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Articles

Fetal and Neonatal Thermal Physiology

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ABSTRACT

Humans have the ability to regulate their body temperature in a narrow range. Infants have decreased ability to regulate their body temperature, producing heat through non-shivering thermogenesis. This review describes the physiology of non-shivering thermogenesis in the term infant and the deficiencies inherent in premature birth related to heat production. Heat loss occurs due to radiation, conduction, convection and evaporation. These factors influence neonates after birth and contribute to periods of heat loss.

Thermoregulation in Humans

Humans are homeothermic in that they can regulate their core body temperature within a narrow limit. Core (internal) body temperature is maintained at approximately 37 °C, but ranges from 36 °C to 37.5 °C.[1] Humans require precisely regulated body temperature because large elevations in temperature can cause nerve malfunction and protein denaturation, and the brain ceases to control temperature after large increases. Heatstroke and brain lesions may occur at 41 °C or higher and 44 °C is probably the absolute limit of survival.[1] Alternatively, severe hypothermia will cause the heart to slow down. Once the internal body temperature reaches 25 °C humans will suffer cardiac standstill and further decline will result in death.

Temperature is regulated by balancing heat production against heat loss, a balance that is continuously being disturbed by changes in metabolic rate or external environment.[1] Human thermoregulation, or the control of heat generation and transfer of heat, is controlled through thermal sensors, afferent pathways, an integration system in the central nervous system, efferent pathways, and target organs.[2]

Central and peripheral thermoreceptors sense the alteration in temperature on the skin and internally. Peripheral thermoreceptors are free nerve endings that are distributed over the entire skin surface and are thermosensitive.[2] These peripheral thermoreceptors provide information that is sent forward through the temperature control pathway and have the ability to detect warm or cold areas on the skin.[1] The skin thermoreceptors provide, by way of afferent nerve fibers that carry sensory information to the hypothalamic regulatory center, an early warning when there is a change in the ambient temperature of the skin. Behavioral reactions are triggered through these sensory impulses which travel by thalamic pathways to the cerebral cortex. Central thermoreceptors are located in deep body structures found mainly in the spinal cord, abdominal viscera and in or around the great veins.[1] Deep thermoreceptors are mainly concerned with detecting cold, rather than warmth and will shift blood flow in order to reduce heat loss in a cold environment.[1,2] This feedback system modifies heat transfer rates to restore core temperature to its regulated level once they detect a core temperature that is colder or warmer than normal.

Peripheral and central thermoreceptors send information to the brain control center, the hypothalamus, which enables signals to be sent through neuronal pathways. The principal area of thermoregulatory regulation is the preoptic and anterior hypothalamic nuclei of the hypothalamus.[1] Changes outside the normal set of thermal conditions will cause the hypothalamus to send efferent commands to alter the rate of heat generation and modify the rate of heat transfer within and from the body.

Neuronal effector mechanisms attempt to increase or decrease body temperature through sending signals by way of sympathetic nerves going to the sweat glands, adjusting smooth muscle tone of cutaneous arterioles to control blood flow to the skin surface, activating motor neurons to the skeletal muscles or activating chemical thermogenesis.[1] In humans other than infants, changes in muscle activity constitute the major control for temperature regulation. In the case of cold exposure, the hypothalamus causes motor neurons to the skeletal muscles to produce shivering which is oscillating rhythmical muscle contractions and relaxations occurring at a rapid rate. The rapid muscle contractions produce heat and can be called shivering thermogenesis. When there is too much heat, basal muscle contractions are reflexively decreased and voluntary movement slows.

The autonomic system controls cutaneous blood flow over most of the skin, the body's largest organ. The flow of blood to the skin is the most effective way to transfer heat from the body core to the skin.[1] A minor reduction in cutaneous blood flow is caused by cutaneous vasoconstriction, mediated by sympathetic nerves because of changes in core body temperature, which causes heat to be conserved. If the heat load increases, the autonomic nervous system activates the

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eccrine sweat glands, which cause sweat to be secreted onto the skin's surface. Sweating increases the partial pressure of water vapor on the skin and causes evaporation and loss of heat. One of the most important variables in control of body temperature is the deviation of skin temperature from its preferred level.[2]

Chemical thermogenesis provides heat without muscle activity by increased sympathetic stimulation causing increased norepinephrine and epinephrine circulation in the blood leading to an immediate increase in the rate of cellular metabolism.[1] Chemical thermogenesis, also called brown fat metabolism or non-shivering thermogenesis (NST), is the primary method of heat production for the infant up to 1 year of age (see Fig. 1).[3] The degree of chemical thermogenesis that occurs in an animal is almost directly proportional to the amount of brown fat that exists in that animal.[1]

Heat Transfer

Heat is a by-product of metabolism. The metabolic rate of the body (rate of heat production) is determined by the basal rate of metabolism of all body cells and extra metabolism caused by muscle activity, thyroxine on the cells, sympathetic stimulation of the cells, and an increase in chemical activity in the cells themselves.[1]

Human thermoregulation attempts to keep body temperature in a steady state, in which heat production equals heat loss. The rate at which heat is lost depends on how rapidly heat can be conducted from where it originates within the body and how fast heat can be transferred from the skin to the environment. Insulation from heat loss is accomplished through the skin barrier, subcutaneous tissues and fat.[1] Conduction of heat through fat is reduced by one third when compared to other tissues in the body. Researchers have found that human body temperature will vary by 1 °C for every 25° to 30 °C of change in environmental temperature.[1] Heat is lost to the environment through radiation, conduction, convection and evaporation (Fig. 1).

Heat decreases or increases by way of *radiation*, which is the process by which all body surfaces emit heat in the form of electromagnetic waves.[1] Human bodies radiate heat in all directions and heat is also emitted from non-human surfaces. The rate of heat loss is proportional to the temperature difference between the skin and the radiating body. For example, heat can be transferred from the infant's body to a colder wall near the infant. Alternatively, heat may be absorbed into the skin from a heat source near the infant. After the first week of life, radiation becomes the most important route of heat loss in premature infants and is as high as 60% of total heat loss in adults.[1,4]

Moreover, heat transfers to or from the skin surface by way of *conduction* when the skin touches another solid object of a different temperature.[1] Surfaces should be warmed in the neonatal unit to prevent heat loss by conduction. Heat moves from molecule to molecule as the molecules from the skin surface and another surface collide. This object might be air, water, or a solid surface on which the infant rests. About 3% of heat is lost to surfaces in adults and 15% is lost to the air.[1]

Heat is transferred by *convection* through moving air or fluid over the body surface.[1] If the body surface is warmer than the surrounding environmental air, heat is first conducted into the air then swept away by convective air currents. Warm molecules are less dense and therefore rise into the air from the skin. Adults lose about 15% of their heat through convection.[1] An infant can lose heat to the air when moved through a cold room such as after birth in a delivery room.

Heat is lost through *evaporation* when water is transmitted insensibly through the skin and membrane linings of the respiratory tract.[1] Evaporation causes 0.58 kcal of heat to be lost for every 1 g of water that evaporates from the body. In an adult, there is a continual loss of 600–700 ml/day of water, which equals 16–19 cal per hour.[1]

A neutral thermal environment promotes a stable body temperature at rest. Sauer has defined the neutral thermal environment for infants as the ambient temperature where the premature infant's body temperature is between 36.7° and 37.3 °C at rest with the core and skin temperature changes of less than 0.2° to 0.3 °C/hour respectively.[5] Heat loss or gain through radiation, conduction, convection and evaporation would be minimal in a neutral thermal environment and promote thermal stability.

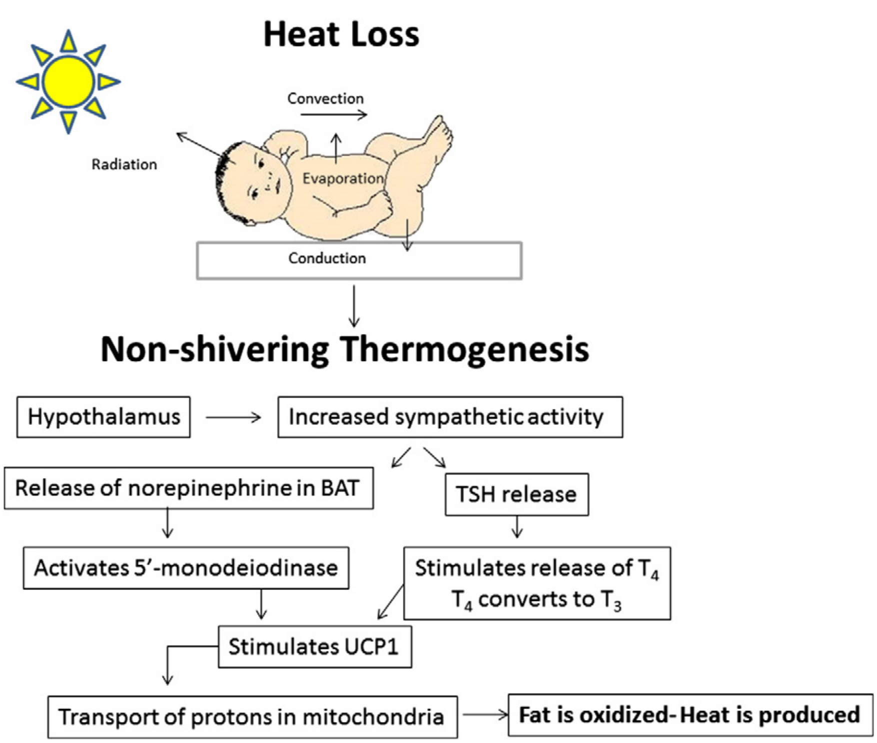

Fig. 1. Non-shivering thermogenesis and heat loss. (Color version of image can be found online.)