Effect of low temperatures on the organism

Homothermic animals try to maintain a constant body temperature, due to the functionality of enzymes precisely at this temperature. The human organism is an open thermodynamic system, i.e. a system that exchanges energy with the environment. There are a number of mechanisms that **maintain a constant body temperature** to change the temperature of the environment:

1. **Tremor thermogenesis**
2. **Non-shivering thermogenesis**

There is a **constant heat exchange** between the environment and the organism with a different temperature, these processes lead to a state of **thermal equilibrium**. Heat is exchanged by conduction (https://en.wikipedia.org/wiki/Thermal_conduction), radiation (https://en.wikipedia.org/wiki/Radiation) and convection (https://en.wikipedia.org/wiki/Thermal_conduction). The ideal temperature of the human body is 36.6 °C.

Homothermic animals produce heat and maintain a **constant temperature of the core** (internal organs), which is almost independent of the environment. By the **thermal balance of the body**, we mean the state where t**he production of heat corresponds to its output**. Animals maintain thermal balance mainly by regulating the rate of heat removal, and its production is little regulated. Heat is removed through the skin and lungs, inside the body it is removed mainly by blood exchange and therefore the thermal conductivity of internal tissues for heat distribution is not so important under normal circumstances.

Heat loss

Heat loss from the body occurs through mechanisms that are divided into direct and indirect:

Direct heat loss:

- radiation
- conduction
- convection (flow)

Indirect heat loss:

- evaporation (sweating)
  - noticeable
  - imperceptible
- evaporation from the lungs

Radiation (https://en.wikipedia.org/wiki/Radiation)

Every body emits heat in the form of electromagnetic radiation. The wavelengths (https://en.wikipedia.org/wiki/Wavelength) of this radiation vary depending on the ambient temperature, i.e. at high temperatures they correspond to ultraviolet radiation, at low temperatures to visible light and in normal conditions to infrared radiation.

According to the Stefan-Boltzmann law (https://en.wikipedia.org/wiki/Stefan–Boltzmann_law), the amount of radiated energy is proportional to the fourth power of the body's absolute temperature (https://en.wikipedia.org/wiki/Thermodynamic_temperature). Given that the environment affects the organism in the same way, the total radiated energy is then proportional to the difference of the fourth powers of the surface temperature of the body and the temperature of the objects in its vicinity.

For the radiation intensity (derived for the ideal case of radiation from an absolutely black body):

$$E = \sigma T^4$$

σ - Stefan-Boltzmann constant = $5{,}670400.10^{-8}$ $Wm^{-2}K^{-4}$

Radiation heat losses make up around 40-60% of total heat losses, their exact amount also depends on the ambient temperature and humidity. The amount of heat radiated is regulated by the amount of blood flow, changes in skin temperature and the size of the surface. The amount of heat loss can be reduced by using suitable clothing (or the color of the fur in animals). The wavelength (https://en.wikipedia.org/wiki/Wavelength) of skin radiation is 5-20 micrometers.

Conduction (https://en.wikipedia.org/wiki/Thermal_conduction)

By heat conduction we mean the transfer of heat from a warmer place to a colder place, whereby the molecules of the warmer place transfer their kinetic energy to the neighboring molecules in the colder area. During conduction, only thermal energy is transferred, not matter.

The amount of energy Q transferred during the time r [s] between two places by the line depends on the difference in the distance between the places d [m], the difference in their temperatures Δt [K], the area S [m^2] over which the transfer takes place, and the coefficient of thermal conductivity λ [J/m.s.K], which indicates the ability of the substance to conduct heat, according to this relationship:

$$Q = \lambda S \Delta t \tau / d$$

Liquids are good conductors, so blood conducts heat in the body. The function of heat insulator in the human body is mainly occupied by adipose tissue. Conduction losses account for 15-30% of total losses and are affected by ambient conditions.

Convection (https://en.wikipedia.org/wiki/Convection)

It is very closely related to heat conduction. The heat must first be transferred by conduction to the substance, through which it is then removed to the surroundings. During flow, in addition to energy transfer, matter is also transferred. The amount of heat that is removed during the time t (s) by the flow from the surface of the body with an area S (m^2) to the surroundings with a temperature lower by Δt (K) can be expressed by the relation:

$Q = \alpha S \Delta t \tau$, where (W/K.$m^2$) is the interface heat transfer coefficient.

The coefficient α is not a material constant, because its value depends on many factors that are difficult to measure. It is determined experimentally using so-called alphameters. It is known, for example, that the organism tolerates frost better at low relative air humidity than temperatures above the freezing point with intense flow and high air humidity.

Evaporation (https://en.wikipedia.org/wiki/Evaporation) of water

Evaporation of water occurs during breathing and sweating. These losses account for up to 25% of body heat loss. When breathing, the exhaled air is almost saturated with water vapor. Sweating does not occur at low temperatures.

Tremor thermogenesis

It is a primal response to cold. At first, only the **muscle tone** increases, this condition gradually turns into a spontaneous tremor with a frequency of 10-20 contractions per second, during which the muscles do not perform any work, but only generate heat. Its activation and regulation is controlled in the front part of the hypothalamus, it is a process not controlled by the will.

Non-shivering thermogenesis

Two basic reactions are described here:

1. Increase in metabolism
2. Blocking oxidative phosphorylation in brown fat

Increase in metabolism

A process controlled humorally by the release of adrenaline and noradrenaline into the bloodstream. Physiological reactions result from this, such as an increase in heart rate, the breakdown of fats and glycogen, an increase in the concentration of glucose in the blood, and an increase in the diameter of the bronchi in the lungs. During prolonged exposure to cold, the function of adrenaline and noradrenaline is taken over by the hormone thyroxine, which accelerates the breakdown of fats and increases the activity of mitochondria.

Blocking oxidative phosphorylation in brown fat

Brown fat is a special tissue that is found in greater quantities in young non-furred mammals and hibernators. In children, the largest deposits of brown fat are on the neck, around the shoulder blades and around the kidneys. The brown coloring is due to the huge number of mitochondria in this tissue. Heat is generated in the mitochondria, which have blocked ATP synthesis. For a simple idea, this action can be described as spinning the ATP mill on empty. Some studies prove that hard people can delay the start of tremor thermogenesis, the explanation could be the use of brown fat.

Temperature control in thermoregulatory centers of the hypothalamus

Control of body temperature takes place through **thermoreceptors** located in the skin, intestines (these are not involved in the conscious perception of temperature) and the CNS (hypothalamus). **The hypothalamus** has the function of the **body's thermoregulatory center**, it is superior to other thermoreceptors. It receives information from thermoreceptors (located in the skin) for cold and heat. The hypothalamus then sends out impulses that change **muscle tone**. The hypothalamus can also send impulses to the pituitary gland, which, by controlling the activity of the thyroid gland and thus the hormone thyroxine, helps in long-term adaptation to the cold.

Mechanisms that help increase or decrease the temperature of the organism (vasoconstriction, vasodilatation, thermogenesis, cold shivering, etc.) always try to compare the body temperature with the temperature in the **thermoregulatory center**. Then there are processes that maintain the body's normal temperature.

Pathological effect of cold

With long-term exposure to cold and total exhaustion of the organism, hypothermia occurs, which is a condition where the temperature of the body's core drops below 35°C. First, the peripheral parts of the body and the surface layers are cooled, then the cold spreads to the core of the body to the deep-seated organs. The factor that differentiates the effects of low temperatures on the organism is **the amount of exhaled air** (causes considerable heat loss), the time for which the body is exposed to cold (the process of cooling the organism from the periphery to the core is gradual) and the surface of exposed parts of the body (the share of heat loss in this way is greater, the greater the temperature difference between exposed and uncovered parts of the body).

Hypothermia initially causes **tachycardia** (increases body temperature) and **changes in blood circulation**. In this state, the blood circulation tries to maintain the temperature necessary for the performance of basic vital functions, which results in significant differences in blood temperature between the core and the periphery. When treating an individual affected by long-term effects of cold, it is necessary to pay attention to this, and therefore, for example, giving alcohol to a hypothermic individual is quite counterproductive, because the blood from the core and periphery will be diluted, which can have fatal consequences, because the blood in the core will cool quickly .

Tachycardia is followed by **bradycardia**, which is part of the gradual **weakening of the organism**, which can lead to sleep (as a result of general depression).

When the core temperature drops to 34°C, disturbances of consciousness begin, at 32°C, unconsciousness occurs. If the core temperature falls below 24°C, it is **a lethal condition** and **heart failure** occurs.

Frostbite can occur when the limbs are exposed to low temperatures for a long time. This process occurs at an ambient temperature of 15 °C and below. The organism tries to cope with this condition by reducing the blood flow in the peripheries so that **the core of the body remains undamaged**. Frostbite is divided into 4 groups according to severity (necrosis of the affected part of the body may occur).

However, the effect of low temperatures on the organism also has positive uses. In addition to **cryotherapy**, it is **mainly about hypothermia of the organism during operations**. For example, during heart surgery, when blood circulation is cut off, which under normal conditions would lead to damage to the CNS, hypothermia of the body reduces oxygen consumption by the brain (at 30°C by half, at 20°C even by only a tenth), which leads to extend the time when the patient can tolerate a longer interruption of blood circulation without consequences.

Links

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