Body temperature and its regulation

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Abstract

Humans are homeotherms, i.e. they fix their temperature regardless of their environment. This is vital for normal cellular function and for metabolism to be independent of external temperature. The body has a warm 'core' and a cooler peripheral 'shell' whose role is to regulate heat transfer in and out of the core. Body temperature is controlled by a feedback system with both peripheral and central sensors, and an integrator located in the hypothalamus. Anaesthesia exposes patients to thermoregulatory challenges due to enhanced heat loss from the core to the shell to the environment, and interference with the hypothalamic temperature 'set-point'. In extreme circumstances, deliberate hypothermia may provide benefits that outweigh the risks.

Keywords Heat loss; temperature regulation; thermoregulation; hypothermia

Royal College of Anaesthetists CPD Matrix: 1A01

Learning objectives

After reading this article, you should be able to:

- understand why the human body maintains a core temperature within defined limits (*homeothermy*)
- understand the mechanisms responsible for maintaining homeothermy
- explore the consequences of deviations from optimal core body temperature and when these may occur
- understand the effect of anaesthesia and surgery on body temperature regulation

Why is body temperature important to maintain?

Man is a *homeotherm*: an organism that maintains a fairly constant core body temperature, largely independent of its environment. In our case, this core temperature is usually between 36.1°C and 37.8°C, and it varies with a well-defined circadian rhythm, being 0.5°C cooler in the early hours of the morning than it is in the late afternoon. In women there is also an element of monthly rhythm to body temperature, with core temperature rising around 1°C following ovulation.

The reason for homeothermy is the temperature dependence of the enzymatic reactions underlying all cellular functions. At higher temperatures (>42°C) cellular proteins are damaged and cells die, whereas when cooler (<36.1°C), the rate of reactions drops – reducing cell, and hence bodily, function (see Figure 1).

The shell and the core

To understand the regulation of body temperature, one must think of the body as two separate compartments:

- The *core compartment* containing the main heat producing organs at rest: the brain, thoracic and abdominal compartments.
- The *peripheral shell* comprising the skin and subcutaneous fat, most importantly that of the limbs, that is cooler and acts as insulation for the core compartment.

The core compartment contains those organs most susceptible to temperature damage, and the relative importance of protecting this internal milieu is illustrated somewhat by the finding that responses to 1°C change in core temperature are nine times that of responses to 1°C changes in peripheral temperature.

Heat is transferred between the two compartments via the circulation, and in this article the specialized mechanisms of the two compartments to preserve and generate, or dissipate heat energy, shall be explored.

How is a change in temperature sensed?

Body temperature regulation functions as a feedback loop system. The set point is defined by the hypothalamus, and it is here where integration of error signals from the central and peripheral temperature receptors is thought to occur, and most effector responses originate (see Figure 2).

Situated in the walls of the third ventricle, superior to the pituitary gland, the hypothalamus contains the most important central temperature receptors, but there are also contributions from temperature receptors in the spinal cord, abdominal viscera and in the walls of the great vessels. These centrally positioned temperature receptors predominantly respond to temperature rises, as might be expected given that an upward deviation in core temperature is potentially more injurious than a downward one.

The peripheral temperature receptors are situated in the skin. With a rapidly adapting firing pattern, there are both cool receptors (maximally firing at 25°C) and warm receptors (maximally firing at 44°C); however, the cool receptors predominate. Their signals are transmitted via the spinothalamic tract in the spinal cord to the thalamus, and then to the hypothalamus.

The integration of these two inputs occurs in the hypothalamus, and whereas the anterior hypothalamus (preoptic area) is thought to trigger mechanisms of heat loss, the posterior hypothalamus promotes heat conservation and generation.

How is body temperature altered?

To explain how these mechanisms of heat loss or conservation occur, it is necessary to understand the various modes by which heat transfer can occur. These phenomena are described here,

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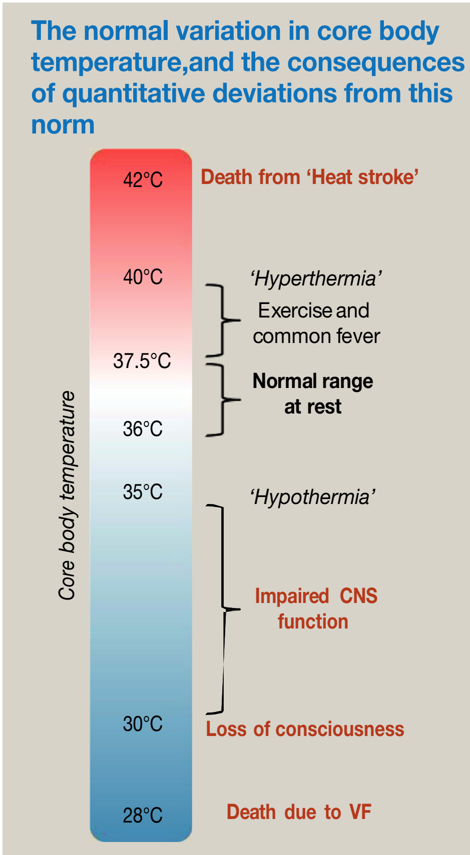

Figure 1

with the percentage heat loss each contributes to a naked human in an ambient temperature of 21–25°C given in parentheses.

- *Radiation* (60%) – this involves the transfer of energy by infrared rays from a hotter body to a cooler one. Although a major component of heat loss for naked human at 21–25°C, person can also absorb radiant heat in direct sunlight or from open fire or radiator. As

  $$\text{Radiant heat loss} \propto (\text{Temperature difference between two bodies})^4$$

  it is clear that reducing the temperature of the peripheral shell, such that it is closer to the ambient temperature, can drastically reduce radiant heat loss.

$$\text{Body heat} = \text{metabolic heat production} \pm (\text{conductive, convective and radiant heat exchange}) - \text{evaporative heat loss}$$

- *Evaporation* (20%) – water requires heat energy to convert it from a liquid to a vapour. This is called the *latent heat of vaporization* and for water has a value of 538 kcal/kg. Daily insensible loss is around 800 ml at rest, but as shall be explored later, sweating can drastically increase this form of heat loss.
- *Convection* (15%) – this involves transfer of heat by the motion of a gas or liquid across a surface, sweeping away skin-warmed air molecules. Normally this can be minimized by clothing, which traps the air next to the skin. A strong wind can increase convective heat loss markedly –

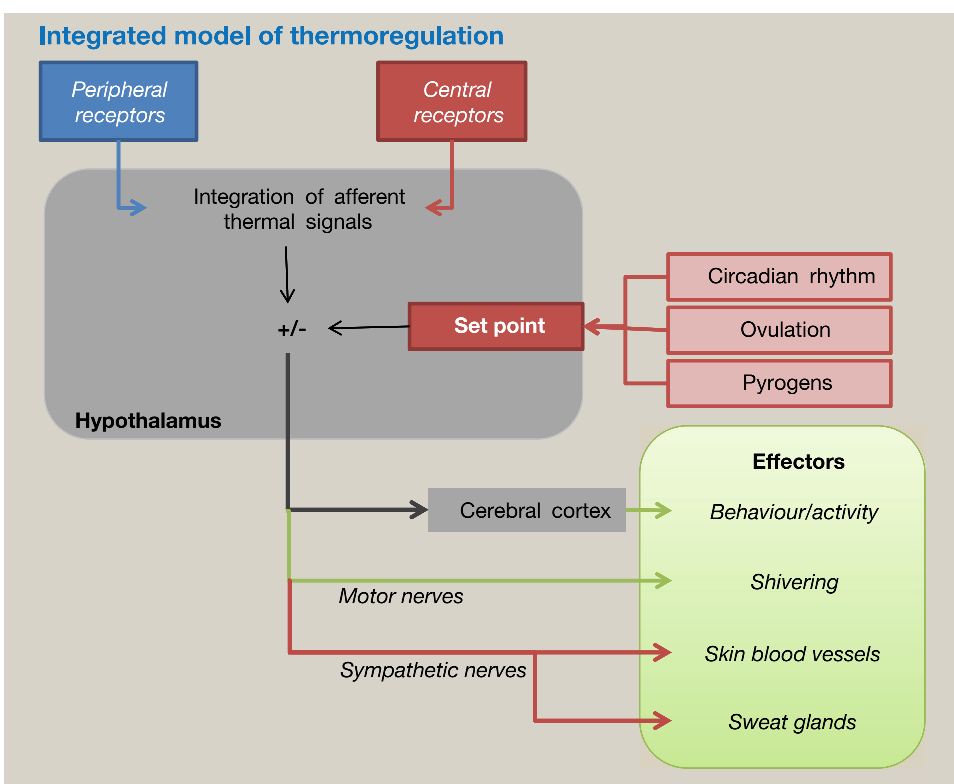

Figure 2

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