Title: Thermoregulation

Teacher(s): Prof. Teresa Torlińska MD PhD, Marek Tuliszka PhD
Coll. Anatomicum, Święcicki Street no. 6, Dept. of Physiology

The temperature of the body is determined by the balance between the rate of heat production and the rate of heat loss.

In man, normal body temperature is commonly considered to be 37°C or 98.6°F. This temperature only represents an average core temperature for adult populations; basal body temperature normally exhibits daily variations of as much as 1°C, and during heavy exercise core temperatures can rise 2 to 3°C.

A. Production of body heat
1. Heat is derived from biochemical reactions in all living cells. At the mitochondrial level, energy (from the catabolism of metabolites such as glucose) is used in oxidative phosphorylation, converting adenosine diphosphate (ADP) to adenosine triphosphate (ATP). The efficiency of this chemical reaction may vary but is usually less than 50%. The rest of energy is released in the form of heat.
2. The rate of heat production is controlled by the metabolic rate of the body. All of the metabolic processes in the body produce heat as a by-product. In the average person about 2500 Calories (kcal) of heat are formed daily. Heat production increases greatly during exercise.
3. In addition to normal metabolic processes generating heat formation mammals possess thermogenic processes to increase heat production during cold exposure and during the initiation of fever. These processes include:
   a. Shivering thermogenesis
   b. Nonshivering thermogenesis

For adult humans and most large mammals, shivering is the primary means of increasing heat production in response to a cold environment. Nonshivering thermogenesis is more important in smaller mammals and newborns, and is closely linked to brown adipose tissue.

B. Distribution of body heat.

Because most heat-producing organs lie deep within the body core, the circulatory system plays a vital role in distributing heat throughout the body. The nervous system regulates the core temperature by controlling blood flow to the skin.

C. Heat balance

If body temperature is to remain constant, heat production must equal heat loss. In short, all of the heat generated as a result of cellular metabolism equals the heat lost through the skin and respiratory tract.

D. Heat transfer
1. Direct transfer of heat involves three processes:
   a. Conduction
   b. Convection
   c. Radiation

2. Heat can be also transferred indirectly, as a result of evaporation of water.
3. Heat is lost from the body by convection, radiation, and evaporation.

Normally, about 60% of the heat loss from a nude person sitting in the room at 21°C (70°F) is by radiation. Approximately 18% of the heat is lost by conduction to objects touching the body or to surrounding air. Evaporation of water accounts for about 22% of the heat loss from the nude person.

E. Set-point temperature regulation
1. Body temperature is controlled by the „hypothalamic thermostat“. An extremely important thermoregulatory area is located in the preoptic area and anterior hypothalamus. The preoptic region regulates its own temperature at constant level or set point.
2. Temperature signals from the skin also play a role in body temperature regulation (impulses from warm and cold receptors in skin are transmitted to the preoptic area of hypothalamus).
3. The Hammel model suggests that in the preoptic region population of warm-sensitive and temperature-insensitive neurons synaptically control separate populations of effector neurons for each thermoregulatory response. Set point occurs when the synaptic input from warm-sensitive neurons is „functionally” equal and opposite to the synaptic input from temperature-insensitive neurons.
4. Temperature-increasing mechanisms include:
   a. Skin vasoconstriction
   b. Increased heat production:
      - shivering thermogenesis (the most potent mechanism for increasing heat production)
      - hormonal thermogenesis (epinephrine, thyroid hormones)
5. Temperature-decreasing mechanisms include:
   a. Skin vasodilation due to a decrease in sympathetic tone to cutaneous blood vessels
   b. Sweating
   c. Decreased heat production

**F. Fever - a change in the regulated set point**
1. Pyrogens cause fever by elevating the regulated set-point temperature.
2. Pyrogens increase the production of interleukin-1 (IL-1) in phagocytic cells. IL-1 acts on the anterior hypothalamus to increase the production of prostaglandins. Prostaglandins increase the set-point temperature, setting in motion the heat-generating mechanisms that produce fever
3. Primary effect of pyrogens on preoptic neurons is to decrease the firing rate of warm-sensitive neurons, which in turn leads to a decrease in heat loss and an increase in heat production.
4. There are three phases of febrile response:
   a. Fever initiation
   b. Steady-state fever
   c. Defervescence (when fever „breaks“)
5. During the course of febrile illness an individual experiences chills while body temperature is rising and sweating while the body temperature is falling.
6. Antipyretic drugs such as aspirin, indomethacin and ibuprofen interfere with arachidonic acid cascade and block prostaglandin formation.
7. Fever implies hyperthermia, but not all cases of hyperthermia constitute fever. The heat-producing and heat-conserving mechanisms in fever promote an increased body temperature, whereas during exercise-induced hyperthermia, the cooling mechanisms are striving to return the body temperature to its normal steady-state.

**G. Hyperthermia**
1. The term „hyperthermia“ refers to unregulated rise in body temperature, due to the accumulation of heat and/or the inability to dissipate heat.
2. Heat exhaustion is caused by excessive sweating. As a result, blood volume and arterial blood pressure decrease and syncope (fainting) occurs
3. Heat stroke occurs when body temperature increases to the point of tissue damage (core temperature is above 40.5 °C). The normal response to increased ambient temperature (sweating) is impaired. A medical emergency that is fatal if not recognized and treated
4. Malignant hyperthermia
Genetic mutation of the ryanodine receptor in the sarkoplasmic reticulum of the skeletal muscle results in excessive Ca^{++} release when the susceptible individual is exposed to certain gaseous anesthetic (halothane). Increased Ca^{++} leads to severe muscle contraction, rigidity and heat production.

H. Hypothermia - results when the ambient temperature is so low that heat-generating mechanisms (e.g., shivering, metabolism) cannot adequately maintain core temperature near the set point.