Effects of high temperatures on the organism

Introduction

Man, as a warm-blooded (**homoiothermal**) animal, is characterized by the fact that he is able to maintain **a constant temperature of the core**, i.e. deep-seated organs, almost independent of changes in the surrounding environment, using thermoregulatory mechanism. An organism as an open system is in constant interaction with its environment. Constant temperature maintenance is possible only if **heat production is in balance with heat output.**

From the point of view of thermodynamics, the human organism is **an open thermodynamic system**. Such systems exchange substances, energy and information with the environment. Under normal conditions, the organism obtains a substantial part of its energy from food in the form of chemical energy. A small part of the energy from the surrounding environment consists of chemical, light, mechanical and **thermal energy**, causing irritation of the relevant receptors and subsequently and adequate perception.

Heat in the body is produced mainly as a **by-product of other forms of energy**, only exceptionally is it produced purposefully (cold shivering as a mechanism of thermoregulation). In order to prevent this heat from accumulating in the organism and thereby increasing its temperature, the organism is able to regulate its discharge to the environment to a certain extent. High temperatures prevent the body from cooling down and cause **heating**.

The system is able to **regulate its temperature within a certain range**, but if it is exceeded and temperature regulation is no longer possible, the temperature of the core (deep-seated organs) rises. This leads to overheating and collapse of the organism. **Self-regulation of temperature is a feedback loop of the organism**. Its principle is that the control center constantly compares the required temperature with the actual temperature of the core and controls the intake and output of heat based of their difference.

The center of temperature regulation is the Centrem regulace teploty je **hypothalamus**. Central thermoreceptors are located in the anterior hypothalamus. Two-thirds of them react to heat, a third to cold. The thermoregulatory center located in the posterior hypothalamus itself is not sensitive to temperature, but it "calculates" information coming from peripheral thermoreceptors, which are located mainly in the skin, and sends out control signals. There are ten times more cold receptors (*Krause corpuscles*) than heat receptors (*Ruffiini corpuscles*). (see Thermoregulation)

The constant human body temperature is set at **37°C**.

Mechanism of heat exchange and effects of climatic conditions on the organism

Heat exchange takes place until an equilibrium state is reached.

The heat received (given out) by a body depends on the mass of the body (m), to increase (decrease) body temperature $(t - t_0)$, $(t_0 - t)$ and on the type of fabric c (specific heat capacity).

Calorimetric equation:

Heat received: $Q_1 = m \cdot c \cdot (t - t_0)$
Heat transferred: $Q_2 = m \cdot c \cdot (t_0 - t)$

Radiation

Radiation is the transfer of heat from one body to another with a different temperature by **infrared electromagnetic radiation**, without the two objects touching. The amount of heat thus transferred according to the **Stefan-Boltzmann law** corresponds to the function of the fourth power of the temperature of the radiating body. The environment affects the human body through the same mechanism, which means that the total radiated energy is proportional to the difference of the fourth powers of the surface temperature of the body and the temperature of objects in the environment. The temperature of the air through which the thermal radiation, a person can feel cold in a room with cold walls, even if the air in the room is relatively warm. A person in a cold environment loses heat by conduction into the air that surrounds him and by radiation to cold objects in his vicinity. On effe contrary, an individual in an environment warmer than his body's body temperature receives heat through the same mechanisms and his temperature rises. On a cold, sunny day, the sun's thermal radiation is reflected off bright objects and thus contributes to warming. **60%** of total heat loss.

Conduction

Conduction is the transfer of heat through contact between two bodies of different temperatures. It involves the **transfer of thermal energy** from a place (body) with a higher temperature to a place (body) with a lower temperature. Molecules are in motion and the energy of their motion is proportional to temperature. Molecules of warmer body collide with molecules of a colder body and thereby transfer part of their thermal energy to them. The amount of heat transferred is proportional to the temperature difference of the two touching objects (thermal gradient). Heat can also be transferred by conduction to the surrounding air. In the human body, the most important heat transfer mechanism is **blood circulation**. On the other hand, the thermal insulator in the body is **fat tissue** (it has 3x less thermal conductivity than blood). By driving, one loses about **15%** heat energy. Air that does not flow intensively is a thermal insulator. If the body is surrounded by water or moist, intensively flowing air, then heat loss through conduction will be decisive.

Convection

Convection (flow) is the movement of air or water molecules in the direction away from the point of contact based on the temperature gradient in the environment. Convection is closely related to heat conduction. Increases heat output by conduction by maintaining a large temperature gradient. The heat must first be transferred by conduction to the substance, through which it is then removed to the surroundings.

The amount of heat that is per time τ carried away by flow from the surface of the body about the area S to surroundings with a lower temperature o Δt, can be expressed by the relation $Q = \alpha \cdot S \cdot \Delta t \cdot \tau$.

α is the coefficient of heat transfer through the interface, which is determined experimentally using **alphameters**. An object that is in contact with air of a different temperature changes its specific gravity because it affects its temperature. As warm air rises and cold air descends, new air comes into contact with the object. Convection increases strongly if the object moves in the environment or if the environment flows around the object (a person swimming in water or a fan in a room). Wind cools because it replaces the warm and humid air from the immediate surroundings of the body with cooler and drier air. The effects of flow and heat conduction are evident under extreme climatic conditions. The organism tolerates frost better at low relative air humidity and when there is no wind than at temperatures above the freezing point with intense currents and high air humidity

Evaporation

During heavy physical exertion, radiation and **conduction alone** are not enough to protect the body from overheating. Under these conditions, heat output is increased by evaporation of water during perspiration. **By evaporating 1 g of water, the organism loses about 0.6 kcal of heat**. Fluid reaches the surface of the skin by diffusion and secretion from sweat glands. Evaporation cools the skin to a temperature lower than the ambient temperature. At an ambient temperature higher than 36°C, heat removal is effective only through the evaporation of water. At an ambient temperature significantly higher than 37°C, the body gains heat from the environment by radiation and conduction. In this case, the balance between the intake and output of heat is maintained by profusion sweating, the effectiveness of which is inversely proportional to the humidity of the air. Once the humidity reaches a certain value, the body's ability to cool itself by sweating becomes limited and the expelled sweat will not evaporate from the skin. **One liter of evaporated liquid takes more than 2428 KJ (580kcal) from the body**. This mechanism makes it possible to tolerate dry heat (e.g. desert) at temperatures well above body temperature (in the case of replacing fluid and salt losses caused by sweating). However, if the surrounding air is highly saturated with vapors (tropical jungle), evaporation is prevented and it is difficult to tolerate temperatures above 34°C. With higher air humidity, a person feels the heat more strongly. Evaporation occurs from the surface of a liquid at any temperature at which the liquid state exists. The rate of evaporation of any liquid will increase if the temperature of the liquid increases, if its surface area increases, and if the vapors formed above the liquid are removed (suction, blowing, wind).

The relative share of each of the processes described above in removing heat from the organism depends on the **temperature of the environment**. At temperatures below 19°C, heat output is reduced due to minimal blood flow to the skin due to peripheral vasoconstriction. In the temperature range of 19–31°C, the blood circulation of the skin can ensure a balance between the produced and dissipated heat. At temperatures above 31°C, evaporation is added to radiation, flow and heat conduction. **Evaporation** is the only possible cooling mechanism in cases where the ambient temperature is higher than the body temperature.

The body reacts to a hot surrounding environment or increased production of metabolic heat by **vasodilation** (widening of the subcutaneous vessels). In this way, the heat of the body's core is transferred to the blood and transferred to the surface of the body if its temperature is lower than the internal temperature. As a result of the increase in skin temperature, the removal of heat from the body increases. If an increase in skin temperature cannot restore thermal balance, sweat glands are activated and evaporative cooling begins. If these mechanisms do not restore the body's thermal balance, **hyperthermia**, an increase in the body's core temperature and overheating of the organism, will occur. If the system's ability to regulate its tempetrautre is exceeded, the energy of thermal oscillations approaches the energy of weak chemical bonds, resulting in overheating and collapse of the organism. The first symptoms are: weakness headache, loss of appetite,nausea, shortness of breath, rapid pulse (up to 150/min), shiny eyes, mental restlessness, apathy or, on the contrary, irritability. In heat shock, the body temperature rapidly rises above 41°C, sweating stops, coma begins and death occurs.

The ideal temperature of the external environment for a person undressed in resting conditions is 28°C, for a light worker 25°C, for longer endurance loads 15°C.

Factors affecting thermal comfort

1. Air temperature.
2. Radiant temperature of surfaces in space.
3. Operative temperature – the temperature of a black enclosed space in which the organism would share the same amount of heat by convection and radiation as in the real environment.
4. Effective temperature – the room temperature at 50%, relative humidity that causes the same total heat loss from the skin as in the real environment.
5. Air humidity – i.e. mass amount of water vapor in 1 kg of dry air.
6. Air flow speed and its turbulent. The speed of air movement affects heat transfer by flow and evaporation of moisture from the skin.
7. The value of metabolism indicates the heat output of a person. It depends on the activity, the person (figure, age and physical condition) and the conditions in which the person is.
8. Clothing is an important factor affecting heat transfer from the body to the environment.
9. Body shape and subcutaneous fat. Heat production is proportional to body mass, but heat loss depends on body surface area.
10. Age and gender. Older people have narrower range of optimal temperatures, women often prefer a higher ambient temperature than men.

The effect of high temperatures on the organism

Effects on the human organism

1. *Vasodilatation* (expansion of skin vessels - increases the transfer of heat to the skin).
2. Sweating(takes place from 37°C; water losses in a warm environment can be up to 5 liters per hour, at the same time ion losses occur; excessive Na and Cl losses are prevented due to higher aldosterone production).
3. *Limitation of heat production.*
4. *More intense breathing.*
5. *Acceleration of blood circulation.*
6. *Reduction of muscle tension. relaxing effects.*
7. *Increased capillary permeability.*

Shock states of the organism associated with high temperature

Heat stroke

Heat stroke (*siriasis*) is shock state of the organism caused by the accumulation of heat in the body. It occurs when the organism is unable to remove a sufficient amount of heat from the body with the help of thermoregulation. The body's temperature is raised above **40,5°C by external infuences**[1]. Heat stroke is mainly caused by a failure of thermoregulation, namely a failure of sweat secretion, the onset of paradoxical "cold" tremors delirium, convulsions. [2]. Heat stroke can cause severe brain damage, often quickly leading to death.

Burn

Sunburn (*insolation*) is mainly caused by direct sunlight falling on the head and neck area, where there is rapid rise in temperature in the thermoregulatory centers. It leads to malaise, impaired concentration, headache, dizziness, nausea, vomiting, stiff neck. It causes congestion of the meninges (up to brain edema), it can be fatal.

Collapse from the heat

It is a special form of orthostatic collapse. Extreme vasodilatation during heat stress while standing quietly leads to a "pooling" of larger volumes of blood in the veins of the legs and abdomen, and thus to a drop in blood pressure and unconsciousness. It is relatively risk-free. [2]

Adaptation of the organism to heat

1. **Sweat secretion doubles**
2. **The sweating threshold shifts to lower core temperatures**.
3. the concentration of ions in sweat decreases
4. **The feeling of thirst increases.**

Heat utilization

The effect of heat has therapeutic effects on the organism in certain cases. Thermotherapy is one of the basic physical treatments used especially in spa medicine, where its analgesic and spasmolytic effect is mainly used.

- Thermotherapy
- Hyperthermia
- Microwave thermotherapy

The heat balance of the organism

The heat balance of the human body can be expressed by the equation:

$$M \pm R \pm Cv \pm Cd - Ediff - Ersw - Eresp - L = \Delta S(W)$$

M – value of metabolism; R – heat loss (gain) by radiation; Cv – heat loss (gain) by flow; Cd – heat loss (gain) by conduction; $Ediff$ – heat loss by skin diffusion; $Erws$ – heat loss through normal sweating; $Eresp$ – heat loss through respiration (latent); L – heat loss through breathing (sensible); ΔS – change in heat capacity.

Specific examples of energy and heat exchange in the organism:

Average food intake during 24 hours

Proteins – 250 g, i.e. 5550 kJ

Fats – 80 g, i.e. 3112 kJ

Carbohydrates – 150 g, i.e. 2565 kJ

Total energy intake from food 11227 kJ.

Metabolism value: 8 hours of office work, i.e. $8 \times 75 = 600$ W/m^2

8 hours of sleep: $8 \times 50 = 400$

2 hours of light walking: $2 \times 140 = 280$

6 hours rest: $6 \times 65 = 390$

Total in 24 hours: 1670 W/m^2 = 1942 kcal/m^2 = 7 769 kJ x 1,72 m^2 = 13 363 kJ

Heat transfer by radiation = body temperature ^{4} – temperature of surrounding objects^4

Average sweating, 600 ml of sweat per day, resulting energy loss 1200 kJ

One hour spent in the sun during a summer afternoon, heat intake 700 W.m^{-2} = 1628 kcal x 1,72 = 2800 kcal = 11 724 kJ

Links

Related arcicles

- Termoregulation
- Termotherapy

References

- NAVRÁTIL, Leoš – ROSINA, Jozef, et al. *Medicínská biofyzika.* 1. edition. Praha : Grada, 2005. 524 pp. ISBN 80-247-1152-4.

- SCHMIDT, Robert. *Memorix - Fyziologie.* 1. edition. SCIENTIA MEDICA, 1993. 336 pp. ISBN 80-85526-18-2.

- GANONG, William F.. *Přehled lékařské fyziologie.* 1. edition. H and H, 1995. 685 pp. ISBN 80-85787-36-9.

- BARTUŠKA, RNDr. Karel, et al. *Molekulová fyzika a termika - Fyzika pro gymnázia.* 4. edition. Prometheus Praha, 2000. 244 pp. ISBN 80-7196-200-7.

External links

- Fyziologie tělesné zátěže (https://is.muni.cz/elportal/estud/fsps/js07/fyzio/texty/ch09s02.html)
- Tepelná pohoda a nepohoda (http://www.tzb-info.cz/404-tepelna-pohoda-a-nepohoda)
- Template:Mefanet

Refernces

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