convert pounds to kilograms: } 154 \text{ lb} \div 2.2 = 70 \text{ kg}$$

$$(2) 1 \text{ kcal} \times 70 \text{ kg} \times 24 \text{ hr} = 1680 \text{ kcal}/24 \text{ hr}$$

For a 121-lb woman:

$$0.9 \text{ kcal} \times \text{kg body weight} \times 24 \text{ hours}$$

$$(1) \text{ Convert pounds to kilograms: } 121 \text{ lb} \div 2.2 = 55 \text{ kg}$$

$$(2) 0.9 \text{ kcal} \times 55 \text{ kg} \times 24 \text{ hr} = 1188 \text{ kcal}/24 \text{ hr}$$

The Mifflin-St. Jeor equations, the Harris-Benedict equations, and the equations that were used for the 2002 Dietary Reference Intake values provide an alternate method of estimating the BMR or RMR that is more specific to the individual (Box 6-1). Of these equations, studies found the Mifflin-St. Jeor equation to give the most reliable RMR measures.³

In addition, thyroid function tests may be used as an indicator of BMR, because the thyroid hormone regulates metabolism. Thyroid function tests measure the activity of the thyroid, the serum thyroxine levels, and the serum protein-bound iodine and radioactive iodine uptake levels. Iodine's basic function is in the synthesis of the prohormone **thyroxine**. Such tests are not associated with a kilocalorie amount in terms of total energy needs. However, they can be used as a gauge of normal metabolic function. Abnormal results require the attention of a physician for treatment.

Factors That Influence Basal Metabolic Rate.

Several factors influence the BMR and should be kept in mind when related test results are interpreted. The major factors that affect BMR relate to lean body mass, growth periods, body temperature, and hormonal status, as follows:

- **Lean body mass:** One of the largest contributors to overall metabolic rate is the relative percent of lean body mass. This is caused by the greater metabolic activity that occurs in lean tissues (i.e., muscles and organs) as compared with fat and bones. Overall metabolic rates are higher in lean bodies, thereby requiring more energy.⁴ Other factors (e.g., gender) only influence the metabolic rate as they relate to the lean body mass.^{5,6} Although lean body mass is lost with advanced age, lowered metabolic rate in the elderly population is not exclusively caused by changes in body composition.^{7,8}
- **Growth periods:** During rapid growth periods, human growth hormone stimulates cell regeneration and raises BMR to support anabolic metabolism. Thus, growth spurts during childhood and adolescence reflect periods of elevated BMR and energy needs per kilogram of body weight. As growth and the rate of cellular regeneration decline into old age, so does BMR. BMR rises significantly

thyroxine (T₄) thyroid prohormone; the active hormone form is T₃; it is the major controller of basal metabolic rate.

BOX 6-1 EQUATIONS FOR ESTIMATING RESTING ENERGY NEEDS

Mifflin-St. Jeor**Men:**

$$\text{TEE (kcal/day)} = (\text{Weight [kg]} \times 10 + \text{Height [cm]} \times 6.25 - \text{Age} \times 5 + 5) \times \text{PA}$$

Women:

$$\text{TEE (kcal/day)} = (\text{Weight [kg]} \times 10 + \text{Height [cm]} \times 6.25 - \text{Age} \times 5 - 161) \times \text{PA}$$

PA coefficient:

- 1.200 = Sedentary (little or no exercise)
- 1.375 = Lightly active (light exercise/sports 1 to 3 days/wk)
- 1.550 = Moderately active (moderate exercise/sports 3 to 5 days/wk)
- 1.725 = Very active (hard exercise/sports 6 to 7 days/wk)
- 1.900 = Extra active (very hard exercise/sports and physical job)

Harris-Benedict**Men:**

$$\text{TEE (kcal/day)} = 66.5 + 13.75 \times \text{Weight (kg)} + 5 \times \text{Height (cm)} - 6.76 \times \text{Age} \times \text{PA}$$

Women:

$$\text{TEE (kcal/day)} = 655 + 9.56 \times \text{Weight (kg)} + 1.7 \times \text{Height (cm)} - 4.7 \times \text{Age} \times \text{PA}$$

PA coefficient:

- 1.200 = Sedentary (little or no exercise; desk job)
- 1.375 = Lightly active (light exercise/sports 1 to 3 days/wk)
- 1.550 = Moderately active (moderate exercise/sports 3 to 5 days/wk)
- 1.725 = Heavy exercise (hard exercise/sports 6 to 7 day/wk)

2002 Dietary Reference Intake Energy Calculation

$$\text{EER} = \text{TEE} + \text{Energy deposition}$$

Children 0 to 36 Months Old:

- 0 to 3 months: $(89 \times \text{Weight [kg]} - 100) + 175$ kcal
- 4 to 6 months: $(89 \times \text{Weight [kg]} - 100) + 56$ kcal
- 7 to 12 months: $(89 \times \text{Weight [kg]} - 100) + 22$ kcal
- 13 to 36 months: $(89 \times \text{Weight [kg]} - 100) + 20$ kcal

Boys 3 to 8 Years Old:

$$\text{EER} = 88.5 - (61.9 \times \text{Age [yr]}) + \text{PA} \times (26.7 \times \text{Weight [kg]} + 903 \times \text{Height [m]}) + 20 \text{ kcal}$$

PA coefficient:

- 1.00 if PAL is estimated to be ≥ 1.0 but < 1.4 (sedentary)
- 1.13 if PAL is estimated to be ≥ 1.4 but < 1.6 (low active)
- 1.26 if PAL is estimated to be ≥ 1.6 but < 1.9 (active)

1.42 if PAL is estimated to be ≥ 1.9 but < 2.5 (very active)

Girls 3 to 8 Years Old:

$$\text{EER} = 135.3 - (30.8 \times \text{Age [yr]}) + \text{PA} \times (10.0 \times \text{Weight [kg]} + 934 \times \text{Height [m]}) + 20 \text{ kcal}$$

PA coefficient:

- 1.00 if PAL is estimated to be ≥ 1.0 but < 1.4 (sedentary)
- 1.16 if PAL is estimated to be ≥ 1.4 but < 1.6 (low active)
- 1.31 if PAL is estimated to be ≥ 1.6 but < 1.9 (active)
- 1.56 if PAL is estimated to be ≥ 1.9 but < 2.5 (very active)

Boys 9 to 18 Years Old:

$$\text{EER} = 88.5 - (61.9 \times \text{Age [yr]}) + \text{PA} \times (26.7 \times \text{Weight [kg]} + 903 \times \text{Height [m]}) + 25 \text{ kcal}$$

PA coefficient:

- 1.00 if PAL is estimated to be ≥ 1.0 but < 1.4 (sedentary)
- 1.13 if PAL is estimated to be ≥ 1.4 but < 1.6 (low active)
- 1.26 if PAL is estimated to be ≥ 1.6 but < 1.9 (active)
- 1.42 if PAL is estimated to be ≥ 1.9 but < 2.5 (very active)

Girls 9 to 18 Years Old:

$$\text{EER} = 135.3 - (30.8 \times \text{Age [yr]}) + \text{PA} \times (10.0 \times \text{Weight [kg]} + 934 \times \text{Height [m]}) + 25 \text{ kcal}$$

PA coefficient:

- 1.00 if PAL is estimated to be ≥ 1.0 but < 1.4 (sedentary)
- 1.16 if PAL is estimated to be ≥ 1.4 but < 1.6 (low active)
- 1.31 if PAL is estimated to be ≥ 1.6 but < 1.9 (active)
- 1.56 if PAL is estimated to be ≥ 1.9 but < 2.5 (very active)

Men 19 Years Old and Older:

$$\text{EER} = 662 - (9.53 \times \text{Age [yr]}) + \text{PA} \times (15.91 \times \text{Weight [kg]} + 539.6 \times \text{Height [m]})$$

PA coefficient:

- 1.00 if PAL is estimated to be ≥ 1.0 but < 1.4 (sedentary)
- 1.11 if PAL is estimated to be ≥ 1.4 but < 1.6 (low active)
- 1.25 if PAL is estimated to be ≥ 1.6 but < 1.9 (active)
- 1.48 if PAL is estimated to be ≥ 1.9 but < 2.5 (very active)

Women 19 Years Old and Older:

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

PA coefficient:

- 1.00 if PAL is estimated to be ≥ 1.0 but < 1.4 (sedentary)
- 1.12 if PAL is estimated to be ≥ 1.4 but < 1.6 (low active)
- 1.27 if PAL is estimated to be ≥ 1.6 but < 1.9 (active)
- 1.45 if PAL is estimated to be ≥ 1.9 but < 2.5 (very active)

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



DRUG-NUTRIENT INTERACTION

ABSORPTION OF LEVOTHYROXINE

Levothyroxine (Synthroid) is a synthetic hormone that is prescribed to treat hypothyroidism and to regulate energy balance. It is absorbed primarily in the jejunum and ileum of the small intestine. Many nutritional factors affect the absorption of the drug^{1,2}:

- Levothyroxine absorption is maximized in an empty stomach, which suggests the importance of gastric acid. Food also tends to delay the drug's absorption.
- Dietary fiber reduces the bioavailability of levothyroxine by binding the drug and causing it to be eliminated.
- Calcium and iron supplements or soy products interfere with the drug's absorption and reduce its bioavailability.
- Gastrointestinal disorders: Celiac disease, lactose intolerance, *Helicobacter pylori* infection, and chronic gastritis all affect the absorptive ability of the

digestive system and consequently interfere with the absorption of the drug.

Levothyroxine should be taken at least 1 hour before or 2 hours after a meal, especially a meal that is high in fiber. If an appropriate meal and drug regimen cannot be implemented, higher doses of the drug may be required. Therefore, a consistent schedule is key.¹ Levothyroxine should be taken at least 4 hours before consuming soy products or before taking calcium or iron supplements (however, normal amounts of these minerals in foods do not seem to pose a problem).¹

The prevalence of celiac disease is higher among patients with autoimmune thyroid disorders.³ When a patient has celiac disease or lactose intolerance, drug absorption does not improve sufficiently with higher doses of the drug until dietary restrictions for the disorder are followed.²

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1. American Thyroid Association. *ATA hypothyroidism booklet*. Falls Church, Va: American Thyroid Association; 2003.

2. Liwanpo L, Hershman JM. Conditions and drugs interfering with thyroxine absorption. *Best Pract Res Clin Endocrinol Metab*. 2009; 23(6):781-792.

3. Sattar N, Lazare F, Kacer M, et al. Celiac disease in children, adolescents, and young adults with autoimmune thyroid disease. *J Pediatr*. 2011;158(2):272-275, e1.

during pregnancy, which is a period of rapid growth that requires an additional 340 to 450 kcal/day on average. However, this value is highly variable among women, and it is correlated with total weight gain and prepregnancy percentage of body fat. BMR increases above prepregnancy rates with the progression of pregnancy; average increases with each trimester are 4.5%, 10.8%, and 24%, respectively.⁹ During the period of lactation, the breastfeeding mother's BMR remains elevated to cover the added metabolic cost of producing milk.

- **Body temperature:** Fever increases BMR by approximately 7% for each 1° F rise above normal body temperature. In states of starvation and malnutrition, the process of **adaptive thermogenesis** results in lowered heat production (i.e., body temperature) to conserve energy and thus BMR decreases.¹⁰ It has also been speculated that a lower core body temperature may be a contributing factor to the efficiency of storing fat in obese individuals.¹¹ In cold weather, especially in freezing temperatures, BMR rises in response to the generation of more body heat to maintain normal core temperature.
- **Hormonal status:** Energy expenditure is also influenced by hormonal secretions. As previously mentioned, the thyroid function test is a means of measuring metabolism. Individuals with an underactive thyroid gland may develop hypothyroidism,

which results in a decreased metabolic rate. Hypothyroidism is easily treated with medication (see the Drug-Nutrient Interaction box, "Absorption of Levothyroxine," for more information about hypothyroidism medication interactions). Conversely, hyperthyroidism occurs when the thyroid gland is overactive (see the Cultural Considerations box, "Hypermetabolism and Hypometabolism: What Are They, and Who Is at Risk?"). The fight-or-flight reflexes increase metabolic rate in response to the hormone epinephrine. Growth hormone increases metabolism; alternately, a deficiency of normal growth hormone secretions attenuates the metabolic rate and has recently been linked to obesity as a causative factor.¹² Other hormones (e.g., insulin, cortisol) also increase metabolism, and they may fluctuate daily.

Physical Activity

The exercise that is involved in work or recreation (Figure 6-3) accounts for wide individual variations in energy output (see Chapter 16). In addition to increasing energy

adaptive thermogenesis an adjustment to heat production in response to changing environmental influences (e.g., external temperature, diet).



CULTURAL CONSIDERATIONS

HYPERMETABOLISM AND HYPOMETABOLISM: WHAT ARE THEY AND WHO IS AT RISK?

Hypermetabolism and hypometabolism are conditions in which the metabolic rate is either significantly higher (hyper) or lower (hypo) than normal. Because the thyroid gland is responsible for producing the hormone thyroxine, which controls the metabolic rate, such conditions usually result from malfunctions of the thyroid gland. Clinically, hypermetabolism and hypometabolism are referred to as *hyperthyroidism* and *hypothyroidism*, respectively.

An individual with hyperthyroidism has a significantly higher metabolic rate and higher energy needs than normal. Such increases in energy needs are not explained by lean tissue, age, or gender. This individual has an overactive thyroid gland, which means that he or she produces too much thyroxine. As a result, the normal energy intake recommendations do not meet this individual's needs. For example, a woman who is 25 years old, 5 feet and 5 inches tall, and weighs 125 lb normally needs approximately 2200 kcal/day to maintain her weight if she engages in a moderate level of activity. However, the same woman with hyperthyroidism may need 1.5 to 2.5 times as many kilocalories per day to maintain her current weight.

Hypothyroidism is the opposite of hyperthyroidism. Individuals with hypothyroidism do not produce enough thyroxine and therefore require less energy than normal to maintain their current body weight. The Dietary Reference Intakes for energy intake for an individual with hypothyroidism are too high and thus, result in weight gain. However, effective medications are available for hypothyroidism. Typically, both

hyperthyroidism and hypothyroidism are discovered during young adulthood.

Congenital hypothyroidism (CH), which occurs in 4 out of every 10,000 live births in the United States, is a type of hypothyroidism that is present at birth and that can result in mental retardation if it is not treated. Newborn screening for CH began during the 1970s and is now standard. Studies have found that the risk of CH is linked to birth weight, gender, and ethnicity. Both male and female infants who weigh less than 4.5 lb or more than 10 lb have a significantly higher risk of developing CH, and females of any weight have 50% more risk than males. A recent report in the United States noted that the incidence rate of CH was 100% higher in Hispanic newborns and 44% higher in Asian and Native Hawaiian or other Pacific Islander newborns as compared with Caucasian newborns; it was 30% lower in African-American newborns as compared with Caucasian newborns.¹

Another risk factor for the development of abnormal thyroid function and thus, abnormal metabolism is iodine intake. The mineral iodine is an important part of the thyroid hormone thyroxine. The incidence of hyperthyroidism and hypothyroidism has been linked to iodine, with both high and low iodine intakes being associated with thyroid disease.²

The close monitoring of basal metabolism and total energy expenditure is an important aspect of the treatment of thyroid disease. Medications and energy intake are then modified to control weight and prevent complications.

- 1.Hinton CF, Harris KB, Borgfeld L, et al. Trends in incidence rates of congenital hypothyroidism related to select demographic factors: data from the United States, California, Massachusetts, New York, and Texas. *Pediatrics*. 2010;125 (Suppl 2):S37-S47.
- 2.Laurberg P, Jørgensen T, Perrild H, et al. The Danish investigation on iodine intake and thyroid disease, DanThyr: status and perspectives. *Eur J Endocrinol*. 2006;155(2):219-228.



Figure 6-3 Energy output increases during exercise. (Copyright PhotoDisc.)

expenditure and reducing the risk of chronic diseases such as heart disease, diabetes, and certain types of cancer, exercise has positive effects on both physical and mental quality of life.¹³ Table 6-1 gives some representative kilocalorie expenditures of different types of work and recreation. Although mental work or study does not require additional kilocalories, muscle tension, restlessness, and agitated movements may increase energy needs for some individuals.

The energy expenditure that is used for physical activity goes above and beyond the RMR. Keeping track of all energy that is used explicitly for physical activity to calculate total energy requirements is somewhat difficult. Instead, the energy that is used for physical activity can be estimated as a factor of RMR by categorizing the physical activity (PA) level in accordance with standard values (1.0 to 2.5, depending on lifestyle). This factor is then multiplied by the RMR. For example, an individual who

TABLE 6-1 ENERGY EXPENDITURE PER POUND PER HOUR DURING VARIOUS ACTIVITIES

Activity	kcal/lb/hr*
Aerobics, moderate	2.95
Bicycling	
Light: 10 to 11.9 mph	2.72
Moderate: 12 to 13.9 mph	3.63
Fast: 14 to 15.9 mph	4.54
Mountain biking	3.85
Daily Activities	
Cleaning	1.36
Cooking	0.91
Driving a car	0.91
Eating, sitting	0.68
Gardening, general	1.81
Office work	0.82
Reading, writing while sitting	0.70
Sleeping	0.41
Shoveling snow	2.72
Running	
5 mph (12 min/mile)	3.63
7 mph (8.5 min/mile)	5.22
9 mph (6.5 min/mile)	6.80
10 mph (6 min/mile)	7.26
Sports	
Boxing, in ring	5.44
Field hockey	3.63
Golf	2.04
Rollerblading	4.42
Skiing, cross country, moderate	3.63
Skiing, downhill, moderate	2.72
Soccer	3.85
Swimming, moderate	3.14
Tennis, doubles	2.27
Tennis, singles	3.63
Ultimate Frisbee	3.63
Volleyball	1.81
Walking	
Moderate: ≈3 mph (20 min/mile), level	1.50
Moderate: ≈3 mph (20 min/mile), uphill	2.73
Brisk: ≈3.5 mph (17.14 min/mile), level	1.72
Fast: ≈4.5 mph (13.33 min/mile), level	2.86
Weight Training	
Light or moderate	1.36
Heavy or vigorous	2.72

*Multiply the activity factor by the weight in pounds by the fraction of hour spent performing the activity.

Example: A 150-lb person plays soccer for 45 minutes. Therefore, the equation would be as follows: 3.85 (i.e., the factor from the table) $\times 150$ (lb) $\times 0.75$ (hr) = 433.13 calories burned.

Energy expenditure depends on the physical fitness of the individual and the continuity of exercise.

Modified from Nieman DC. *Exercise testing and prescription: a health-related approach*. 5th ed. New York: McGraw-Hill; 2003.

works at a desk job and who has little or no leisure activity would have a PA of approximately 1.2 according to the Mifflin-St. Jeor equation. To get a range of total energy expenditure, multiply the person's RMR by 1.2 (see the Clinical Applications box, "Evaluate Your Daily Energy Requirements," for physical activity factors).

Thermic Effect of Food

After eating, food stimulates the metabolism and requires extra energy for the digestion, absorption, and transportation of nutrients to the cells. This overall stimulating effect is called the *thermic effect of food*. Approximately 5% to 10% of the body's total energy needs for metabolism relates to the digestion and storing of nutrients from food.

Total Energy Requirement

The RMR, physical activities, and the thermic effect of food make up a person's overall total energy requirements (Figure 6-4). To maintain a daily energy balance, food energy intake must match body energy output. An energy imbalance (i.e., when energy intake exceeds energy output) can lead to weight gain (Table 6-2). Treatment should include a decrease in food kilocalories and an increase in physical activity. Extreme and unhealthy weight loss (i.e., anorexia nervosa or starvation) results when food energy intake does not meet body energy requirements for extended periods. Treatment should include a gradual increase in food kilocalories along with moderate activity and rest (see Chapter 15).

The Clinical Applications box entitled "Evaluate Your Daily Energy Requirements" provides a step-by-step example for evaluating your energy needs. You may also wish to record your food and activities for a day and to calculate your energy intake (i.e., kilocalories) and output (i.e., kilocalorie expenditure in activities). Total your

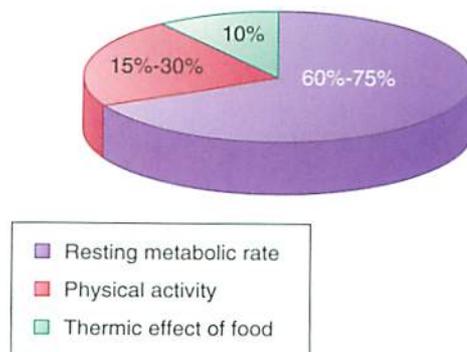


Figure 6-4 The contributions of resting metabolic rate, physical activity, and the thermic effect of food to total energy expenditure.



CLINICAL APPLICATIONS

EVALUATE YOUR DAILY ENERGY REQUIREMENTS

Your estimated energy requirement (in kcal) per day is the sum of your body's three uses of energy, which are as follows:

1. Resting metabolic rate
2. Thermic effect of food
3. Physical activity

Estimated Energy Requirement (EER) as Calculated by the 2002 Dietary Reference Intakes

Men 19 years old and older = $662 - (9.53 \times \text{Age [yr]}) + \text{Physical activity (PA)} \times (15.91 \times \text{Weight [kg]} + 539.6 \times \text{Height [m]})$

Women 19 years old and older = $354 - (6.91 \times \text{Age [yr]}) + \text{PA} \times (9.36 \times \text{Weight [kg]} + 726 \times \text{Height [m]})$

Physical Activity

Estimate your average level of PA. The PA level is the ratio of the total energy expenditure to the basal energy expenditure.

Lifestyle	PA Factor for Men	PA Factor for Women
<i>Sedentary</i> : Mostly resting with little or no planned strenuous activity and only performing those tasks that are required for independent living	1.0	1.0
<i>Low Active</i> : In addition to the activities of a sedentary lifestyle, the added equivalent of a 1.5- to 3-mile walk at a speed of 3 to 4 mph for the average-weight person*	1.11	1.12
<i>Active</i> : In addition to the activities identified for a sedentary lifestyle, an average of 60 minutes of daily moderate-intensity physical activity (e.g., walking at 3 to 4 mph for 3 to 6 miles/day) or shorter periods of more vigorous exertion (e.g., jogging for 30 minutes at 5.5 mph)	1.25	1.27

Lifestyle	PA Factor for Men	PA Factor for Women
<i>Very Active</i> : In addition to the activities of a sedentary lifestyle, an activity level equivalent to walking at 3 to 4 mph for 12 to 22 miles/day (approximately 5 to 7 hours per day) or shorter periods of more vigorous exertion (e.g., running 7 mph for approximately 2.5 hours/day)	1.48	1.45

Example 1

A 32-year-old woman weighs 130 lb (59 kg), is 5 feet and 4 inches tall, and has started and is maintaining a regular physical exercise program. She is currently consuming approximately 2600 kcal/day:

Conversions: 1 pound = 2.2 kg; 39.37 in = 1 m. Thus, $130 \div 2.2 = 59$ kg; 5 feet 4 inches = 64 inches \div 39.37 = 1.626 m.

$\text{EER} = 354 - (6.91 \times 32) + 1.27 [\text{PA}] \times (9.36 \times 59 + 726 \times 1.626)$

$\text{EER} = 354 - 221.12 + 1.27 \times (552.24 + 1180.5)$

$\text{EER} = 2333.5$ kcal/day

Result: This woman will gain weight. Her energy intake is approximately 266 kcal/day more than her energy output. Because 1 lb of body weight equals approximately 3500 kcal, she will gain approximately 1 lb every 13 days with the preceding eating and exercise routine.

Example 2

A 41-year-old man weighs 180 lb (82 kg), is 6 feet tall, and eats an average of 3300 kcal/day while maintaining a very active lifestyle:

$\text{EER} = 662 - (9.53 \times 41) + 1.48 [\text{PA}] \times (15.91 \times 82 + 539.6 \times 1.829 [\text{m}])$

$\text{EER} = 662 - 390.73 + 1.48 \times (1304.62 + 986.93)$

$\text{EER} = 3663$ kcal/day

Result: This man will tend to lose weight with his current exercise and meal plan, because he is consuming approximately 163 kcal less than he is expending. Approximately how many pounds will he lose per month?

*For example, a man who weighs 70 kg and is 1.77 m tall and a woman who weighs 57 kg and is 1.63 m tall, on the basis of the reference body weights for adults.

day's activity, and compare it with the general types of similar activities given in Table 6-1. Estimate the total time that you spent on a given activity by adding up the minutes that you spent on that activity at any time and then converting those minutes to hours (or decimal

fractions of hours) for the day. For example, if you spent 10 minutes at one point and 5 minutes at another point doing the same thing, then your day's total for that activity is 15 minutes or 0.25 hr. Multiply this total time for a given type of activity by the average kilocalories per

TABLE 6-2 ENERGY BALANCE EXAMPLE: A 32-YEAR-OLD WOMAN WHO WEIGHS 120 LB AND WHO IS 5 FEET AND 4 INCHES TALL

Energy Intake	Energy Output	
Breakfast: 450 kcal	Resting metabolic rate: 1240.5 kcal (this includes the thermic effect of food)	Mifflin-St. Jeor equation
Midmorning snack: 175 kcal	Physical activity: an additional 899.4 kcal	Very active (RMR × 1.725)
Lunch: 500 kcal		
Afternoon snack: 250 kcal		
Dinner: 600 kcal		
Evening snack: 200 kcal		
Total intake: 2175 kcal	Total output: 2140 kcal	Positive energy balance of an extra 35 kcal/day

Although it is not much, an extra 35 kcal/day could lead to weight gain. Approximately 3500 kcal are in each pound of fat mass. Therefore, if the excess is maintained, this woman could gain 1 lb of fat in 100 days despite her very active lifestyle. By decreasing her energy intake by 35 kcal/day or by further increasing her energy expenditure by 35 kcal/day, she would then be in energy balance and weight stable.

hour for that activity (see Table 6-1), and then add them up for the day's total kilocalories. Use the following basic steps to estimate your energy expenditure for a day's activities:

1. Total minutes of an activity ÷ 60 = Hours of that activity
2. Total time (hr) × kcal/hr = Total kcal/day for that activity
3. Total kcal/day of all activities = Total kcal energy expenditure for 1 day from activities

RECOMMENDATIONS FOR DIETARY ENERGY INTAKE

General Life Cycle

Growth Periods

During periods of rapid growth, extra energy per unit of body weight is necessary to build new tissue. During childhood, the most rapid growth occurs during infancy and adolescence, with continuous but slower growth taking place in between these periods (Table 6-3). The

TABLE 6-3 APPROXIMATE CALORIC ALLOWANCES FROM BIRTH TO THE AGE OF 18 YEARS

Age (yr)	kcal/lb
Infants	
0 to 0.5	33.4
0.6 to 1.0	35.6
Children	
1 to 2	36.2
Boys	
3 to 8	32
9 to 13	26.3
14-18	24
Girls	
3 to 8	29.7
9 to 13	23.8
14 to 18	19.3

Data from the Food and Nutrition Board, Institute of Medicine: *Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids*. Washington, DC: National Academies Press; 2005.

rapid growth of the fetus and the placenta as well as other maternal tissues make increased energy intake during pregnancy and lactation highly important.

Adulthood

With full adult growth achieved, energy needs level off to meet requirements for tissue maintenance and usual physical activities.

As the aging process continues, a gradual decline in BMR and physical activity decreases the total energy requirement. There is an average decline in BMR of 1% to 2% per decade (assuming that a constant weight is maintained). A more rapid decline occurs around 40 years of age in men and 50 years of age in women. The accelerated loss of fat-free mass during menopause among women is associated with a large drop in BMR.¹ Therefore, food choices should reflect a decline in caloric density and place greater emphasis on increased nutrient density.

Dietary Reference Intakes

To determine recommendations for energy intake, the Food and Nutrition Board of the Institute of Medicine considered the average energy intake of individuals who were healthy, free living, and maintaining a healthy body weight as determined by body mass index measurements.¹ Table 6-4 gives the average total energy expenditure

TABLE 6-4 MEDIAN HEIGHT, WEIGHT, AND RECOMMENDED ENERGY INTAKE

Age (yr)	Mean Weight (kg [lb])	Mean Height (m [in])	Mean Body Mass Index (kg/m ²)	Basal Energy Expenditure (kcal/day)	Mean Physical Activity Level	Mean Total Energy Expenditure (kcal/day)
Infants						
0 to 0.5	6.9 (15)	0.64 (25)	16.86	—	—	501
0.6 to 1.0	9 (20)	0.72 (28)	17.20	—	—	713
Children						
1 to 2	11 (24)	0.82 (32)	16.19	—	—	869
Males						
3 to 8	20.4 (45)	1.15 (45)	15.42	1035	1.39	1441
9 to 13	35.8 (79)	1.44 (57)	17.20	1320	1.56	2079
14 to 18	58.8 (130)	1.70 (67)	20.37	1729	1.80	3116
19 to 30	71 (156)	1.80 (71)	22.02	1769	1.74	3081
31 to 50	71.4 (157)	1.78 (70)	22.55	1675	1.81	3021
51 to 70	70 (154)	1.74 (69)	22.95	1524	1.63	2469
71+	68.9 (152)	1.74 (69)	22.78	1480	1.52	2238
Females						
3 to 8	22.9 (50)	1.20 (47)	15.63	1004	1.48	1487
9 to 13	36.4 (80)	1.44 (57)	17.38	1186	1.60	1907
14 to 18	54.1 (119)	1.63 (64)	20.42	1361	1.69	2302
19 to 30	59.3 (131)	1.66 (65)	21.42	1361	1.80	2436
31 to 50	58.6 (129)	1.64 (65)	21.64	1322	1.83	2404
51 to 70	59.1 (130)	1.63 (63)	22.18	1226	1.70	2066
71+	54.8 (121)	1.58 (62)	21.75	1183	1.33	1564
Pregnant						
First trimester						+0
Second and third trimester						+300/day
Lactating						
First 12 months						+500/day

Data from Food and Nutrition Board, Institute of Medicine. *Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids*. Washington, DC: National Academies Press; 2005.

throughout life. Note the average height, weight, body mass index, and physical activity level within each age and gender group. Because a balance of energy intake and energy expenditure helps with the maintenance of a healthy weight, the Dietary Reference Intakes for energy intake are equal to the total energy expenditure in kilocalories.

Dietary Guidelines for Americans

The *Dietary Guidelines for Americans* address energy needs by making the following recommendations¹⁴:

- Prevent and/or reduce overweight and obesity through improved eating and physical activity behaviors.
- Control total calorie intake to manage body weight. For people who are overweight or obese, this will mean consuming fewer calories from foods and beverages.

- Increase physical activity and reduce the time spent in sedentary behaviors.
- Maintain appropriate calorie balance during each stage of life: childhood, adolescence, adulthood, pregnancy and breast-feeding, and older age.
- Select an eating pattern that meets nutrient needs over time at an appropriate calorie level.

MyPlate

The MyPlate Web site (www.choosemyplate.gov) can help you to determine an individualized calorie level and corresponding serving sizes from each of the food groups to meet nutrient and energy-density needs on the basis of age, gender, weight, height, and activity level.¹⁵ The site also provides helpful information for maintaining a balance between food intake and energy output through physical activity.

SUMMARY

- Energy is the force or power to do work. In the human energy system, food provides energy. Energy is measured in kilocalories. Energy from food is cycled through the body's internal energy system in balance with the external environment's energy system, which is powered by the sun.
 - The metabolism is the sum of the body processes that are involved in converting food into various forms of energy. These forms of energy include chemical, electrical, mechanical, and thermal energy.
- When food is not available, the body draws on its stored energy, which is in the forms of glycogen, fat, and muscle protein.
- Total body energy requirements are based on the following: (1) basal metabolism needs, which make up the largest portion of energy needs; (2) energy for physical activities; and (3) the thermal effect of food (i.e., digesting food and absorbing and transporting nutrients).
 - Energy requirements vary throughout life.

CRITICAL THINKING QUESTIONS

1. What are the fuel factors of the three energy nutrients? What is the fuel factor of alcohol? What do these figures mean? What is the primary energy nutrient? Give examples of foods that provide each of these nutrients.
2. Define *RMR*. What body tissues contribute most to resting metabolic needs? What factors influence basal energy requirements?
3. What factors influence nonbasal energy needs? Identify each as either voluntary or involuntary.

CHAPTER CHALLENGE QUESTIONS

True-False

Write the correct statement for each statement that is false.

1. *True or False:* Vitamins are energy-yielding nutrients in foods.
2. *True or False:* The RMR takes into account energy that is used for physical activity.
3. *True or False:* The thyroid hormone thyroxine is a controlling factor of body metabolism.
4. *True or False:* Because children are smaller, their energy requirements are less per kilogram (or pound) of body weight than those of adults.
5. *True or False:* The thermic effect of food refers to the energy that is necessary for the digestion of food.
6. *True or False:* Different people doing the same amount of physical activity require the same amount of energy in kilocalories.

Multiple Choice

1. In human nutrition, the kilocalorie is used to
 - a. provide vitamins and water.
 - b. measure energy input and output.
 - c. control energy reactions.
 - d. measure electrical energy.
2. In the following family of four, who has the highest energy needs per unit of body weight?
 - a. The 32-year-old mother
 - b. The 35-year-old father
 - c. The 2-month-old son
 - d. The 70-year-old grandmother
3. An overactive thyroid causes
 - a. decreased energy needs.
 - b. no effect on energy needs.
 - c. increased energy needs.
 - d. decreased protein needs.
4. Which one of the following people is using the most energy?
 - a. A teenager who is playing basketball
 - b. A woman who is walking uphill
 - c. A student who is studying for her final examinations
 - d. A man who is driving a car
5. Which of these foods has the highest energy value per unit of weight?
 - a. Bread
 - b. Meat
 - c. Potato
 - d. Butter
6. A slice of bread contains 2 g of protein, 1 g of fat, and 15 g of carbohydrate in the form of starch. What is its kilocalorie value?
 - a. 17 kcal
 - b. 68 kcal
 - c. 77 kcal
 - d. 92 kcal