

THERMO-REGULATION

Terms you will become familiar with in this module

homeostasis	thermoregulation
hypothalamus	interstitium
receptor	oedema
radiation	hypovolemic shock
conduction	cellular shock
convection	metabolism
space blanket	pallor
vapourisation	hypothermia
basal core temperature	antibodies
vaso-constriction	pyrogens
thermostat	axillary temperature
hypothermia	tympanic temperature
ischaemia	rectal temperature

INTRODUCTION

Life can only be maintained with a constant source of energy. The energy in living organisms comes from chemical reactions. Chemical reactions use energy and they produce energy. Some of the energy they produce is in the form of heat. As long as we are alive, heat is produced.

Millions of chemical reactions are constantly taking place for the body to function: moving our muscles, breaking food down to its basic parts and repairing injuries. Even learning uses energy.

The healthy human maintains an almost constant internal temperature to provide an environment that is optimal for the body to function. If it becomes overheated or cools too much, it cannot perform its normal functions, the chemical reactions it needs to make energy do not occur and illness quickly results.

The balance between retaining too much heat and losing too much heat is part of the physical and chemical condition called **homeostasis**. Temperature control is the essential part of maintaining homeostasis. Apart from glands which act as natural internal body temperature regulators, humans consciously use clothing and heating and cooling devices to help maintain their temperature at a constant level.

ANATOMY & PHYSIOLOGY

Heat is produced constantly by the body - even if we do not exert ourselves - so the body needs ways of removing the heat it produces. When it cannot release heat, the body temperature begins to rise by about 1- 2 degrees an hour until we die [above about 40^o, cells cannot easily perform their normal operations so they can begin to break down - brain cells are among the most sensitive to uncontrolled temperature change].

Activities

Very occasionally, endurance athletes such as marathon runners lose their ability to maintain internal body temperature at a constant level.

In discussion with medical staff, find out what happens in such cases and how they are treated. Why is this a more dangerous problem for occasional runners in a fun-run?

To maintain constant temperature, heat loss from the body must vary with changes in heat production caused by factors such as: physical activity, food intake, type of food eaten, outside temperature and the condition of certain **glands** in our body.

Balance between heat production and loss in the body is controlled by the **hypothalamus**, a gland with a built-in thermostat situated at the base of the brain. It receives messages about body temperature from the temperature of the blood circulating through it and from special sensors [**receptors**] which are part of the skin. When the hypothalamus is damaged, the body has almost no protection against over-cooling or over-heating.

Heat loss to the atmosphere

Most heat loss takes place through the skin, but some loss also occurs through the lungs and body excrements. Heat is most commonly lost from the body by the following processes:

Radiation loss occurs when heat is transferred into the air from the skin because the surrounding air is cooler than the body. We usually control this heat loss by wearing warm clothes.

["warm clothes" are materials that trap layers of air within their mesh or between the body and the external environment. Air is a poor conductor of heat so a layer of trapped air catches heat close to or against the body and prevents its loss A hat with a high peak is therefore more effective than one which sits flat on the scalp.]

Questions

A 'space blanket' is not very warm to touch and it does not need to be in contact with the skin to warm the body. How does it prevent radiated heat loss?

Conduction occurs by physical contact with an object or substance that is cooler than body temperature. For instance sitting on a cold floor or in cold water, breathing in cold air, drinking a cold drink. Since humans usually protect themselves with clothing, loss of heat from the skin through conduction is usually quite small.

Questions

Surf riders and long distance swimmers often wear a 'wet-suit' made of fine foam rubber which gets wet and then feels comfortable warm. How does the wet suit work? How does the wet suit help prevent heat loss by conduction?

Convection: Heated air rises and is replaced by cooler denser air. This movement is called convection and heat is lost from the body by convection air currents. As the skin warms the air in contact with it, the air moves upwards and is replaced with cooler air which is then also heated and the process continues - all the time. Fans and cool breezes accelerate the convection effect while clothing prevents the flow of air across the skin and reduces heat loss by convection.

Vaporisation refers to heat lost when water evaporates. Water needs heat to turn to vapour so vapour loss results in heat loss from the body. Some vaporisation occurs in the lungs. Exhaled air is saturated with water vapour from the lining of the lungs. The average loss of water by vaporisation from the lungs is about 300 mls daily. Most vaporisation occurs through the skin as perspiration. The amount lost through perspiration varies greatly with the temperature and relative humidity of the external air. The body can lose up 1.6 litres of sweat in a single hour!!

Temperature regulation

The body's thermostat, the hypothalamus, receives messages about the body's temperature from the blood circulating through it and from special receptors in the skin which send messages directly. The mechanisms activated by the hypothalamus to control temperature are so powerful that the internal **basal core temperature** rarely varies more than a few tenths of a degree. The range of temperature in healthy young adults varies between 35.8°C and 37.4°C with an average of approximately 37°C Centigrade.

Temperature regulation is poorly developed in newborn babies and is especially lacking in premature babies. In infants, a fit of screaming can cause a marked rise in body temperature. Warm and cold baths also alter the temperature of a baby more than an adult.

Questions

If energy is used by the infant to scream, what must be true about the chemical reactions needed to create the physical effort for the screaming?

Suggest why the basal core temperature of a small child would be more likely to change in a cold bath than that of an adult? What does this suggest about the effect of leaving an infant in a closed car on a warm day?

Activities

Take your own pulse rate per minute, respiration rate per minute and temperature. Exercise vigorously for five minutes and take your pulse, respiration rate and temperature again when you stop. Repeat the measurements after another five minutes of resting. How fit are you?

If your starting and final measurements are close to the same, you have recovered your approximate balanced or homeostatic state.

Consider the screaming infant in the previous question: does physical activity in an adult relate to physical activity in a small child? What would you expect to happen to the infant's pulse and temperature as it started screaming?

The temperature of elderly people is usually below normal. The body is less active, the circulation is not as strong, and they are less able to compensate for changes in external environment.

Questions

Nursing staff and relatives sometimes complain about how older people keep their houses too hot and stuffy and wear too many clothes.

What reasons can you provide for the actions of these older people?

Will they benefit by lowering the temperature or opening windows to let in the 'fresh air'?

In an age when nutrition and health care have combined to increase the average age of the population and extend life expectancy, what changes might need to be made in environment control in medical centres? where would these changes need to be reversed?

For normal people, temperature varies on a daily basis. The temperature is lower in the morning after a sleep when there is no food intake and reduced activity. It is higher in the evening after a day of action and food digestion. Normal temperature varies by approximately 0.6° to 1.7° [for a healthy young adult whose average temperature is 37°C].

For women, there is a variation in basal core temperature during the menstrual cycle. Ovulation occurs at the low point of the monthly temperature curve and the temperature then rises to a cyclical high point about 24 hours after ovulation.

CASE STUDIES

Because temperature control has an immediate effect on all other body systems, two case studies have been included.

Case study 1: The skiers

Gina Mitakis and her friend Lucy Wilkinson are strong, athletic 15 year old females. They are very excited about their first trip to the snow and intend to try skiing because everyone else wants to try snow-boarding. At 3pm they have begun to feel confident on the snow and try a more difficult 'blue' run. They reach a steep

section with ice. Lucy falls. She slides off the slope and into the trees. One ski comes off as she falls but the other one stays on and breaks in the crash. Gina climbs down to Lucy and sees that she is bleeding just below the knee of her left leg. Gina tries to remove the broken ski from that boot but Lucy screams that her leg is broken.

The girls don't know what to do. Gina says she will get help but Lucy cries that she doesn't want to be left alone. Lucy stays and helps Gina take off her ski pants to see where the blood is coming from. It takes a long time because of the pain but the girls discover that the leg is broken and the end of the bone has broken the skin. Gina has begun to shiver and her fingers and lips are looking blue. She tries to hunch up to get warm but her leg can't move and it is too painful to put her pants back on. Lucy says that she must go for help but she leaves her coat for Gina to wrap herself in.

Questions

How is Gina probably losing most heat from her body? What effect would the broken leg have on Gina's ability to regulate her own body temperature?

Would her temperature rise or fall as a result of the fracture? Neither of the girls seem to notice the cold at first. Use reference books to discover the effect of emotional shock and physical trauma on adrenalin secretion.

What effect does adrenalin have on body temperature regulation?

What warming equipment would you expect the ski patrol to carry on their stretcher sled?

What effect will the immobilisation of the fracture, the moving onto the stretcher and the sled trip to the base have on Gina's temperature?

Normal response to a drop in external temperature is a feeling of cold. The hypothalamus responds with skin constriction to reduce surface area and raise hairs to trap air [not very useful for humans but cold cats and dogs 'fluff up' more effectively]. Skin changes colour especially that on your hands and feet. The change in skin tone is due to blood vessels being shrunk [**vasoconstriction**] so that they carry less blood to the surface where it would lose heat by radiation then convection. Lack of blood flow to the skin causes the pinkishness to turn to white and blue - and ultimately black. Before this, shivering begins and conscious tensing of muscles. We hug our arms to ourself or crouch in a foetal position. Sometimes we try to keep warm by

jumping up and down or walking around. Eventually, because our body is too cold to keep producing energy, we become drowsy and fall asleep - and keep losing heat

Shivering, moving and tensing up our muscles increases activity within the body and therefore produces heat. Moving to a warmer environment and putting on clothing have more obvious effects.

When we are hot, our skin changes colour to red. We sweat. To reduce the discomfort, we drink cool drinks, seek shade or a fan. We wear light, open clothing as as little as possible.

Questions

If our skin goes pale because of vasoconstriction, how does our “thermostat” cause the skin to go red?

Consider why cooling by evaporation is not as effective in a very hot and humid climate as it is in a very hot and dry environment? Why might athletes be more likely to suffer **hyperthermia** competing in hot, humid conditions than by hot dry conditions? Would swimmers suffer the same problems?

Case Study 2: The Burn victim

Eleven year old Darren McGuire was sleeping beside an open fire when his clothes caught alight. In panic he screamed and ran through the house looking for his parents. By the time his mother woke and threw her blankets over him to put out the fire, Darren was suffering burns to 60 per cent of his body. His hands and arms appeared to be burnt to full depth while his chest, face and upper back were blistered and weeping [supperating] by the time he was brought into the emergency section of your medical centre.

Medical staff inserted a saline drip in a vein in his unburnt ankle and left Darren uncovered on the trolley while they attended to the next emergency.

Questions

Because Darren is unclothed, he will lose body heat by normal processes. What difference will the loss of body fluid into the blisters and from the full depth burns make to the rate of heat loss?

How would you reduce the heat loss without placing anything in direct contact with Darren's extensive burns?

With large expanses of skin burnt, Darren's hypothalamus may not receive accurate information about his core body temperature. How could his body temperature be maintained during the early stages of his treatment in the medical centre? What temperature levels would you expect to find in the intensive care wards of a dedicated burns unit? Suggest reasons why these levels might not be maintained.

Human skin can tolerate temperatures up to 40⁰ C, but cellular destruction follows exposure to temperatures above 45⁰ C. Skin and deeper tissues are injured by direct cellular injury and delayed progressive **ischaemia** [death of tissue due lack of blood flow)].

Severe burns produce devastating physical and psychological effects. Therapy ranges from initial resuscitation to eventual surgery and rehabilitation. Burns patients are most effectively treated by specially trained staff in an isolated environment controlled in temperature and humidity.

With burns to over 50% of the body, a large amount of skin is damaged. Because the skin plays a major role in **thermoregulation**, damage to a large portion alters the body's ability to regulate its own temperature.

Damage to the blood vessels means that circulating blood volume also decreases. This also interferes with thermoregulation.

Cells within the body are destroyed by burns. The cells, together with the blood, contain the body's electrolytes and fluids.

Damage to cells results in a loss of both fluids and electrolytes. Loss of electrolytes causes a serious alteration in *homeostasis*. Among other things, this can change cardiac activity. When the heart does not operate properly, it is unable to distribute blood effectively throughout the body. This adds to the problem of circulating volume.

Altered electrolyte balance can also cause **fluid shifts**. Fluid is normally kept in a balanced state in the body. It is distributed throughout the blood vessels, the cells and the space between the blood vessels and cells (the **interstitium**). A number of important factors help to control this state of fluid balance.. Electrolytes are vital in maintaining the balance as is the integrity of the walls of the blood vessels. The amount of pressure placed

on the walls of the blood vessels by the circulating blood volume plays a part as well.

When someone is seriously burned, electrolyte balance is impaired, the vessel walls are damaged and fluid shifts into compartments where it is not normally present in large amounts. Marked swelling [**oedema**] occurs. This means that even less fluid is available to circulate through the veins and arteries.

The metabolic shifts created by the tissue damage and fluid shifts create a condition known as **burn shock**. This is a combination of **hypovolemic shock** and **cellular shock**. It is therefore important to maintain environmental temperature at an appropriate level.

Activity

Regulating a burns client's temperature can be more difficult than expected. A range of inter-related factors make temperature control a very complicated issue.

Use your reference sources and discussion with nursing and medical staff to consider the following. Establish the effects these conditions would have on the basal core temperature of a normally healthy adult male.

- Burn tissue is very susceptible to invasion by bacteria causing infection. [About 50% of burns victims who die do so because of systemic infections).

-Airway injury to lung and respiratory cells can be caused by direct flame injury, smoke inhalation or toxic fumes from burning clothes or other combustibles.

-*Metabolic* effects of burns relate to electrolyte imbalance: if a persons *metabolism* can increase due to nitrogen loss. What happens to the basal core temperature if metabolic rates increase (increased chemical activity)? What could happen if a client is cooled too quickly while he/she is suffering an electrolyte imbalance?

ABNORMAL VARIATIONS IN BODY TEMPERATURE

High external temperatures

Heat exhaustion: [Often referred to inaccurately as 'heat stroke']. A person subjected to high external temperatures may perspire so much that heat exhaustion occurs. Temperature

regulation is so important to the body that it takes priority over other important homeostatic mechanisms like fluid and electrolyte balance. It allows the body to lose essential products such as water and salt by perspiration. Water and sodium chloride (salt) are vital to bodily function. So excessive perspiration *without constant fluid replacement* can cause severe **dehydration** and **sodium chloride loss** which results in severe muscle cramps, **pallor**, low blood pressure, dizziness, weakness, nausea, vomiting, and fainting.

Heat stroke: Heat stroke occurs when a person is exposed to high temperatures and has inadequate cooling defenses. It is an extremely serious condition and usually occurs in people who have pre-existing acute or chronic disease causing a malfunction in the normal cooling process. The malfunctions usually result in inadequate or non-existent sweat secretion during exposure to extremely high temperatures. When a major pathway of heat loss, such as the evaporation of sweat, is prevented, the body temperature rises very quickly. Typically the affected person's skin is dry and flushed. If untreated, the person becomes unconscious and death almost always occurs if the body temperature rises above 46°C.

Questions

In the James Bond film, *Goldfinger*, a young woman is completely painted with gold paint. She dies. What effect would the coating of paint have on the woman's ability to perspire? What might have been the effect on the woman if only 70 per cent of her body had been painted?

Low external temperature

Hypothermia: Exposure to excessive cold or immersion in very cold water can cause the basal core temperature to fall by several degrees. This creates a feeling of exhaustion and an uncontrollable desire to sleep. Respiration slows down, blood pressure drops, oxygen uptake from the blood decreases and as cerebral metabolism slows down, unconsciousness [coma] follows.

When the body temperature falls below 34°C, the body's thermostat, the hypothalamus, cannot operate properly and temperature regulation is impaired. It is lost completely when the body temperature falls below 28°C.

[Frostbite is a condition created by impaired circulation to the hands, feet and other exposed parts such as the ear lobes and the tip of the nose. It is caused by vasoconstriction and possibly the formation of ice crystals within the cells. Because water expands below 4°C as it crystallises, the microscopic cell structures are broken open and the cells are irreparably damaged].

Hypothermia can be artificially created for therapeutic purposes. During surgery on the heart, or any of the large blood vessels or blood vessels supplying the brain, it is necessary to interrupt the blood flow to those areas. Artificially lowering the body temperature decreases metabolism, the chemical activity occurring in the body, and the body's need for oxygen is reduced. As a result, circulation can be interrupted for a much longer time without damage to the brain if core temperature is deliberately reduced.

Questions

Many species of bears hibernate during winter. If they are woken from hibernation, they usually die.

How do the effects of hypothermia suggest the reason for the death of the hibernating bear after its wakening?

Fever

Fever is an elevation of the body temperature beyond the normal range.

The most frequent cause of fever is infection. Less frequently it can be caused by a drug or a brain tumour affecting the hypothalamus.

The exact significance of a fever is not fully understood. It is known that bacteria and viruses do not multiply well at higher temperatures. It is also known that the body manufactures *antibodies* (infection fighting cells) more readily at high temperatures. In the presence of bacteria or viruses the body produces **pyrogens**. These are large molecules that act to “turn up” the setting on the body's thermostat. The thermostat with its new setting of, for example, 40°C will put into action all the mechanisms for heat production and minimisation of heat loss to raise the temperature to the new level.

Questions

Recall the mechanisms which act to maintain a constant basal core temperature.

How do the metabolic changes related to a heightened fever temperature result in us feeling cold?

Once the new temperature is reached it is regulated at that level. It will stay there until a new factor breaks the disease process [for example the use of antibiotics to destroy bacteria] and the body's thermostat is turned down again. Now the mechanisms for heat loss are activated, vasodilatation, and sweating occur. [This is the origin of the the belief in “sweating out” a fever]

Some drugs [**Aspirin** and **Paracetamol**] can cause a decrease in body temperature and are used in the case of extremely high temperatures. Some drugs lower both a *normal* body temperature and a fever temperature. Morphine and general anaesthetics have this effect.

Alcohol causes vasodilation [increased blood flow to the skin]. This makes the skin appear flushed and actually feel warm, however it is a false assumption that alcohol will warm you up in a cold environment.

Questions

Why would it be dangerous for first-aid teams to use alcohol as a stimulant for people rescued from freezing conditions?

Warnings against the use of alcohol with some medications are printed on packs of prescription drugs.

What effects might a combination of alcohol and prescription drugs such as paracetamol have on body temperature?

TAKING THE TEMPERATURE

The close observation and monitoring of body temperature in ill persons, especially small children and others whose temperature regulating mechanisms are unstable, is important. The temperature may be taken in the mouth, the rectum, under the arm (axillary), or in the ear (timpanic).

The familiar **mouth temperature** is most variable because it is affected by eating hot or cold foods, smoking, breathing and talking. An oral thermometer should be placed under the tongue and left in place with the mouth closed for 2 -3 minutes.

The **rectal temperature** is an accurate guide to internal body temperature and generally reads about 0.4 degrees higher than oral.

Axillary temperature is about 0.7 C cooler than mouth temperature and may be influenced by the presence of sweat. The thermometer needs to be under the arm for at least 5 -7 minutes.

Timpanic temperature is also very accurate and using a highly sensitive device it takes only seconds to register an accurate temperature.

Activity

Core temperature can be taken by **insertion of a thermometer into the bladder**. Though this is very accurate and can be monitored continuously, it is not a common method. Using your reference books and discussion with clinical staff, discover why the method is not more widely used.

References

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