Humans are warm-blooded mammals. As such, we must maintain a constant internal body temperature for our biochemical and physiological processes to function normally. This special JEMS’ article offers a comprehensive summary of the body’s critical heating and cooling mechanisms.

The temperature of the body’s deep tissues, called the core temperature, remains almost exactly constant. In fact, it varies by only 1° F (0.6° C), except when a person develops a febrile illness. An unclothed human can maintain a constant core temperature even when exposed to dry air as cold as 55° F (12.8° C) or as warm as 130° F (54.4° C).

No normal core temperature exists for humans. However, the normal range is from a low of 97° F (36.1° C) to a high of 99.5° F (37.5° C). The average normal core temperature is anywhere from 98°-98.6° F (36.7°-37° C) when measured orally (1° F higher when measured rectally). Basically, a normal core temperature is what’s normal for the individual in question.

**Physiology**

Body temperature at any given time is a function of heat loss and heat production. That is, in order to warm the body, heat production is increased, heat loss is reduced, or a combination of both occurs. To cool the body, heat production is decreased, heat loss is enhanced, or a combination of both occurs.

Heat is the kinetic energy of molecules in motion. The greater the molecular motion, the greater the heat. When the temperature of an object reaches absolute zero (-460° F or -273° C), molecular motion totally stops. Although an object’s temperature can approach absolute zero, it can never actually reach it due to factors described by the Third Law of Thermodynamics. There’s always some heat, no matter how small, present in the environment. Even in outer space, the lowest temperature that can be reached is -454° F or -270° C.

The difference in temperature between two objects is called the thermal gradient. The warmer object transfers heat to the cooler object until a steady state, called thermal equilibrium.
occurs. Example: If you drop an ice cube into a glass of room-temperature water, a thermal gradient exists. Because the water molecules have more kinetic energy than the ice molecules do, heat transfers from the water to the ice until both are at the same temperature (thermal equilibrium).

Heat production

Heat production is a common byproduct of many of the body's normally occurring biochemical processes. Most heat production occurs within the deep organs—especially the liver, brain and heart. During physical activity, the skeletal muscles produce heat that is subsequently transferred to the deep organs and tissues via the circulatory system. The circulatory system plays a major role in the transfer of heat throughout the body.

The rate of heat production is referred to as the body's metabolic rate. While the body is at rest, this rate of heat production is called the basal metabolic rate.

In addition to heat production from normal metabolic activities, heat can also result from enhanced metabolic processes—most often occurring in muscles.

When necessary, the body can activate specialized biochemical pathways known as futile cycles. Unlike the other biochemical processes of the body, a futile cycle uses energy to generate heat as the principal effect (chemical thermogenesis). This augments the heat generated during the normal metabolic processes.

The contracting and relaxing of muscle fibers, commonly called shivering, also serves to produce heat when needed. Shivering augments the body's other heat-producing mechanisms and occurs as the core temperature falls. It's a medium-to-late response to a falling core temperature.

Heat loss

When the body needs to be cooled, heat is transferred from the deeper structures, such as the liver, heart and brain, to the skin. Blood vessels within the skin dilate, allowing the transfer of heat to the skin. Once there, the heat is transferred to the surrounding air. The rate of heat loss is determined by how rapidly heat can be conducted from deep tissues to the skin and then transferred to the environment.

Although the skin can transfer heat to the environment, it's also important in retaining heat. The skin and the fatty subcutaneous tissues located immediately under the dermis serve as an effective body heat insulator. In fact, the fatty subcutaneous tissues conduct heat significantly less efficiently than other body tissues. Consequently, the skin serves as an insulator, allowing the body to maintain a normal core temperature even when the temperature of the skin surface approaches that of the surrounding environment.

Four methods by which heat is lost from the skin are radiation, conduction, convection and evaporation.

Radiation

All objects in the environment (e.g., walls, trees and furniture) not at absolute zero radiate heat. Infants have a greater surface-area-to-weight ratio and immature temperature-regulating physiology and, thus, experience more rapid increases and decreases in body temperature.

Conduction

Conduction is the loss of body heat by direct contact of the skin with another cooler, solid object. As previously mentioned, heat flows from higher temperature matter to lower temperature matter. However, only about 3% of body heat is lost through this mechanism. Heat is also conducted to the air (provided the ambient air temperature is lower than the body temperature). Loss of heat by conduction to air represents approximately 15% of total body heat loss.

Convection

Heat loss from air currents passing over the body is called convection. Heat, however, must first be conduct-
ed to the air before being carried away by convection currents. Some convection almost always occurs because air adjacent to the skin becomes heated by the body. When heated, the air rises, allowing cooler air to take its place, thus repeating the cycle. This is an ongoing process.

Heat is lost to the environment. When the environmental air is heated, it rises, and cooler air takes its place. Then, the whole process is repeated.

Even without gross air movement, an unclothed person loses approximately 15% of their body heat through conduction of heat to the air and subsequent heat loss through convection.

Environmental temperature and wind velocity affect cooling. The greater the difference between the body temperature and the environmental temperature and the greater the wind velocity, the greater the cooling effect. This is the basis for the development of wind chill factor (WCF) tables (Figure 1, p. 41).

Evaporation
Evaporation is the change of a liquid to a vapor. Evaporative heat loss occurs as water evaporates from the skin. When water evaporates from the skin, heat is lost along with the water. Even when a person isn’t sweating, water still evaporates from the skin. This loss is typically called the insensible loss. In addition, a great deal of heat loss occurs through evaporation of fluids in the lungs. Water normally evaporates from the skin and lungs at
When the relative humidity of an environment increases, evaporation becomes less effective. This important consideration is the basis for the development of the heat index used in the warmer climates and during summer months (Figure 2, above).

The heat index (measured in degrees Fahrenheit) is an accurate measure of how it really feels when relative humidity is added to the actual air temperature. The greater the air temperature and relative humidity, the less effective the body’s cooling mechanisms.

**Control of body temperature**

Body temperature is controlled almost entirely by temperature-regulating centers in the hypothalamus. Near the base of the brain, the hypothalamus functions as the body’s thermostat and strives to maintain a constant temperature by adjusting heat production and loss as needed.

Body temperature control is achieved through both nervous and hormonal mechanisms. Nervous mechanisms react rapidly while hormonal mechanisms take considerably longer. The principle nervous mechanism involves the autonomic nervous system—particularly the sympathetic component.

Hormonal effects are primarily regulated through the release of hormones via the hypothalamus. These hormones stimulate the anterior pituitary gland to release a thyroid-stimulating hormone, which, in turn, stimulates the thyroid gland. Thyroxine, a principle thyroid hormone, increases the rate of cellular metabolism and, subsequently, heat production. However, it can take days to weeks before a demonstrable effect can be detected.
Temperature receptors located throughout the body detect even subtle changes in body temperature. The skin contains both heat and cold detectors, with cold receptors predominating. Heat and cold temperature receptors also exist in the body’s deeper tissues, specifically the spinal cord, abdominal viscera and in or around the great veins of the abdomen and thorax. Like the skin, they mainly detect cold rather than heat.

When the hypothalamic temperature control centers detect that body temperature is either too hot or too cold, they initiate a series of physiological maneuvers to raise or lower the body temperature as needed.

**Mechanisms that decrease body temperature**

The body uses three physiological mechanisms to reduce body temperature when it becomes too hot:

1. **Vasodilation.** Blood vessels in the skin dilate due to inhibition of sympathetic nervous system function by the hypothalamus. This results in the almost immediate transfer of heat to the skin and, subsequently, to the environment. Clinically, this appears as red, warm skin.

2. **Sweating.** An increase in body temperature results in sweat production. When stimulated by the hypothalamus via the sympathetic nervous system, specialized glands (sweat glands) within the skin secrete a fluid on the skin surface. The fluid is similar to blood plasma—but without the plasma proteins. Clinically, this manifests as perspiration.

3. **Decreasing heat production.** Body cooling also occurs via inhibition of mechanisms that cause excess heat production: namely shivering and chemical thermogenesis. This occurs somewhat slowly.
Mechanisms that increase body temperature

When body temperature is too cold, various mechanisms are instituted to return the body temperature to normal:

1. Vasconstriction of blood vessels in the skin. In order to conserve heat, blood vessels to the skin constrict through activation of components of the sympathetic nervous system. Clinically, this results in pale, cool skin.

2. Piloerection causes what most people refer to as "goose bumps." This process, which causes hairs in the skin to stand erect, occurs through sympathetic stimulation of small muscles (arrector pili) attached to the hair fibers within the hair follicle. The process traps a layer of insulating air next to the skin in order to diminish heat loss. Piloerection is an evolutionary remnant from a time in our species' distant past in which we were covered with hair. Today, it's much less effective in humans, but remains important in lower animals.

3. Increase in heat production. Sympathetic stimulation of heat-generating processes and the release of thyroxine from the thyroid gland can increase heat production. Mechanisms include activation of chemical thermogenesis pathways and shivering.

Populations at risk

Several population groups are at risk for the development of temperature-regulation problems. These include those at the extremes of age, the ill, the injured and those with drug or alcohol abuse problems. Both physiological and pathophysiological factors can predispose a person to develop a heat-related illness.

People at increased risk from heat stress include infants. An infant's greater surface-area-to-weight ratio and immature temperature-regulating physiology cause them to experience more rapid increases and decreases in body temperature than healthy adults would experience in the same environment. Also, infants can't respond to excess heat by removing themselves from the stressful environment or pursuing other behavioral defenses, such as seeking shade or air-conditioning.

The elderly also tend to have problems with temperature regulation. Impaired circulation, such as that which occurs with peripheral vascular disease, interferes with heat transfer from one part of the body to another. Medical conditions, such as diabetes mellitus and stroke, can impair the body's ability to detect temperature changes, especially in the skin. Also, the elderly tend to have fewer insulating fat stores, which causes them to lose heat more readily than their younger counterparts.

From a social standpoint, the elderly may not have the financial resources to keep their homes cool in the summer and warm in the winter. Likewise, they may not eat properly because they can't purchase needed food or aren't able to prepare food for themselves. Both malnutrition and dehydration contribute to temperature-regulation problems.

Both illness and trauma can predispose a patient to the development of temperature-regulation disorders. Any condition that affects the central nervous system also affects regulation of temperature.
system (CNS) (which controls temperature regulation), the circulatory system (which transfers heat throughout the body) or the integrity of the skin (which decreases the body’s insulating effects) can lead to a temperature-regulation disorder.

Many drugs are associated with temperature-regulation problems. Alcohol, commonly associated with both hypothermia and hyperthermia, impairs the CNS and can inhibit normal physiological responses. It’s also a diuretic and can lead to dehydration. In warm environments, drinking alcohol products instead of water can lead to the development of dehydration and electrolyte disorders.

Drugs associated with hyperthermia include stimulants, such as cocaine, amphetamines and MDMA (ecstasy). Drugs associated with hypothermia include CNS depressants (barbiturates, narcotics, benzodiazepines) and certain blood pressure medications (vasodilators).

Abnormalities of temperature regulation

Three recognized clinical conditions result from abnormalities in body-temperature regulation:

• Fever;
• Hyperthermia; and
• Hypothermia.

Although hypothermia and hyperthermia are abnormal, fever is an important physiological mechanism that aids the body in fighting infection.

Fever

Fever, an increase in body temperature above the normal range, is caused by the resetting of the body’s temperature set-point to above normal and can be caused by abnormalities in the brain, dehydration or toxic substances within the body that affect temperature-regulating centers.

Several substances, usually derived from proteins, can cause the temperature set-point in the hypothalamus to rise. These substances, referred to as pyrogens, are often released from toxic bacteria, viruses or degenerating body tissues. An increase in the temperature set-point activates the various heat-generating mechanisms previously described, and heat-loss mechanisms are inhibited.

It’s believed that increasing the body’s internal temperature makes it a less hospitable host to an invading infection and can play a role in fighting that infection.

Fever can also result from problems within the brain’s structure. Some of the more common noninfectious causes of fever are brain tumors and hemorrhages that compress the hypothalamus. It’s not uncommon for fever to develop following neurosurgical procedures during which the neurosurgeon either accidentally or intentionally manipulated the tissues around the hypothalamus.

Fever results in several signs and symptoms, including chills, flushing of the skin and, occasionally, chattering of the teeth. When the temperature set-point sud-
Patients with mild hypothermia should receive rewarming with active external methods (blankets, heat packs and, occasionally, warm water immersion).

This occurs because the blood temperature is now lower than the body's temperature set-point. In addition, the skin becomes cool to the touch because vasoconstriction is shunting blood away from the skin to the core of the body. Chills and shivering may continue until the body temperature reaches its new set-point.

Once the substance (pyrogen) causing the increased body temperature set-point is removed by various components of the body's immune system, the set-point of the hypothalamus returns to normal. Cooling mechanisms are activated, resulting in sweating and the development of warm, red skin due to vasodilation. This sudden change of events is known as the crisis or flush. Once this occurs, body temperature begins to fall. The administration of medications that reduce fever (antipyretics) can often cause the flush when they take effect.

Fever: Clinical considerations

A fever can be uncomfortable, especially in adults because it takes longer to cool and warm the body due to their size and mass. However, it's important to remember that fever is a normal component of the body's defense mechanism against infection. Although uncomfortable, fever is rarely harmful.

In addition to the fever, the pyrogens that cause an increase in body temperature can also decrease appetite and increase sleepiness. On the positive side, the pyrogens appear to enhance the body's immune system response. Although most people consider fever an unpleasant side effect of illness, many cultures believe fever is a disease entity in and of itself.

Fever is clinically defined as any oral temperature above 100°F (37.8°C). The reported upper limit of fever in humans is 105.8–107.6°F (41.5–42°C). Although it has long been taught that a temperature greater than 106°F (41.1°C) can cause brain damage, no human studies supporting this belief have been published.

One concern of fever in children is the development of febrile seizures. The incidence of febrile seizures in the United States is fairly low (2–5%). They tend to affect younger children (six to 36 months of age), with boys affected more frequently than girls. Febrile seizures often occur with the first fever of an illness and tend to last for less than 15 minutes. Studies have shown that susceptibility to febrile seizures tends to run in families. As many as one-third of children who suffer a febrile seizure will have a recurrent seizure at some point in their lives.

It had been taught that febrile seizures were due to the rate at which a fever developed rather than its severity or length. However, recent studies have failed to show the rate of temperature rise has any bearing on the development of febrile seizures. The bottom line: We really don't know what causes febrile seizures. Although extremely disconcerting to the parents, febrile seizures are more scary than dangerous.

Most febrile seizures resolve spontaneously without treatment. Additionally, it's important to point out that not all seizures associated with fever are febrile seizures. Other more sinister problems, such as meningitis and sepsis, can also cause a seizure. A controversy has developed regarding whether or not prehospital personnel should treat fever in the field. Antipyretic medications, such as ibuprofen (Motrin) and acetaminophen (Tylenol), are effective in the treatment of fever. A potential benefit of prehospital antipyretic therapy is that it can make a patient considerably more comfortable.

Potential problems can occur when the response to prehospital antipyretic therapy is rapid and effective. Some parents may elect not to have the child definitively treated.

Another perceived problem relates to local physician preference. Some physicians prefer to document a fever and see the child in the febrile state. One additional potential problem with prehospital antipyretic therapy is that emergent treatment of fever may reinforce unfounded fears that fever is bad. Regardless, prehospital treatment of fever should be addressed in local protocols, based on the direction of the system medical director.

Hypothermia & heat-related illnesses

Hypothermia is an abnormal elevation in body temperature. Unlike fever, it's not a normal physiologic response. Factors leading to the development of hyperthermia can either be environmental or result from problems within the body.

Changes in the environment are a common reason people develop hyperthermia and heat-related illnesses. Any increase in the environmental temperature decreases the rate at which the body can cool itself. Other factors, such as increased humidity and still air, can further decrease the effectiveness of the body's cooling mechanisms.

Heat waves occur regularly in the United States. However, in areas of the country where excessive heat is uncommon, heat waves can be particularly devastating. People living in these areas often don't have access to air-conditioning or facilities where they can seek respite from the heat. In addition, they haven't had time to
adjust to the sudden change in temperature. Factors like these caused more than 600 deaths due to heatstroke and other heat-related illness during the 1995 Chicago heat wave.7

Any factor inhibiting heat loss or causing heat production predisposes a person to hyperthermia. These include excessive exercise and improper hydration. Over time, they adjust to a warm environment through a process called acclimatization, which enhances heat tolerance.

Hyperthermia can result in several clinical conditions. These include:
- Heat cramps;
- Heat tetany;
- Heat exhaustion;
- Heat syncope; and
- Heatstroke.

**Heat cramps**
Heat cramps, brief, painful muscle cramps, are a frequent complication of heat exhaustion. They’re common in athletes and workers exposed to unusually hot environments. Salt depletion and other electrolyte problems are often associated with heat cramps. They’re self-limited, and treatment is symptomatic.

**Heat tetany**
In extremely warm environments, people tend to hyperventilate as an additional cooling mechanism (similar to panting in a dog) and as a result of metabolic acidosis. People who suddenly start to hyperventilate develop respiratory alkalosis (lowered pH) and tend to develop spasms of their fingers and toes (carpopedal spasms). This problem, called heat tetany, is self-limited and disappears when the hyperventilation ceases—often when the patient is moved to a cooler environment.

**Heat exhaustion**
A more severe heat-related illness is heat exhaustion. It results from cardiovascular strain as the body strives to maintain a normal temperature. Heat exhaustion usually develops and continues over several days. It continues as long as the body has the ability to sweat and maintain adequate hydration. As soon as the body loses the ability to sweat, heatstroke develops rapidly.

Most commonly, heat exhaustion occurs at body temperatures between 102.9° and 104° F (39.4°–40° C). However, this is a rather unreliable finding, and EMS personnel should rely on the physical assessment to make the determination as to whether a patient is suffering from heat exhaustion. Firefighters dressed in heavy gear or encapsulated suits and subjected to high heat are often victims of heat exhaustion. Establish a rehab sector early at major incidents to avoid heat-related problems.

The symptoms of heat exhaustion include dizziness, headache, fatigue, irritability, anxiety, chills, nausea, vomiting and heat cramps. On physical examination, tachycardia, hyperventilation, hypotension and, in some
cases, syncope manifest.
Treat heat exhaustion by removing the patient from the warm environment, providing rest and replacing fluids and electrolytes.

**Heat syncope**
Heat syncope is a form of postural hypotension resulting from massive peripheral vasodilation, which occurs when the body attempts to rapidly cool itself, and dehydration. It usually occurs in people not yet acclimatized to the heat and during the early stages of heat exposure. Treatment is symptomatic and similar to that provided for any syncope victim.

**Heatstroke**
Heatstroke is a life-threatening emergency, defined as the following triad of signs and symptoms:
- Core temperature greater than 104.9°F (40.5°C);
- Loss of sweating (anhidrosis); and
- Altered mental status (CNS dysfunction).

It's important to note that anhidrosis may not be present for various reasons. However, assume that any patient with the combination of an elevated temperature and altered mental status has heatstroke until proven otherwise.

Heatstroke represents a total failure of temperature regulation. That is, the body’s cooling mechanisms have collectively failed. Heatstroke can be rapidly fatal, and emergency treatment measures should be initiated as soon as possible. These include CPR, fluid and electrolyte administration and immediate cooling.

The goal of cooling is to get the body temperature to 104°F (40°C). The preferred method of cooling the heatstroke victim is immersion in a cold water or ice water bath. Care must be taken to remove the patient from the bath as soon as the target temperature is reached. Cooling the patient below the target temperature can cause shivering and peripheral vasoconstriction that can result in a rebound rise in body temperature. Evaporative cooling, such as cool wet sheets and ice packs, may be utilized, but generally proves less effective than immersion therapy.

**Hypothermia**
Hypothermia is defined as a core temperature of less than 95°F (35°C) and is usually classified as mild or severe. Mild hypothermia is defined as a core temperature of less than 95°F (35°C) and greater than 90°F (32°C). Severe hypothermia is defined as a core temperature less than 90°F (32°C).

The body’s response to hypothermia varies significantly between individuals. Outdoor accidents and injury are associated with a risk of hypothermia that can be exacerbated by the use of cold IV fluids and prolonged exposure of the patient awaiting examination. Hemorrhagic shock secondary to trauma can intensify and worsen hypothermia.

As hypothermia develops, an exi-
A patient with heat exhaustion may present with dizziness, headache, fatigue, irritability, anxiety, chills, nausea, vomiting and/or heat cramps.

Treatment depends on the severity of hypothermia. Generally, you should remove all wet garments and protect the patient from additional heat loss. Maintain the patient in a horizontal position. Take particular care to avoid handling the patient in a rough manner because this may trigger a dysrhythmia. If possible, measure and monitor the core temperature as well as the ECG and vital signs.

If protocols allow, rewarm the patient. Rewarm mildly hypothermic patients via active external methods (blankets, heat packs and, occasionally, warm-water immersion). With the advent of portable prehospital IV fluid warmers, active internal rewarming with heated IV fluids can also be initiated. Internal rewarming is much more effective than external rewarming. If available, administer warmed, humidified oxygen.

Patients with severe hypothermia tend to develop numerous complications during the rewarming process. Most patients who die during active rewarming do so from ventricular fibrillation. Because of this, rewarming of severe hypothermia patients is best deferred to a hospital setting using a predefined protocol. However, if transport times exceed 15 minutes, rewarming may need to begin in the field. Always follow local protocols with regard to the prehospital treatment of hypothermia.

Summary

Humans are warm-blooded mammals and must maintain a constant internal temperature. Body temperature is controlled by the hypothalamus in the brain, with input from sensory receptors throughout the body. At any given time, body temperature is a function of heat production and heat loss.

Temperature-regulation problems can result in several conditions. These include fever, hyperthermia and hypothermia. EMTs and paramedics must be familiar with the physiological and pathophysiological processes resulting from these disorders. By close observation of the patient, it should be fairly easy to determine which underlying processes are causing the observed signs and symptoms. With this knowledge, you can provide competent, compassionate prehospital care.

References