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Physiology, Thermal Regulation

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Introduction

Normal Body Core Temperatures [1][2]

- The normal core body temperature range can vary from individual to individual, and can also be influenced by age, activity, and time of day: 36.1 C (97 F) to 37.2 C (99 F).
- During strenuous exercise, the temperature can rise temporarily to as high as 40 C (104 F).
- When the body is exposed to extreme cold, the temperature can fall below 35.6 C (98 F).
- An unclothed person can be exposed to temperatures as low as 12.8 C (55 F) or as high as 54.4 C (130 F) in dry air and still maintain almost constant core temperature.

Skin Temperature

In contrast to the core temperature, the skin temperature (shell), falls and rises with the temperature of the surroundings.

Issues of Concern

Thermoregulatory Impairment [3]

Hypothermia

- Hypothermia, defined as a drop in core body temperature below 35 C (95 F), results in initial/mild impairment in the body's thermoregulatory capacity. Greater impairment occurs with increasing severity of hypothermia; severe hypothermia is defined as core body temperature dropping below 28 C (82.4 F)
- Core body temperature below 29.4 C (85 F) impairs the ability of the hypothalamus to regulate body temperature is lost
- Part of the reason for this diminished regulation is that the rate of chemical heat production in each cell is depressed almost 2-fold for each 10 F decrease in body temperature.
- Extreme symptoms indicative of severe hypothermia include mental status changes, slurred speech, unconsciousness, ventricular arrhythmias, and gross motor skill impairment. End-stage presentation includes central nervous system (CNS) depression (coma), which ultimately suppresses all thermoregulatory function of the body (including the ability to "shiver").

Heat Illness Spectrum

- Excessive core body temperature presents along with a clinical spectrum, with heat stroke presenting as an emergent clinical condition defined by a core body temperature exceeding 40 C (104 F)
- Other conditions along the heat illness spectrum include:
  - Heat edema
  - Heat syncope
  - Heat-associated cramping
  - Heat exhaustion

Cellular

Heat Production [3][4][5]

Heat production is determined by metabolism.

- Basal metabolism
- Muscle activity, by shivering and muscle contractions
- Extra metabolism caused by the effect of sympathetic stimulation and norepinephrine, epinephrine on the cells
- Extra metabolism caused by increased chemical activity in the cells, especially when the cell temperature increases
- Extra metabolism caused by thyroid hormone and, to a lesser extent, testosterone and growth hormone on the cells
- Extra metabolism needed for digestion, absorption, and storage of food
- Most of the heat produced in the body is generated in the liver, brain, heart, and in the skeletal muscles during exercise.

Heat Loss

The rate at which heat is lost is determined almost entirely by:

- How rapidly heat is transferred from the skin to the surroundings
- How rapidly heat is conducted from where it is produced in the body core to the skin

Development

Brown Fat

- Brown fat is richly supplied with sympathetic nerves that release norepinephrine, which stimulates tissue expression of mitochondrial uncoupling protein (UCP, also called thermogenin) and increases thermogenesis. Uncoupled oxidation occurs in this type of fat because it contains large numbers of special mitochondria. In animals, the amount of brown fat in the tissues is directly proportional to the degree of chemical thermogenesis that occurs.
- There is a small amount of brown fat in the interscapular space in infants. Chemical thermogenesis can increase the rate of heat production in human neonates, by one hundred percent.
- There is nearly no brown fat in adult humans. In adults, it is rare to increase the rate of heat production by more than 10% to 15% by chemical thermogenesis.

Organ Systems Involved

Anterior Hypothalamic-Preoptic Area in Thermostatic Detection of Temperature

- The anterior hypothalamic-preoptic area contains cold and heat -sensitive neurons-central thermoreceptors.
- The temperature sensory signals from the central anterior hypothalamic-preoptic area are transmitted into the posterior hypothalamic area.
- When the preoptic area is heated, the skin all over the body immediately breaks out in a profuse sweat, and the blood vessels over the whole-body surface become dilated.
- Also, any excess body heat production is inhibited.

Posterior Hypothalamus Integrates the Peripheral and Central Temperature Sensory Signals

- The temperature sensory signals from the central anterior hypothalamic-preoptic area are transmitted into the posterior hypothalamic area.
- The temperature sensory signals from the peripheral thermoreceptors are transmitted to the posterior hypothalamus.
- These signals are integrated to control the heat-conserving and heat-producing reactions of the body.

Detection of Temperature by Receptors in the Deep Body Tissues

- Deep body temperature receptors are in the abdominal viscera, the spinal cord, around or the great veins in the thorax, and upper abdomen
- The deep thermos-sensitive receptors, like the skin temperature receptors, detect mainly cold rather than warmth.
- It is probable that both the deep body receptors and the skin receptors are concerned with preventing hypothermia, that is, preventing low body temperature.

Detection of Temperature by Receptors in the Skin

- The skin has both warmth and cold receptors.
- The warmth receptors at the skin are much less than cold receptors. Therefore, peripheral detection of temperature mainly concerns detecting cool and cold temperatures.
- When the skin is chilled over the entire body, immediate reflexes are invoked that include sweating inhibition, shivering, skin vasoconstriction to diminish the loss of body heat.

Function

Insulator System of the Body [6][7]

- Heat insulator of the body composed of, the skin, the subcutaneous tissues, and the adipose tissues.
- The subcutaneous fat is important because it conducts heat poorly.
- Insulator properties of the female body are better than the male body.

Blood Flow to the Skin from the Body Core Provides Heat Transfer

- Blood vessels are distributed profusely under the skin.

- The presence of continuous venous plexus that is supplied by an inflow of blood from the skin capillaries is very important for thermoregulation.
- Also, blood is supplied to the plexus directly from the small arteries through highly muscular arteriovenous anastomoses in hands, feet, and ears.

Effect of the environmental temperature on heat conductance from the body core to the skin

- The skin is an effective controlled "heat radiator" system.
- The flow of blood to the skin is a most effective mechanism for heat transfer from the body core to the environment.

Basic Physics of How Heat Is Lost from the Skin Surface

Heat dissipated by radiation, evaporation, and conduction.

Evaporation and conduction of the air are accelerated by convection.

Evaporation Is a Necessary Cooling Mechanism at High Air Temperatures

- When the temperature of the environment becomes greater than that of the skin, the body gains heat by both conduction and radiation.
- So, the evaporation is the only way by which the body can rid itself of heat under these conditions.
- Therefore, anything that prevents adequate evaporation when the surrounding temperature is higher than the skin temperature will cause the internal body temperature to rise.
- Inadequate perspiration occurs patients who are born with congenital absence or malfunctioning of sweat glands (Ectodermal dysplasia). These patients are in danger of overheating in hot environments.

Clothing Reduces Conductive and Convective Heat Loss

- Clothing entraps air next to the skin, thereby increasing the thickness of the so-called private zone of air adjacent to the skin and also decreasing the flow of convection air currents.
- When clothing becomes wet, the effectiveness of clothing in maintaining body temperature is almost completely lost, because the high conductivity of water increases the rate of heat transmission through a cloth.

Mechanism

Temperature-Decreasing Mechanisms

- Inhibition of the sympathetic centers in the posterior hypothalamus (that control blood vessel tone), cause vasodilation of skin blood vessels.
- When the body core temperature rises above the critical level of 37 C (98.6 F), there is an increase in the rate of heat loss by sweating.
- Shivering and chemical thermogenesis are strongly inhibited.

Temperature-Increasing Mechanisms

- Stimulation of the posterior hypothalamic sympathetic centers causes vasoconstriction of skin blood vessels.
- Also, piloerection will take place, which means hairs "standing on end." This mechanism is not important in humans.

- Increase in thermogenesis by promoting shivering, sympathetic excitation of heat production, and thyroxine secretion

Related Testing

Set Point for Temperature Control

- 37.1 C (98.8 F).
- This optimum temperature is called the “set point” of the temperature control mechanism—that is, all the temperature mechanisms continually attempt to bring the body temperature back to this set point.

Artificial Hypothermia

- The temperature of a person can be decreased by first administering a strong sedative to depress the reactivity of the hypothalamic temperature controller and then cooling the person with ice or cooling blankets.
- The temperature can then be maintained below 90°F for an extended period by a continual sprinkling of cool water or alcohol on the body.
- Such artificial cooling has been used during heart surgery so that the heart can be stopped artificially for many minutes at a time.
- Cooling to this extent does not cause tissue damage, but it does slow the heart and greatly depresses cell metabolism so that the body's cells can survive one hour without blood flow during the surgical procedure.

Pathophysiology

Sweating and Its Regulation by the Autonomic Nervous System

- Stimulation of the anterior hypothalamus, a preoptic area in the brain by excess heat causes sweating.
- The sweat glands are innervated by cholinergic nerve fibers that secrete acetylcholine that runs in the sympathetic nerves along with the adrenergic fibers.
- Sweat glands can also be stimulated by norepinephrine or epinephrine, which is important during periods of intense physical activity (work or exercises).

Mechanism of Sweat Secretion

- The sweat gland consists of two parts: the duct that passes through the skin and reabsorbs salt and water, and the deep subdermal coiled gland that secretes the sweat.
- Sweat gland secretes a fluid called the precursor secretion; the concentrations of constituents in the fluid are then modified in the duct.

Precursor Secretion

- Cholinergic sympathetic nerve fibers stimulate the secretion.
- The composition of the precursor secretion is similar to the plasma, except that it does not contain plasma proteins.
- The concentration of sodium is about 142 mEq/L, and that of chloride is about 104 mEq/L.

Reabsorption

- When sweat glands are weakly stimulated, the precursor fluid passes through the duct slowly; and the concentration sodium and chloride ions fall to as low as five mEq/L.
- Reabsorption of sodium and chloride reduces the osmotic pressure of the sweat fluid and lead to reabsorption of water, whereas other constituents such as urea, lactic acid, and potassium are concentrated in the sweat.
- When the sweat glands are strongly stimulated, a large amount of precursor fluid is formed, and the duct reabsorbs only about half the sodium chloride secreted (resulting in 50 to 60 mEq/L sodium and chloride ions).
- Strongly stimulated sweat flows through the glandular tubules so rapidly that little of the water is reabsorbed. In these conditions, the other dissolved constituents of sweat (urea, lactic acid, and potassium) are only moderately increased in concentration compared to plasma.

Hypothalamic Stimulation of Shivering

- The primary motor center for shivering is located in the dorsomedial portion of the posterior hypothalamus.
- Shivering is normally inhibited by signals from the heat center in the anterior hypothalamic-preoptic area but is excited by cold signals from the spinal cord and skin.

Sympathetic "Chemical" Excitation of Heat Production

- An increase in circulating epinephrine and norepinephrine in the blood rapidly increase the rate of cellular metabolism
- This effect is called chemical thermogenesis, or no shivering thermogenesis
- No shivering thermogenesis results from the ability of norepinephrine and epinephrine to "uncouple oxidative phosphorylation."

Clinical Significance

Heat Stroke[3][8]

- The ambient conditions significantly impact the body's ability to release heat into the surrounding environment
- Clinicians utilize various environment heat stress indices (such as the Wet Bulb Globe Temperature [WBGT]) to predict the current hazardous potential of the surrounding environment
  - WBGT combines the ambient temperature, humidity, wind speed, and solar radiation into a calculated value that is used to estimate the current (or anticipated) risk of heat-related illness and injury
  - The relative humidity is the largest contributing factor to the overall heat index score
- Risk factors for heat stroke include[9]:
  - Obesity
  - Dehydration (including predisposing risk factors such as illnesses, diarrhea)
  - History of prior heat illness
  - Poor physical conditioning status (sedentary lifestyle)
  - Sleep deprivation
  - Sweat gland dysfunction
  - Medications include:

    - Anticholinergics
    - Antihistamines
    - Stimulants
    - ACE inhibitors
    - Diuretics

- If the air is 100% humidified or if the body is in water; body temperature rises any time the environmental temperature rises above 34.4 C (94 F).
- If the air is dry and sufficient convection air currents are flowing; a person can withstand many hours of air temperature at 54.4 C (130 F).
- If the person is doing heavy work; the critical environmental temperature above which heatstroke is likely to occur may be as low as 29.4 C to 32.2 C (85 F to 90 F).
- When the temperature of the body rises beyond a critical temperature into the range of 40.6 C to 42.2 C (105 F to 108 F), heatstroke is likely to develop.
- The hyperpyrexia is exceedingly damaging to the body tissues, especially the brain, and even a few minutes of very high body temperature can sometimes be fatal.

Treatment for Heat Stroke[3][8]

After following the standard ATLS resuscitation protocol (airway, breathing, circulation), the next step is to cool the body to reduce core body temperature rapidly. Whole-body cooling units on-site should be utilized. As long as the patient is stable, the rapid cooling protocol takes priority even before transportation to the local emergency department is commenced.

Questions

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