THERMOREGULATION

Energy is the capacity of a system to perform work and it may exist in several different forms including mechanical, electrical, light, and kinetic.

Temperature is a measure of the average kinetic energy of individual atoms and molecules that make up a substance.

Heat is the transfer of kinetic energy from one medium or object to another, or from an energy source to a medium or object.

Specific Heat is the amount of energy per unit mass required to raise the temperature of the substance by one degree (Celsius or Kelvin)

Latent Heat is the amount of energy released or absorbed during a change of state (eg from solid to liquid). This is important from a physiological perspective with regard to evaporative heat losses.

Radiation is the transfer of heat by infrared electromagnetic waves from a warm object to a cooler one. It depends of the fourth power of temperature difference. Therefore if the temperature of the OT is raised by 2 degrees decreasing the temperature difference between the body and the ambient air by 2, radiation heat loss is decreased by a factor of 16 (2^4). It accounts for up to 60% of heat loss.

Conduction results from direct contact of the skin with a cooler substance and accounts for only 1-2% of heat loss.

Convection relates to the layer of air in direct contact with the skin, when it is disturbed insulative properties are removed and this may become significant accounting to up to 25% of heat loss.

Evaporation refers to the energy expended to do vapourisation of water, literally the heat loss due to the latent heat of water. It usually accounts for <10% but this increases dramatically with increased sweating and in pathological states and surgery.

Shivering is an involuntary contraction of muscle fibres occurring in an uncoordinated pattern in which fibres contract and relax out of phase with one another causing an increase in ATP hydrolsis which produces heat. It can increase heat production five fold but cannot be sustained for long periods of time.

Non shivering thermogenesis is whereby the energy of metabolism is dissapated as heat and none is stored as ATP. It is due to the uncoupling of oxidative phosphorylation in brown adipose tissue. It is particularly important in neonates where it can increase heat production three fold.

Thermoneutral zone refers to the range of environmental temperatures over which metabolic heat production is minimal and thermoregulation is maintained by vasomotor activity. In a 70kg naked man, the thermoneutral zone is 27-31 degrees. Above and below this range are critical temperatures where a further increase or decrease leads to an increase in metabolic activity.

Hypothermia is defined as a core temperture less than 35 degrees. When the temperature falls below 35 there is muscle weakness, resulting in decreased mobility and decreased shivering. At temperatures below 34 degrees mental confusion occurs and consiciousness is lost between 32 and 30 degrees. Hypothermia also decreases the heart rate by slowing the rate of discharge from the sinoatrial node. At core temperatures below 28 degrees cardiac arrhythmias are frequent and ventricular fibrillation may occur.

Hyperthermia under conditions of extreme heat the thermoregulatory mechanisms may fail and cause either heat stroke, heat exhaustion or heat collapse. Heat stroke is characterised by a loss of energy and irritability progressing to neurological disturbances caused by a complete loss of thermoregulation. Cessation of sweating appears to be the primary cause of this loss of thermoregulation. The individual becomes unconscious as the core temperature rises above 42 degrees. Cellular damage and coagulation of protiens with high core temperatures lead to death.

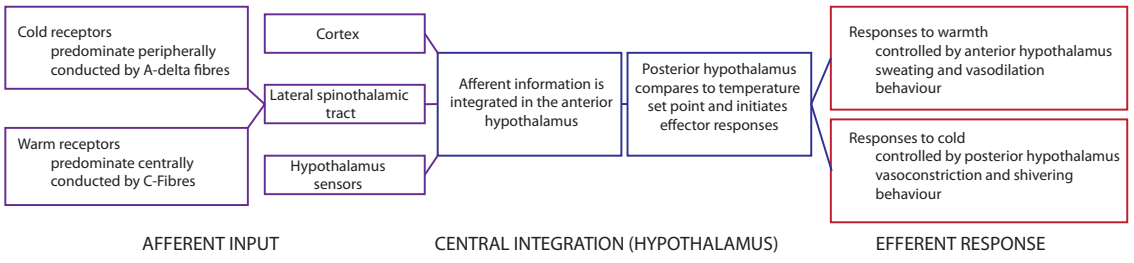
Heat production and loss

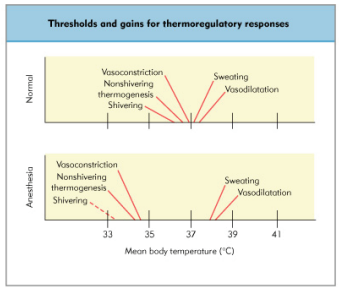
Total body heat content is the balance between heat production and loss. Heat may be lost in the by radiation, conduction, convection and evaporation (see above for definitions), Heat is produced by metabolism, shivering, nonshivering thermogenesis and exercise. Basal metabolic rate which is defined as the energy cost of maintaining homeostasis at rest, amounts to 40 kcal/m^2/hr, or approximately 1700 kcal/day for an average 70kg male. BMR is independent of thermoregulatory mechanisms, higher in children and increased by hormones such as thyroxine, catecholamines and growth hormone. The amount of heat produced by cellular metabolism is dependent on the metabolic substrate. Glucose and protiens produce about 4.1 kcal/kg whereas fats release about 9.3 kcal/kg. Around 2/3 of energy produced during the metabolism of carbohydrates, protiens and fats is dissapated as heat, the remainder being stored (usually as ATP). Heat may also be produced by exercise, shivering and non shivering thermogenesis. The principle autonomic mechanisms whereby heat is preserved and heat production increased are vasocontristriction and shivering. Behaviour including exercise is the important conscious mechanism of preserving and increasing heat production. Exercise may increase production by up to 20 times. Other behavioural mechanisms include warm clothing, shelter and moving towards or creating a heat source.

Table 67.1 Mechanisms of heat production and heat loss

Heat production	Heat loss
Basal metabolism (40 kcal/M^2/h)	Radiation (60%) Increased in vasodilatation; depends on $(T_1-T_2)^4$
Shivering; can increase heat production sixfold	Evaporation of sweat (17%) 0.58 kcal lost per kg sweat
Nonshivering thermogenesis (neonates); can increase heat production threefold	Convection (20%)
Exercise; can increase heat production 20-fold	Conduction (1%)
Behavior (e.g. use of warm clothing, taking shelter, move towards heat source, etc.)	Behavior (e.g. reduce clothing, reduce activity, seek shade, etc.)

Simplified thermoregulatory control system





Neonate temperature regulation

differs significantly from adults due to increased losses, impaired responses and a higher degree of brown adipose tissue required for non shivering thermogenesis

more rapid loss
- high SA to weight ratio
- high BMR (double adult rate per unit SA)

impaired responses
- poor vasoconstriction
- no shivering
- no sweating
- limited behavioural responses

increased response
- non-shivering thermogenesis from brown fat

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