Physiology of thermoregulation
Role of the hypothalamus

- An area of the hypothalamus serves as the primary overall integrator of the reflexes, but other brain centers also exert some control over specific components of the reflexes.
- Output from the hypothalamus and the other brain areas to the effectors is via: (1) sympathetic nerves to the sweat glands, skin arterioles, and the adrenal medulla; and (2) motor neurons to the skeletal muscles.
Body temperature rises above normal

Nervous system signals dermal blood vessels to dilate and sweat glands to secrete

Body heat is lost to its surroundings

Body temperature drops toward normal

Normal body temperature
$37^\circ C$ (98.6°F)

Body temperature drops below normal

Nervous system signals dermal blood vessels to constrict and sweat glands to remain inactive

If body temperature continues to drop, nervous system signals muscles to contract involuntarily

Body heat is conserved

Muscle activity generates body heat

Hypothalamus

Hypothalamic set point
D. Neural factors affecting thermoregulation

- Central thermosensors
  - Hypothalamus
    - Sympathetic nervous system
      - Cholinergic
      - $\alpha_1$-adrenergic
    - Somatic nervous system
      - $\beta_3$-adrenergic
      - Cholinergic

- Peripheral thermosensors

- Sweat glands: Heat loss by evaporation
- Blood vessels: Internal flow of heat (core $\rightarrow$ skin)
- Brown fat: Non-shivering thermogenesis (in infants)
- Skeletal muscle: Heat production by shivering
Control of Heat Loss by Evaporation

• Even in the absence of sweating, there is loss of water by diffusion through the skin, which is not waterproof. A similar amount is lost from the respiratory lining during expiration.

• These two losses are known as insensible water loss and amount to approximately 600 ml/day in human beings. Evaporation of this water accounts for a significant fraction of total heat loss. In contrast to this passive water loss, sweating requires the active secretion of fluid by sweat glands and its extrusion into ducts that carry it to the skin surface.
Sympathetic nerves effect

- Production of sweat is stimulated by sympathetic nerves to the glands.
- These nerves release acetylcholine rather than the usual sympathetic neurotransmitter norepinephrine.
- Sweat is a dilute solution containing sodium chloride as its major solute. Sweating rates of over 4 L/h have been reported; the evaporation of 4 L of water would eliminate almost 2400 kcal from the body.
Control of Heat Loss by Radiation and Conduction

• For purposes of temperature control, it is convenient to view the body as a central core surrounded by a shell consisting of skin and subcutaneous tissue; we shall refer to this complex outer shell simply as skin.

• It is the temperature of the central core that is being regulated at approximately 37°C. As we shall see, the temperature of the outer surface of the skin changes markedly.
Heat Exchange in the Skin

- Blood vessel dilates (vasodilation)
- Heat loss across epidermis
- Epidermis

(a) Increased heat loss

- Blood vessel constricts (vasoconstriction)
- Heat conservation
- Epidermis

(b) Heat conservation
Nonshivering thermogenesis

- Muscle contraction is not the only process controlled in temperature-regulating reflexes. In most experimental animals, chronic cold exposure induces an increase in metabolic rate (heat production) that is not due to increased muscle activity and is termed **nonshivering thermogenesis**.

- Its causes are an increased adrenal secretion of epinephrine and increased sympathetic activity to adipose tissue, with some contribution by thyroid hormone as well. However, nonshivering thermogenesis is quite minimal, if present at all, in adult human beings, and there is no increased secretion of thyroid hormone in response to cold. Nonshivering thermogenesis does occur in infants.
Shivering thermogenesis

- Changes in muscle activity constitute the major control of heat production for temperature regulation. The first muscle changes in response to a decrease in core body temperature are a gradual and general increase in skeletal-muscle contraction.
- This may lead to shivering, which consists of oscillating rhythmical muscle contractions and relaxations occurring at a rapid rate. During shivering, the efferent motor nerves to the skeletal muscles are influenced by descending pathways under the primary control of the hypothalamus. Because almost no external work is performed by shivering, virtually all the energy liberated by the metabolic machinery appears as internal heat and is known as shivering thermogenesis. People also use their muscles for voluntary heat-producing activities such as foot stamping and hand clapping.
Termoregulatory muscular tonus

- Primarily on the muscle response to cold; the opposite muscle reactions occur in response to heat. Basal muscle contraction is reflexly decreased, and voluntary movement is also diminished.
- These attempts to reduce heat production are relatively limited, however, both because basal muscle contraction is quite low to start with and because any increased core temperature produced by the heat acts directly on cells to increase metabolic rate.
Scheme of reflex arc
The skin’s effectiveness as an insulator

• The skin’s effectiveness as an insulator is subject to physiological control by a change in the blood flow to it. The more blood reaching the skin from the core, the more closely the skin’s temperature approaches that of the core. In effect, the blood vessels diminish the insulating capacity of the skin by carrying heat to the surface to be lost to the external environment.

• These vessels are controlled largely by vasoconstrictor sympathetic nerves, the firing rate of which is reflexly increased in response to cold and decreased in response to heat. There is also a population of sympathetic neurons to the skin whose neurotransmitters cause active vasodilation. Certain areas of skin participate much more than others in all these vasomotor responses, and so skin temperatures vary with location.
Loosing heat by panting

- Some mammals lose heat by **panting**. This rapid, shallow breathing greatly increases the amount of water vaporized in the mouth and respiratory passages and therefore the amount of heat lost. Because the breathing is shallow, it produces relatively little change in the composition of alveolar air.

- The relative contribution of each of the processes that transfer heat away from the body varies with the environmental temperature. At 21 °C, vaporization is a minor component in humans at rest. As the environmental temperature approaches body temperature, radiation losses decline and vaporization losses increase.
Effect of relative humidity

• It is essential to recognize that sweat must evaporate in order to exert its cooling effect. The most important factor determining evaporation rate is the water-vapor concentration of the air—that is, the relative humidity.

• The discomfort suffered on humid days is due to the failure of evaporation; the sweat glands continue to secrete, but the sweat simply remains on the skin or drips off.
C. Heat production at different environmental temperatures (unclothed, at rest)

Room temperature

- Total heat loss: 63 J·m⁻²·s⁻¹ = 100%
  - By way of:
    - 13% Evaporation
    - 26% Conduction and convection
    - 61% Radiation

Distribution:

20°C:
- 27% Evaporation
- 46% Conduction and convection

30°C:
- 27% Evaporation
- 27% Conduction and convection

36°C:
- 100% Evaporation
Head Thermogram

- **Infrared (IR)** radiation is electromagnetic radiation of a **wavelength** longer than that of **visible light**, but shorter than that of **radio waves**. The name means "below red" (from the **Latin infra**, "below"), red being the **color** of visible **light** of longest wavelength. Infrared radiation spans three orders of magnitude and has wavelengths between approximately **750 nm** and **1 mm**.
Infrared thermography

Infrared thermography is a non-contact, non-destructive test method that utilizes a thermal imager to detect, display and record thermal patterns and temperatures across the surface of an object.
Thermal imaging

Thermography, or thermal imaging, is a type of infrared imaging. Thermographic cameras detect radiation in the infrared range of the electromagnetic spectrum (roughly 900–14,000 nanometers or 0.9–14 µm) and produce images of that radiation.
Thermology

- Thermology is the medical science that derives diagnostic indications from highly detailed and sensitive infrared images of the human body. Thermology is sometimes referred to as medical infrared imaging or tele-thermology and utilizes highly resolute and sensitive infrared (thermographic) cameras. Thermology is completely non-contact and involves no form of energy imparted onto or into the body. Thermology has recognized applications in breast oncology, chiropractic, dentistry, neurology, orthopedics, occupational medicine, pain management, vascular medicine/cardiology and veterinary medicine.
Thermography in medical practice

- Right breast cancer
Behavioral mechanisms

- There are three behavioral mechanisms for altering heat loss by radiation and conduction: changes in surface area, changes in clothing, and choice of surroundings.
- Curling up into a ball, hunching the shoulders, and similar maneuvers in response to cold reduce the surface area exposed to the environment, thereby decreasing heat loss by radiation and conduction. In human beings, clothing is also an important component of temperature regulation, substituting for the insulating effects of feathers in birds and fur in other mammals. The outer surface of the clothes forms the true "exterior" of the body surface.
- The skin loses heat directly to the air space trapped by the clothes, which in turn pick up heat from the inner air layer and transfer it to the external environment. The insulating ability of clothing is determined primarily by the thickness of the trapped air layer.
Clothing and body temperature

- Clothing is important not only at low temperatures but also at very high temperatures. When the environmental temperature is greater than body temperature, conduction favors heat gain rather than heat loss.

- Heat gain also occurs by radiation during exposure to the sun. People therefore insulate themselves in such situations by wearing clothes. The clothing, however, must be loose so as to allow adequate movement of air to permit evaporation. White clothing is cooler since it reflects more radiant energy, which dark colors absorb. Loose-fitting, light-colored clothes are far more cooling than going nude in a hot environment and during direct exposure to the sun.
The third behavioral mechanism

• The third behavioral mechanism for altering heat loss is to seek out warmer or colder surroundings, as for example by moving from a shady spot into the sunlight.

• Raising or lowering the thermostat of a house or turning on an air conditioner also fits this category.
Integration of Effector Mechanisms

• By altering heat loss, changes in skin blood flow alone can regulate body temperature over a range of environmental temperatures (approximately 25 to 30°C or 75 to 86°F for a nude individual) known as the **thermoneutral zone**.

• At temperatures lower than this, even maximal vasoconstriction cannot prevent heat loss from exceeding heat production, and the body must increase its heat production to maintain temperature. At environmental temperatures above the thermoneutral zone, even maximal vasodilation cannot eliminate heat as fast as it is produced, and another heat-loss mechanism—sweating—is therefore brought strongly into play. Since at environmental temperatures above that of the body, heat is actually added to the body by radiation and conduction, evaporation is the sole mechanism for heat loss.

• A person’s ability to tolerate such temperatures is determined by the humidity and by his/her maximal sweating rate.
B. Mechanisms of heat loss

1. Radiation
   - Heat rays

2. Conduction and convection
   - Convection

3. Evaporation
   - Loss of heat by evaporation
   - Sweat glands
   - Skin
   - $H_2O$
## Summary of Effector Mechanisms in Temperature Regulation

<table>
<thead>
<tr>
<th>Desired Effect</th>
<th>Mechanism</th>
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<tr>
<td><strong>STIMULATED BY COLD</strong></td>
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<tr>
<td>Decrease heat loss</td>
<td>1. Vasoconstriction of skin vessels</td>
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<td></td>
<td>2. Reduction of surface area (curling up, etc.)</td>
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<td></td>
<td>3. Behavioral response (put on warmer clothes, raise thermostat setting, etc.)</td>
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<tr>
<td>Increase heat production</td>
<td>1. Increased muscle tone</td>
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<td></td>
<td>2. Shivering and increased voluntary activity</td>
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<td></td>
<td>3. Increased secretion of epinephrine (minimal in adults)</td>
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<td>4. Increased food appetite</td>
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<tr>
<td><strong>STIMULATED BY HEAT</strong></td>
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<tr>
<td>Increase heat loss</td>
<td>1. Vasodilation of skin vessels</td>
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<td></td>
<td>2. Sweating</td>
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<td></td>
<td>3. Behavioral response (put on cooler clothes, turn on fan, etc.)</td>
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<tr>
<td>Decrease heat production</td>
<td>1. Decreased muscle tone and voluntary activity</td>
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Peculiarities of temperature homeostasis in children

- Newborns thermoregulatory system is well developed, but in newborns different condition of temperature exchange and present some peculiarities of thermoregulation. Children have another than adults ratio of body surface and weight.

- Body square is more than body weight that is why lost of temperature increase and regime of temperature comfort change in side of increase of external temperature to 32-34 °C. Big body square developed condition for more intensive cool and heating. Children have more thin thermo isolative layer of subcutaneous fat.
Role of brown fat

• In newborns very important role in thermo regulative processes has brown fat. It’s present under the skin of neck, between scapulars. That gives condition for blood supply of brain, where the cells are very sensate to disbalance of temperature homeostasis. Brown fat is well innervated by sympathetic nerves and well provided with blood.

• In the cells of brown fat small drops of fat are present. In a white cells there is only one drop of fat. Quantity of mitochondria, cytochroms is greater in brown fat. Speed of fat acids oxidation 20 times higher, but absent synthesis and hydrolysis of ATP, that is why the heat produced immediately. That is caused by presents of special membrane polypeptide – termogenine. When it is necessary increase of brown fat oxygenation may be added to increase the heat production in 2-3 times. Children, especially of first year life, do not so sensitive as adult to change of temperature homeostasis. That's why they don't cry when they lost heat.
Body fluids

- The cells that make up the bodies of all but the simplest multicellular animals, both aquatic and terrestrial, exist in an "internal sea" of extracellular fluid (ECF) enclosed within the integument of the animal. From this fluid, the cells take up O2 and nutrients; into it, they discharge metabolic waste products. The ECF is more dilute than present-day sea water, but its composition closely resembles that of the primordial oceans in which, presumably, all life originated.

- In animals with a closed vascular system, the ECF is divided into 2 components: the interstitial fluid and the circulating blood plasma. The plasma and the cellular elements of the blood, principally red blood cells, fill the vascular system, and together they constitute the total blood volume. The interstitial fluid is that part of the ECF that is outside the vascular system, bathing the cells. The special fluids lumped together as transcellular fluids are discussed below. About a third of the total body water (TBW) is extracellular; the remaining two-thirds are intracellular (intracellular fluid).
Size of the Fluid Compartments

- In the average young adult male, 18% of the bodyweight is protein and related substances, 7% is mineral, and 15% is fat.
- The remaining 60% is water. The intracellular component of the body water accounts for about 40% of body weight and the extracellular component for about 20%.
- Approximately 25% of the extracellular component is in the vascular system (plasma == 5% of body weight) and 75% out-side the blood vessels (interstitial fluid = 15% of body weight).
- The total blood volume is about 8% of body weight.
Extracellular Fluid Volume

- The ECF volume is difficult to measure because the limits of this space are ill defined and because few substances mix rapidly in all parts of the space while remaining exclusively extracellular. The lymph cannot be separated from the ECF and is measured with it. Many substances enter the cerebrospinal fluid (CSF) slowly because of the blood-brain barrier.

- Equilibration is slow with joint fluid and aqueous humor and with the ECF in relatively avascular tissues such as dense connective tissue, cartilage, and some parts of bone. Substances that distribute in ECF appear in glandular secretions and in the contents of the gastrointestinal tract. Because they are not strictly part of the ECF, these fluids, as well as CSF, me fluids in the eye, and a few other special fluids, are called transcellular fluids. Their volume is relatively small.
Interstitial Fluid Volume

• The interstitial fluid space cannot be measured directly, since it is difficult to sample interstitial fluid and since substances that equilibrate in interstitial fluid also equilibrate in plasma. The volume of the interstitial fluid can be calculated by subtracting the plasma volume from the ECF volume.

• The ECF volume/intracellular fluid volume ratio is larger in infants and children than it is in adults, but the absolute volume of ECF in children is, of course, smaller than it is in adults. Therefore, dehydration develops more rapidly and is frequently more severe in children than in adults.
Intracellular Fluid Volume

• The intracellular fluid volume cannot be measured directly, but it can be calculated by subtracting the ECF volume from the total body water (TBW). TBW can be measured by the same dilution principle used to measure the other body spaces. Deuterium oxide (D;0, heavy water) is most frequently used. D20 has properties that are slightly different from H20, but in equilibration experiments for measuring body water it gives accurate results. Tritium oxide and aminopyrine have also been used for this purpose.

• The water content of lean body tissue is constant at 71 - 72 mL/100 g of tissue, but since fat is relatively free of water, the ratio of TBW to body weight varies with the amount of fat present. In young men, water constitutes about 60% of body weight. The values for women are somewhat lower.
The distribution of electrolytes in the various compartments

- The composition of intracellular fluid varies somewhat depending upon the nature and function of the cell.
- Electrolyte concentrations differ markedly in the various compartments. The most striking differences are the relatively low content of protein anions in interstitial fluid compared to intracellular fluid and plasma, and the fact that Na+ and C- are largely extracellular, whereas most of the K+ is intracellular.
Size of the Fluid Compartments

- In the average young adult male, 18 % of the body weight is protein and related substances, 7 % is mineral, and 15 % is fat. The remaining **60 % is water**.
- The intracellular component of the body water accounts for about 40 % of body weight and the extra cellular component for about 20 %.
- Approximately 10 % of the body water is inside the blood vessels.
- Interstitial fluid = 15 % of body weight.
- The total blood volume is about 6-8 % of body weight.