thermostat, ensuring an essentially constant, stable body temperature. By influencing the effector organs, the hypothalamus achieves a relatively precise balance between heat production and heat loss. In a healthy individual, the hypothalamic thermostat is set and carefully maintained at 98.6° ± 1.8°F (37° ± 1°C).[31] In situations in which input from thermoreceptors indicates a drop in temperature below the "set" value, mechanisms are activated to conserve heat. Conversely, a rise in temperature will activate mechanisms to dissipate heat. Mechanisms to dissipate heat are particularly important during strenuous exercise. Figure 2.4 summarizes the primary physiological adjustments to exercise or increases in environmental temperature that occur during heat acclimation (physiological adaptations to dissipate and improve tolerance to heat). These responses are activated through hypothalamic control of the effector organs. Input to the effector organs is transmitted through pathways of both the somatic and autonomic nervous systems.[31,32,35,36]

Effector Organs

The effector organs respond to both increases and decreases in temperature. The primary effector systems include vascular, metabolic, skeletal muscle (shivering), and sweating. These effector systems function either to increase or to dissipate body heat.

Conservation and Production of Body Heat

When body temperature is lowered, mechanisms are activated to conserve heat and increase heat production. The following are descriptions of heat conservation and production mechanisms:

- *Vasoconstriction of blood vessels:* The hypothalamus activates sympathetic nerves, an action that results in vasoconstriction of cutaneous vessels throughout the body. This significantly reduces the lumen of the vessels and decreases blood flow near the surface of the skin, where the blood would normally be cooled. Thus, the amount of heat lost to the environment is decreased.
- *Decrease (or absence) of sweat gland activity:* To reduce or to prevent heat loss by evaporation, sweat gland activity is diminished. Sweating is totally abolished with cooling of the hypothalamic thermostat below approximately 98.6°F (37°C).[31]
- *Cutis anserina or piloerection*: Also a response to cooling of the hypothalamus, this heat conservation mechanism is commonly described as "gooseflesh." The term *piloerection* means "hairs standing on end." Although of less significance in humans, this mechanism functions to trap a layer of insulating air near the skin and decrease heat loss in lower mammals with greater hair covering.

The body also responds to decreased temperature with several mechanisms, including shivering and hormonal regulation, designed to produce heat. These mechanisms are activated when body temperature falls below a critical temperature level.[32] The primary motor center for shivering is located in the posterior hypothalamus. This area

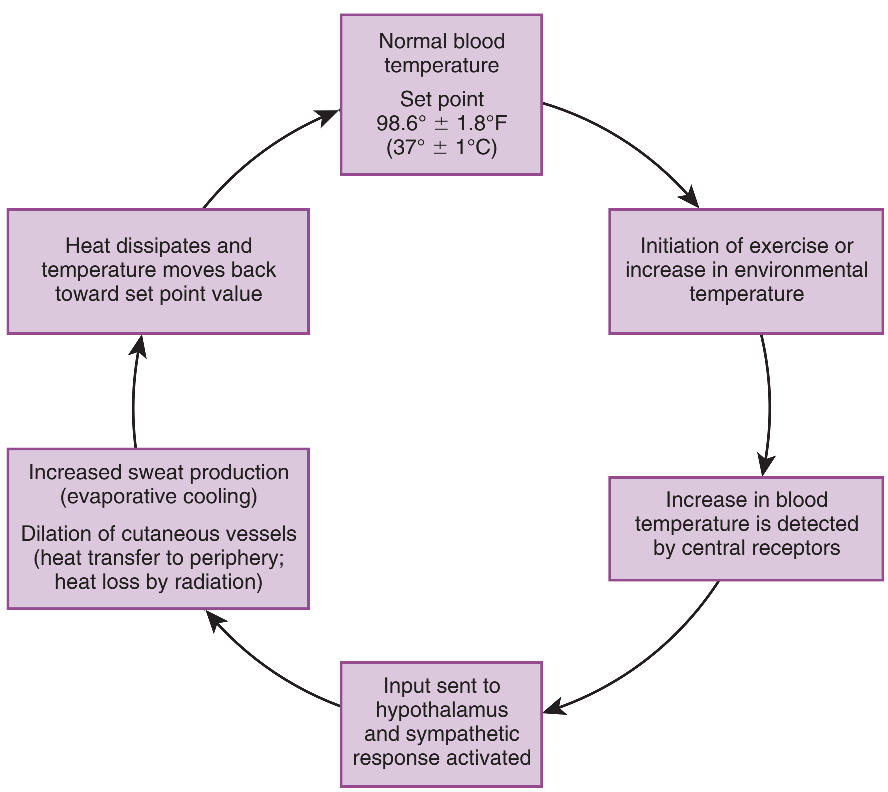

Figure 2.4 Thermoregulatory response during heat acclimation. Increased body temperature activates heat (loss) dissipation to maintain normal body temperature.

is activated by cold signals from the skin and spinal cord. In response to cold, impulses from the hypothalamus activate the efferent somatic nervous system, causing increased tone of skeletal muscles. As the tone gradually increases to a certain threshold level, *shivering* (involuntary muscle contraction) is initiated, and heat is produced. This shivering reflex can be at least partially suppressed through conscious cortical control and voluntary muscle activity.[37]

The function of hormonal influence in thermal regulation is to increase cellular metabolism, which subsequently increases body heat. Increased metabolism occurs through circulation of two hormones from the adrenal medulla: *norepinephrine* and *epinephrine*. This is called *chemical thermogenesis*. Circulating levels of these hormones, however, are of greater significance in maintaining body temperature in infants than in adults. Heat production by these hormones can be increased in an infant by as much as 100%, as opposed to 10% to 15% in an adult.[32]

A second form of hormonal regulation involves increased output of *thyroxine* by the thyroid gland. Thyroxine increases the rate of cellular metabolism throughout the body. This response, however, occurs only as a result of prolonged cooling, and heat production is not immediate.[31] The thyroid gland requires several weeks to hypertrophy before increased demands for thyroxine can be achieved.

Loss of Body Heat

Excess heat is dissipated from the body through four primary methods: radiation, conduction, convection, and evaporation.

- *Radiation:* The transfer of heat by electromagnetic waves from one object to another is accomplished by radiation. This heat transfer occurs through the air between objects that are not in direct contact. Heat is lost to surrounding objects that are colder than the body (e.g., a wall or surrounding objects in the room).
- *Conduction:* The transfer of heat from one object to another through a liquid, solid, or gas takes place by conduction. This type of heat transfer requires direct molecular contact between two objects, as when a person is sitting on a cold surface, or when heat is lost in a cool swimming pool. Heat is also lost by conduction to air.
- *Convection:* The transfer of heat by movement of air or liquid (water) is achieved by convection. This form of heat loss is accomplished secondary to conduction. Once the heat is conducted to the air, the air is then moved away from the body by convection currents. Use of a fan or a cool breeze provides convection currents. Heat loss by convection is most effective when the air or liquid surrounding the body is continually moved away and replaced.
- *Evaporation:* Dissipation of body heat by the conversion of a liquid to a vapor occurs by evaporation. This form of heat loss occurs on a continual basis through the respiratory tract and through perspiration from the skin. Evaporation provides the major mechanism of heat loss during heavy exercise. Profuse sweating provides a significant cooling effect on the skin as it evaporates. In addition, this cooling of the skin functions to further cool the blood as it is shunted from internal structures to cutaneous areas. Figure 2.5 illustrates the mechanisms of heat loss from the body.

Abnormalities in Body Temperature

Increased Body Temperature

Pyrexia is the elevation of normal body temperature, more commonly referred to as fever. Fever is part of the body's natural defense against infectious disease (invading pathogens). Increasing internal temperatures creates an environment less favorable for viruses and bacteria to replicate. Fever occurs when the "set" value of the hypothalamic thermostat is triggered to rise by circulating pyrogens (fever-producing substances) secreted primarily

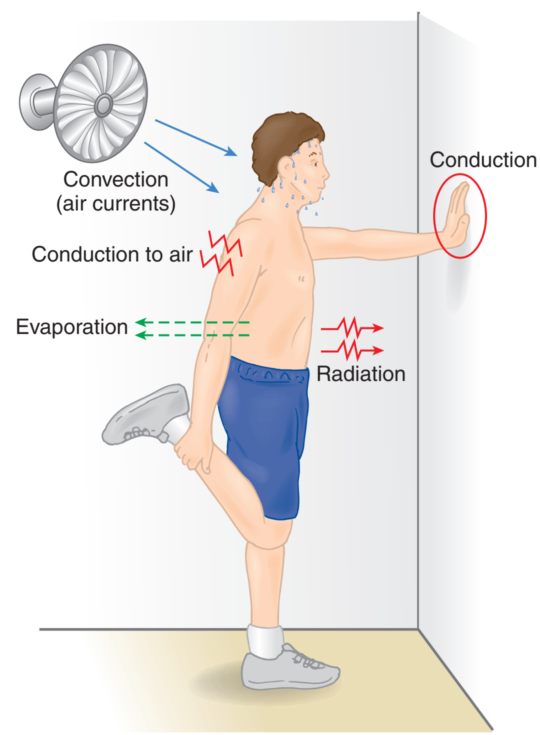

Figure 2.5 Mechanisms of heat loss from body. *Conduction* is the transfer of heat by direct contact between two objects (hand on wall); *radiation* occurs through electromagnetic waves between objects not in direct contact with each other (subject's body and wall); heat loss by *convection* is accomplished via air currents (wall fan) after the heat is conducted to air; *evaporation* converts liquid (perspiration) to a vapor.

from toxic bacteria, viruses, or injured body tissue. The effects of these pyrogens result in fever during illness. As a result of the new, higher thermostat value, the body responds by activating its heat conservation and production mechanisms. These mechanisms raise body temperature to the new, higher value over a period of several hours. Thus a fever, or febrile state, is produced.

The clinical signs and symptoms of a fever vary with the level of disturbance of the thermoregulatory center and with the phase of the fever. These signs and symptoms may include general malaise, headache, increased pulse and respiratory rate, chills, piloerection, shivering, loss of appetite (anorexia), pale skin that later becomes flushed and hot to the touch, nausea, irritability, restlessness, constipation, sweating, thirst, coated tongue, decreased urinary output, weakness, and insomnia.[23,38]

The *prodromal* period of fever occurs just prior to onset; nonspecific symptoms may be experienced, such as a slight headache, muscle aches, general malaise, or loss of appetite. Three phases (stages) have been identified to describe a fever:

- *Phase 1—Onset:* This is the period from either gradual or sudden rise until the maximum temperature is reached; symptoms include chills, shivering, and pale appearance of skin. As body temperature is raised (e.g., in response to infection), cutaneous vasoconstriction moves blood to the interior of the body to retain heat. The skin becomes cool, and shivering is initiated to produce more heat. Attempts to preserve and produce heat continue until a new, higher temperature is reached.
- *Phase 2—Course:* This is the point of highest elevation of the fever. Once the new higher temperature is reached, it remains relatively stable (fever is sustained); heat production and heat loss are equal and shivering stops; skin may be warm and appear flushed.
- *Phase 3—Termination (defervescence* or *crisis):* This is the period during which the fever subsides and temperatures lower and move toward normal. Cutaneous vasodilation occurs, and sweating is initiated to help cool the body.

Several types of fevers present unique characteristics that are named based on their distinguishing clinical feature: *continuous, intermittent, relapsing,* or *remittent* (Box 2.2).

An unusually high fever above 106.7°F (41.5°C) is called *hyperpyrexia*. Hyperthermia is an uncontrolled increase in body temperature with an unchanged setting of the thermoregulatory center. Excessively high body temperatures are caused by an inability of the thermoregulatory system to lose heat fast enough to balance excessive heat production or high environmental temperatures. Examples of hyperthermia include heat exhaustion and heat stroke. *Heat exhaustion* is associated with exercise and physical exertion in high environmental temperatures where the cardiovascular system cannot meet the demands of blood flow to the skin (thermoregulation) and to the muscles (metabolic exercise requirements). Symptoms include profuse sweating, fatigue, faintness, dizziness, weak and rapid pulse, nausea, headache, and vomiting. Treatment typically includes stopping physical activity, moving to a cooler environment, drinking fluid, removing tight clothing, assuming a supine position with legs elevated, and applying available cooling methods such as fans or ice packs or towels. *Heat stroke* is a more severe form of hyperthermia in which the thermoregulatory system essentially fails. It can be life-threatening and requires immediate emergency medical attention to rapidly reduce body temperature (ice water immersion, ice packs). Symptoms include rapid and shallow breathing; mental status changes (confusion, delirium); strong, rapid pulse; lack of sweating; faintness; throbbing headache; and eventually loss of consciousness or death.[8,32,40-43]

Decreased Body Temperature

Exposure to extreme cold produces a lowered body temperature called *hypothermia*. With prolonged exposure to cold, there is a decrease in metabolic rate, and body temperature gradually falls. As cooling of the brain occurs, there is a depression of the thermoregulatory center. The function of the thermoregulatory center becomes seriously impaired when body temperature falls

Box 2.2 Common Types of Fever

Continuous (also known as *constant* or *sustained*): Body temperature is constantly elevated above normal throughout day but does not fluctuate by more than 1.8°F (1°C) in 24 hours; seen in uncomplicated minor infection, urinary tract infection, lobar pneumonia, typhoid (foodborne illness), infective endocarditis, and typhus (flea-borne disease).
Intermittent: Body temperature alternates between periods of fever for some hours of the day with return to normal temperatures for the remaining hours; seen in malaria and septicemia.
Relapsing (also known as *recurrent* or *periodic*): Periods of fever are interspersed with normal temperatures; each last at least one day; seen in non-infectious inflammatory diseases such as rheumatoid arthritis and Crohn's disease, recurrent infections, malignancy (neoplastic fever), and infections caused by certain species of Borrelia spirochetes (ticks and lice).[39]
Remittent: Elevated body temperature throughout day that fluctuates more than 3.6°F (2°C) within a 24-hour period but never returns to normal; seen in infective endocarditis and typhoid infection.

below approximately 94°F (34.4°C) and is completely lost with temperatures below 85°F (29.4°C).[33] Therefore, the body's heat regulatory and protection mechanism is lost. Symptoms of hypothermia include decreased HR and RR, cold and pale skin, cyanosis, decreased cutaneous sensation, depression of mental and muscular responses, and drowsiness, which may eventually lead to coma. If hypothermia is left untreated, the progression of these symptoms may lead to death.

Factors Influencing Body Temperature

A statistical average or normal temperature of 98.6°F (37°C) taken orally has been established for body temperature in an adult population. However, a range of values is more representative of normal body temperature because certain everyday circumstances (e.g., time of day) or activities (e.g., exercise) influence the body's temperature. In addition, some individuals typically run a *slightly higher* or *lower* body temperature than the statistical average. Therefore, deviations from the average will be apparent from individual to individual, as well as between measures taken from the same person under varying circumstances.

Time of Day

The term *circadian rhythm* describes a 24-hour cycle of normal variations in body temperature. Certain predictable and regular changes in temperature occur on a daily basis. Body temperature tends to be lowest between 4:00 and 6:00 a.m. and highest between 4:00 and 8:00 p.m. Digestive processes and the level of skeletal muscle activity significantly influence these regular changes in body temperature. For individuals who work at night, this pattern is usually inverted.[31,33]

Age

Compared with adults, infants demonstrate a higher normal temperature owing to the immaturity of the thermoregulatory system. Infants are particularly susceptible to environmental temperature changes, and their body temperature will fluctuate accordingly. Young children also average higher normal temperatures because of the heat production associated with increased metabolic rate and high physical activity levels. Elderly populations tend to demonstrate lower than average body temperatures, owing to a variety of factors, including lower metabolic rates, decreased subcutaneous tissue mass (which normally insulates the body against heat loss), decreased physical activity levels, and inadequate diet.

Emotions/Stress

Stimulation of the sympathetic nervous system causes increased production of epinephrine and norepinephrine with a subsequent increase in metabolic rate.

Exercise

The effects of exercise on body temperature are an important consideration for physical therapists. Strenuous exercise significantly increases body temperature because of an increase in metabolic rate. Active muscle contractions are an important and potent source of heat production. During exercise, body temperature increases are proportional to the relative intensity of the workload. Vigorous exercise can increase the metabolic rate by as much as 20 to 25 times that of the basal level.[31]

Menstrual Cycle

Increased levels of progesterone during ovulation cause body temperature to rise 0.5°F to 0.9°F (0.3°C to 0.5°C). This slight elevation is maintained until just prior to the initiation of menstruation, at which time it returns to normal levels.

Pregnancy

Because of increased metabolic activity, body temperature remains elevated by approximately 0.9°F (0.5°C). Temperature returns to normal after parturition.

External Environment

Generally, warm weather tends to increase body temperature, and cold weather decreases body temperature. Environmental conditions influence the body's ability to maintain constant temperatures. For example, in hot, humid environments, the effectiveness of evaporative cooling is severely diminished because the air is already heavily moisture laden. Other forms of heat dissipation are also dependent on environmental factors such as movement of air currents (convection). Clothing also can be an important external consideration because it can function either to conserve or to facilitate release of body heat. The amount and type of clothing is important. To dissipate heat, absorbent, loose-fitting, light-colored clothing is most effective. To conserve heat, several layers of lightweight clothing to trap air and to insulate the body are recommended.

Measurement Site

Body temperatures vary among body parts. Rectal and tympanic (ear) membrane temperatures are from 0.5°F to 0.9°F (0.3°C to 0.5°C) higher than oral temperatures; axillary temperatures are approximately 1.1°F (0.6°C) lower than oral temperatures. Oral temperature in a healthy adult population is generally considered to be 98.6°F (37°C), and for rectal and tympanic membrane temperatures the value is 99.5°F (37.5°C). Being an external measure, the axillary value is somewhat lower at 97.6°F (36.5°C).

Ingestion of Warm or Cold Foods

Oral temperatures will be affected by oral intake, including smoking. Patients should refrain from smoking or eating for at least 15 minutes (preferably 30 minutes) prior to an oral temperature reading.

Figure 2.6 presents a comparison of Fahrenheit and centigrade temperature values with ranges of normal and altered body temperature. If a situation occurs that requires changing a temperature reading from one scale to the other, a conversion formula can be used. To convert centigrade into Fahrenheit, multiply the centigrade value by 9/5 and add 32 (F = [9/5 × C°] + 32°). To change from Fahrenheit into centigrade, subtract 32 from the Fahrenheit value and multiply by 5/9 (C = [F – 32°] × 5/9).

Types of Thermometers

Glass Mercury Thermometers

For many years, temperatures had been taken using a glass thermometer, which consists of a glass tube with a bulbous tip filled with mercury. Once the bulb is in contact with body heat, the mercury expands and rises in the glass column to register body temperature. A narrowing of the base prevented reflux of mercury down the tube. The device had to be shaken vigorously to return the mercury to the bulb before the next use. Owing to the highly poisonous nature of mercury and breakability of glass, automated thermometers have largely replaced their use in patient care settings. The World Health Organization (WHO),[44] the U.S. Environmental Protection Agency,[45] and the National Institute of Standards and Technology[46] warn against using mercury thermometers and encourage replacement with non-mercury-containing devices whenever possible. Some states have laws restricting the manufacture and sale of mercury thermometers. Many areas also offer collection/exchange programs for mercury-containing devices.[45]

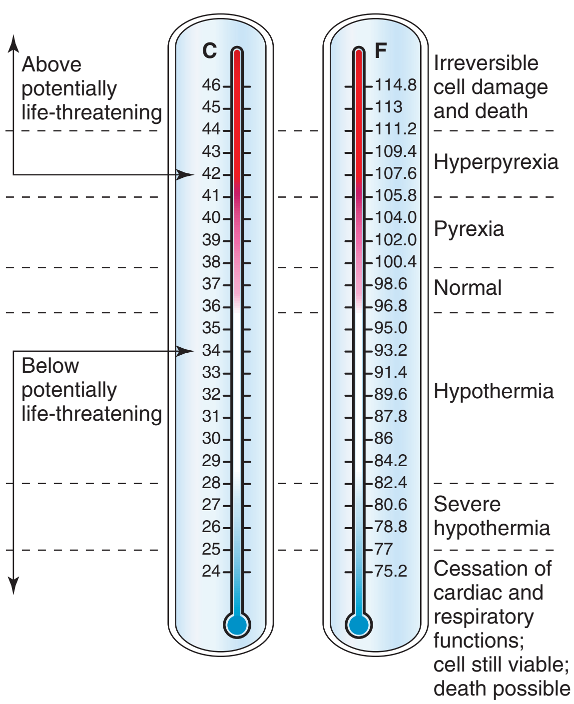

Figure 2.6 Comparison of Fahrenheit and centigrade scales indicating ranges of normal and altered body temperature. *(Adapted from Wilkinson, et al,[8, p. 423] with permission.)*

> **Clinical Note:** Glass thermometers containing mercury may still be found in the home care setting. Their continued use should be discouraged whenever possible. Replacement with an automated thermometer should be encouraged.

Automated Thermometers

Automated thermometers are widely used in patient care settings. They provide a rapid (several seconds), highly accurate measure of body temperature, displayed digitally. Standard clinical automated thermometers consist of a portable battery-operated unit, an attached probe, and plastic disposable probe covers (Fig. 2.7A). An important advantage of these thermometers is the low chance of cross-infection, so long as the probe covers are used only once. Other automated devices are designed to monitor more than one vital sign and interface directly with the electronic health record (EHR). By scanning the patient's hospital identification bracelet, two-way wireless communication links ID numbers to patient names for positive identification at the bedside. The device reduces time required and potential errors of manual documentation as data are relayed directly to the EHR. Data (e.g., respiratory rate, pain level) may also be entered manually (Fig. 2.7B).

Oral Thermometers

Handheld automated oral (digital "stick") thermometers are readily available commercially. These units are typically about 5 inches in length with a tapered design (Fig. 2.8). One end of the device has a narrow tip and serves as the probe; in some models the tip is flexible. The opposite end is broad and houses the battery. These thermometers also provide a flashed, digital display of body temperature; most models have memory capabilities. Typically, these devices are used for a single patient; however, they can also be used with disposable probe covers.

Temporal Artery Thermometer

Noninvasive temporal artery thermometers measure body temperature by sliding a probe, held flat against the skin,[47] in a straight line from the center of the forehead, across the temporal artery area to the hairline (Fig. 2.9). The probe is then lifted from the forehead, centered on the mastoid process behind the ear, and slid down to the soft depression behind the earlobe (this helps eliminate the possibility of a false low