THERMOREGULATION

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ABSTRACT
Thermoregulation

Thermoregulation i.e. regulation of temperature, is important in human beings because they need to maintain their core temperature despite being exposed to changes in the surrounding temperature. This homeothermy function is affected when the spinal cord is injured above the T6 and the patient display partial poikilothermy. Thus hypothermia is usually experienced by SCI patients but there is no research of whether it can also occur in two seasonal countries such as ours. In USA, Spinal Cord Injury (SCI) with an incidence of 10,000 cases/year and prevalence of 200,000 cases, is one of the most devastating injuries sustained by an individual. Thermoregulatory disturbances can only be considered to exist in an SCI patient if other cause of fever (above 38oC), including infectious etiology, can be excluded. This paper is written to raise physicians's awareness of the thermoregulation in humans and how it is affected when the spinal is injured because its management will consist of adjustment of the environment temperature, looking for conditions that can compromise the ability to regulate body temperature, and prescribing drugs cautiously so as not to modify the effectiveness of thermoregulation.

Key words: thermoregulation, temperature, spinal cord injury, homeothermy

ABSTRAK
Regulasi temperatur

Regulasi temperatur atau pengaturan suhu merupakan hal yang penting pada manusia karena mereka tetap harus mempertahankan suhu inti tubuh walaupun mereka terpapar terhadap perubahan suhu di sekitarnya. Fungsi hemeotermi ini terpengaruh ketika terjadi cedera korda spinalis di atas T6 sehingga pasien menunjukkan poikilotermi parsial. Dengan demikian hipotermia maupun hipertermia biasanya dialami oleh pasien dengan cedera korda spinalis tetapi tidak ada penelitian apakah hal tersebut juga terjadi di negara-negara dengan dua musim seperti Negara kita. Di Amerika Serikat, cedera kordal spinalis dengan insidens sebanyak 10.000 kasus/tahun dan prevalensi 200.000 kasus, merupakan salah satu cedera yang paling berbahaya yang dapat diderita oleh seseorang. Gangguan pengaturan suhu hanya dapat diperkirakan ada pada seorang penderita cedera korda spinalis apabila penyebab lain dari demam (di atas 38oC) termasuk yang berasal dari agen infeksius telah disingkirkan. Tinjauan pustaka ini ditulis dengan maksud untuk meningkatkan kesadaran dokter tentang pengaturan suhu pada manusia dan bagaimana hal tersebut dipengaruhi oleh adanya cedera korda spinalis. Hal ini penting mengingat bahwa penatalaksanaannya terdiri dari penyesuaian suhu lingkungan, penemuan kondisi yang dapat mengganggu kemampuan pengaturan suhu tubuh, dan pemberian resep obat secara hati-hati agar tidak terjadi modifikasi terhadap pengaturan suhu yang efektif.

Key words: temperatur, pengaturan suhu, cedera korda spinalis, homeotermi.

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INTRODUCTION

Temperature in human beings is divided into two categories: core temperature and skin temperature. Core temperature is the temperature of the deep tissues of the body which remains almost exactly constant, within + 0.6°C, except when a person develops a febrile illness.[1] Skin temperature, on the other hand, rises and falls with the surrounding temperature and also by exercise. This is the temperature that is important when we refer to the ability of the skin to lose heat to surroundings.[1]

Human beings and other warm-blooded animals have to maintain their core temperature despite exposure to wide extremes of environmental temperature. This phenomenon is labeled homeothermy, in contrast to poikilothermy, variation of body temperature with the environmental temperature.[2]

Spinal Cord Injury (SCI) is one of the most devasting injuries an individual can sustain. In the United States, the incidences of SCI are approximately 10.0000 cases/year with prevalence of approximately 200.000 cases.[3] Following injury, the primary concern of clinicians is the thermoregulation function.[4] A patient whose spinal cord is injured above T6 usually has difficulty in maintaining normal body temperature and exhibit partial poikilothermia, with lower core temperatures in cold environment and higher core temperatures in warm environments. This inability to maintain a constant core temperature is caused by the lack of effective afferent pathways from skin receptors and inability to regulate vasoconstriction, vasodilation, and sweating in the insensate portion of the body.[4]

Cardenas et al stated that despite the abnormal thermoregulatory abilities of SCI patients, an elevation of temperature 38°C or more should always necessitate a careful search for a cause of an infectious nature. Only when other potential etiologies of fever are excluded, can an SCI patient be considered as having thermoregulatory disturbances.[5]

PHYSIOLOGY

There are several core temperatures: one at which the body starts to sweat with a sweating threshold of 37 ± 0.3°C; another at which shivering starts with a shivering threshold of 35.6 ± 0,3°C; and one at which the skin begins to cool (vasoconstriction and arteriovenous shunting) with a vasoconstrictive threshold of 36.4 ± 0.3°C. The range in which no sweating or vasoconstriction occurs is called the interthreshold range.[6] A nude person can be exposed to a temperature as low as 12.8°C or as high as 60°C in dry air and still maintain an almost constant internal body temperature.[1] Core temperatures can be accurately mea-sured from the tympanic membrane using infrared sensing technology.

The skin temperature, in contrast to the core temperature, rises and falls with the temperature of the surroundings, thus placing an importance on the ability of the skin to lose heat to the surroundings. The normal temperature has diurnal (circadian) rhythmicity ranges from 36°C in the early morning to 37.5°C in the late afternoon.[1,7] The average normal temperature is generally between 36.7°C and 37°C when measured orally and approximately 0.6°C higher when measured rectally. Becauce the temperature regulatory mechanisms are not 100% perfect, the body temperature varies with exercise and with extremes of temperature of the surroundings. When excessive heat is produced in the body by strenuous exercises, the rectal temperature can rise to as high as 38.3° to 40°C. On the other hand, when the body is exposed to cold, the rectal temperature can often fall to values below 36°C.[1] Normal range of temperature and human thermoregulatory responses also varies according to age, gender, geography and race.[2]

HOMEOTHERMY [1,2,7]

Body temperature is controlled by balancing heat production against heat loss. When the rate of heat production in the body is greater than the rate at which heat is being lost, heat builds up in the body and the body temperature rises. Conversely, when heat loss is greater, both body heat and body temperature decrease. Heat production is one of the principal by products of metabolism. There are different factors that determine metabolic rate of the body which are: basal rate of metabolism of all cells of the body; extra rate of metabolism caused by muscle activity (including muscle contractions caused by shivering), effect of thyroxin on the cells, effect of epinephrine, norepinephrine and sympathetic stimulation on the cells; increased temperature of the body cells.

Most of the heat produced in the body is generated in the deep organs, especially in the liver, the brain, the heart as well as the skeletal muscles and even more so during exercise. This heart is then transferred from the deeper organs and tissues to the skin, where it is lost to the air and other surroundings. Therefore, the rate at which heat is loss is determined almost entirely by two factors: how rapidly heat can be conducted from the core to the skin and how rapidly heat can then be transferred from the skin to the surroundings. There is also an insulator system that insulator system that insulates the core from the skin surface such as skin, subcutaneous tissues and the fat of the subcutaneuous tissues which is especially important because it conducts heat only one-third as readily as other tissues.

Flow of blood to the skin from the body core is gained through blood vessels that penetrate the fatty subcutaneous insulator tissues and are distributed profusely immediately beneath the skin. A high rate of blood flow causes heat to be conducted from the core of the body to the skin with great efficiency whereas reduction in the rate of blood flow decreases the efficiency of heat conduction from the core. There are eightfold increase in heat conductance between the fully vasoconstricted state and the fully vasodilated state making the skin as an effective "radiator" system. Thus the flow of blood to the skin is a most effective mechanism of heat transfer from the body core to the skin.

Heat conduction to the skin by the blood is controlled by the degree of vasoconstriction of the arterioles and arteriovenous anastomoses that supply blood to the venous plexus of the skin. This vasoconstriction in turn is controlled almost entirely by the symphathetic nervous system in response to changes in the body core temperature and changes in the environmental temperature.

Heat is loss from the skin surface by radiation, conduction and evaporation. Loss of heat by radiation means loss in the form of infrared heat rays and a nude person in a room at a normal room termperature loses 60% of the total heat loss by radiation. Thus all objects that are not at absolute zero temperature will radiate such rays. However, heat rays are also being radiated from the walls and other objects toward the body. Therefore when the temperature of the body is greater than the temperature of the surroundings, a greater quantity of heat is radiated from the body than is being radiated to the body.

Only small quantities of heat are normally lost from the body through direct conduction from the surface of the body to other objects such as a chair or a bed. On the other hand, loss of heat by conduction to air amount to a sizable proportion of the body's heat loss even under normal conditions because heat is actually a kinetic energy of molecular motion and the molecules of the skin are continually undergoing vibratory motion hence transferring much of the energy to the air if the air is colder than the skin and increasing the velocity of motion of the air molecules. However, once the temperature of the skin, no further loss of heat from the body to the air can occur. Therefore, conduction of heat from the body to the air is self-limited unless the heated air moves away from the skin so that new, unheated air is continually brought in contact with the skin. This phenomenon is known as air convection.

When water evaporates from the body surface, 0.58 kilocalorie of heat is lost for each gram of water that evaporates. Even though a person is not sweating, water still evaporates from the skin and lungs at a rate of about 600 milliliters per day. This causes continual heat loss at a rate of 12 to 16 klocalories per hour and this evaporation cannot be controlled for purposes of temperature regulation because it results from continual diffusion of water molecules through the skin and respiratory surfaces regardless of body temperature. However, loss of heat by evaporation of sweat can be controlled by regulating the rate of sweating.

As long as skin temperature is greater than the temperature of the surroundings heat can be lost by radiation and conduction and vice versa. Under these conditions, the only means by which the body can rid itself of heat is through evaporation. Therefore, any factor that prevents adequate evaporation when the surrounding temperatures are higher than skin temperatures will cause the body temperature to rise. This occurs occasionally in human beings who are born with congenital absence of sweat glands.

The temperature of the body is regulated almost entirely by nervous feedback mechanisms and almost all of these operate through temperature-regulating centers located in the anterior hypothalamic-preoptic nucleus. Though the signals generated by the temperature receptors of the hypothalamus are powerful in controlling body temperature, receptors in other parts of the body also play important roles in temperature regulation. This is especially true of temperature receptors in the skin (endowed with both cold and warmth receptors) and in a few specific deep tissue of the body. However, there are ten times more cold receptors than warmth receptors in many parts of the skin making peripheral detection of temperature mainly concerns detecting cool and cold instead of warm temperatures. Deep body temperature receptors which also detect mainly cold rather than warmth are found in certain parts of the body: in the spinal cord, in the abdominal viscera and in or around the great veins. However, these deep receptors function differently from the skin receptors because they are exposed to the body core temperature rather than the body surface temperature. It is probable that both the skin and the deep body receptors are concerned with preventing hypothermic.

Temperature-decreasing mechanisms when the body is too hot are: vasodilation of the skin blood vessels in almost all areas of the body; sweating which increases the rate of evaporative heat loss when the body temperature rises above the critical temperature level of 37°C; decrease in heat production through shivering or chemical thermogenesis.

Temperature-increasing mechanisms when the body is too cold are: skin vasoconstriction throughout the body; piloerection which brings the hairs to an upright stance and allows them to entrap a thick layer of "insulator air" next to the skin so that the transfer of heat to the surroundings is greatly depressed; increase in heat production by the metabolic system.

Aside from the subconscious mechanisms for body temperature control, the body has a more potent behavioral control of temperature which includes postural adjustments, selection of thermal environment and addition or removal of insulating cloting. Whenever the internal body temperature becomes too high, signals from the brain temperature controlling areas give the person a psychic sensation of being overheated so the person extending arm and legs, seek a cooler environment or change into a light-weight cloth. Conversely, whenever the body becomes too cold, signals from the skin and from the deep body receptors elicit the feeling of cold discomfort so the person curling up in a ball, look for a warner environment or add extra cloth. Therefore, the person makes appropriate environmental adjustments to reestablish comfort.

ANATOMY OF THE SPINAL CORD

The spinal cord lies within the vertebral canal and it is continuous above with medulla oblongata.[8] The spinal cord extends from the foramen magnum, the large opening in the base of the skull to the intervertebral disc between L1-L2 and ends as conus medullaris.[9] There are 31 spinal cord segments which are named and numbered according to the attachment of the spinal nerves: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 cocygeal. The length of the spinal cord from its junction with the medulla to the tip of the conus medullaris is about 45 cm in the male and 43 cm in the female with a weight of 35 g.[10]

Spinal cord is divided into 2 divisions that is part of autonomic nervous system[8]: craniosacral parasympathetic system and thoraco-lumbar sympathetic system. The spinal cord connects with the spinal nerves and is the structure through which the brain communicates with all parts of the body below the head. Damage of the spinal cord may result in the loss of general sensations and the paralysis of voluntary movements in parts of the body supplied by spinal nerves.[9]

SPINAL CORD INJURY

Muscle paralysis is only one manifestation of the multisystem dysfunction arising from spinal cord injury (SCI) beside sensory and autonomic function. Eighty-five percent of spinal cord injuries are caused by trauma. Other SCIs are a result of non-traumatic pathologies such as carcinoma, myelitis, ischemia and multiple sclerosis. Three basic mechanisms of injury: flexion, compression or extension can be deduced from the clinical history and the X-ray appearance of the spine.[11]

Autonomic disturbances of spinal origin do not have as clear-cut segmental distribution as the motor and sensory functions. An injury to the midthoracic cord may therefore give rise to anhydrosis of the upper limb without altering motor or sensory function in that same limb.[12]

The annual incidence rate of spinal cord injury in the United States is estimated to be 30-32 cases per million population or 8000-9000 new cases per year. This excludes those who die within 24 hours of injury. Prevalence is estimated to be 700-900 cases per million population or 200,000-250,000 persons. Sixty-one percent of those injured are between the ages of 16 and 30 and 80% are between ages 16 and 45 with a rate of four times greater in males than females. The four leading causes of death after SCI are respiratory problems (usually pneumonia), heart disease, subsequent trauma and septicemia (usually a result of pressure ulcers, urinary tract or respiratory infection).[11]

ASSESSMENT[11] & CLASSIFICATION[13]

Conduct evaluations of the neuromuscular, musculoskeletal, pulmonary, cardiovascular, genitourinary, gastrointestinal and integumentary system. Assess and document their functional status serially i.e. document the precise level of motor and sensory deficits, utilizing standard dermatomal and myotomal references during both acute and later stages.

For sensory examination, pinprick and light touch tested in the 28 dermatomes on the right and left side; for motor examination, testing motor strength in 10 defined myotomes on the right and left side. To differentiate between complete or incomplete, rectal examination has to be done to know whether there is still any anal sensation or voluntary anal contraction. After sensory and motor examination; determine motor and sensory levels on the right and left sides (for those motor levels that are not represented by key muscle groups, the sensory level is used) so we can determine the neurological level which is the most caudal segment with normal sensory and motor function on both sides of the body.

Also document tendon and superficial reflexes sequentially to assist in determining recovery from spinal shock (the initial areflexia and flaccidity seen acutely afer spinal cord injury) or from root injury: the first reflex to recover after spinal shock is typically the bulbocavernosus reflex elicited by squeezing the tip of the penis or clitoris while a gloved finger rests in the rectum whereby the rectum will contract in response to the stimulus if the sacral segments of the spinal cord are intact.

Assessment of the musculoskeletal system includes a preliminary evaluation of spinal column stability, range of motion in all joints and muscle tone and strength. Spinal column stability is evaluated using an anatomical three-column system. If two of three columns are distrupted, the lesion is intrinsically unstable. People with multiple sclerosis and brain injury may have damage to the hypothalamus and develop the poikilothermic syndrome where they lose ability to thermoregulate. Damage to the hypothalamus often cannot be seen on magnetic resonance images but when it occurs, it is reason to suspect spinal cord injury.6 T8 is the highest level at which a patient can maintain rectal temperature at 37oC in an environment temperature from 18 to 40oC. Patients with higher level of damage are poikilothermic in response to heating or cooling but in patients with spinal injury, shivering occurs only in muscles innervated above the level of lesion.

THERAPY[11,13]

After cutting the spinal cord in the neck above the sympathetic outflow, regulation of body temperature becomes extremely poor because the hypothalamus can no longer control the skin blood flow or the degree of sweating in the body. This is true even though the local temperature reflexes originating in the skin, spinal cord and intra-abdominal receptors still exist because these reflexes are not powerful. In persons with this condition, body temperature must be regulated principally by the patients' psychic response to cold and hot sensations in the head region that is by behavioral control of clothing and environment.[1] Spinal cord injury may also reduce or provide abnormal temperature sensations to the brain. Thus, a person with spinal cord injury particularly at cervical levels will often feel cold cold even though core temperature may be normal due to an increased or abnormal activity of thermal information.[6]

In people without injuries, the term hypothermia (low body temperatures) is usually applied to describe people when thermoregulation fails in a normal or cool environment. In normal subjects, the most common medical cause of hypothermia is multiple drugs that affect the sympathetic and parasympathetic system as well as drugs that affect serotonin and dopamine levels in the brain such as anti-depressants, anesthetics, sedatives, alcohol, and opioids and other drugs that impair thermal sensation or regulation.[6] Many conditions may contribute to hypothermia in people with spinal cord injury such as stroke, diabetes, malnutrition, bacterial infection, and thyroid disease. In addition, people with poor blood flow (due to arteriosclerosis) are more susceptible to hypothermia thus these need to be reuled out.

For people with spinal cord injury, hypothermia due to sudden changes in environmental temperature is deadly and is a common cause of incoherence as well as loss of brain function. It reduces brain function, compromises respiration, and can cause fatal cardiac arrhythmias. Therefore it is important to use core temperature to monitor temperature and not rectal or mouth. People should be alert for early symptoms of hypothermia and undertake preventative measures such as drinking warm fluids and preventing heat loss. Since hypothermia depresses cardiac pacemaker cells causing a slower heart rate or bradycardia, it can be refractory to standart therapies such as atropine. Lidocaine and defibrillation are often ineffective for reversing cardiac arrhythmia thus bretyllium (5 mg/kg) is recommended for treating cardiac arrhythmias associated with hypothermia. Emergency personnel therefore should try to warm patients before they carry out cardiopulmonary rescuscitation since the procedure is unlikely to be successful and may precipitate a fatal arrhythmia. Long-term treatments of hypothermia are common sense: to avoid or minimize drugs that compromise thermoregulation and to keep warm with proper clothing where a usual suit of clothes decreases the rate of heat loss to about half that from a nude body. However the effectiveness of cloting in maintaining body temperature is almost completely lost when it becomes wet because the high conductivity of water increases the rate of heat transmission as much as 20-fold or more.[1]

Elevation of body temperature is called hyperthermia (oral temperature > 38°C or rectal temperature >38.4°C14) if it resulted from thermoregulatory failure or called are fever[7] if its homeostatic responses is still intact. In normal subjects, the most-common cause of hyperthermia is fever resulting from release of pyrogens (fever-causing factors) due to infection or inflammation.[6] One or more of the following symptoms may indicate hyperthermia: the skin feels hot, dry and appears flushed; feeling of weakness, dizziness and visual disturbances; headache, nausea and elevated temperature: rapid but irregular or weak pulse. It is important to prevent hyperthermia when exposed to an overheated environment by drinking lots of fluids, wearing protective or light-weight cloting (cotton and light colors).[15] Hyperthermia may be caused by excessive heat production, diminished heat dissipation, or malfunction of the hypothalamic thermostat and often results from mixed disorders of the body;s thermal economy such as exercise, heat stroke.[7]

The most important step in the management of hyperthermia is to diagnose and treat the underlying disorder while providing appropriate cardiovascular and metabolic support. Antipyretic therapy is the obvious response but treatment may consist of evacuating the patient promptly to an emergency room where physical cooling is possible, removal of clothing, application of cool water or ice to the body surface, oral hydration if the patient is alert, intravenous hydration with room-remperature fluids should be initiated as soon as possible, correction of electrolyte and acid-base abnormalities, as well as meticulous cardiovascular.

CONCLUSION

The average normal temperature is between 36.7°C and 37°C varies with exercise and with extremes of temperature of the surroundings. Body temperature is controlled by balancing heat production against heat loss. Heat conduction to the skin by the blood is controlled by the degree of vasoconstriction which in turn is controlled by the sympathetic nervous system and since sympathetic nervous system is part of autonomic nervous system that consists of outflows from the thoracolumbar part of the spinal cord (T1-L3), a person with spinal cord injury can experience difficulty in maintaining the homeothermy of the body.

In persons with this condition, body temperature must be regulated principally by the patients' psychic response to cold and hot sensations i.e. by behavioral control of clothing and environment otherwise hypothermia or hyperthermia can occur. Stroke, diabetes, malnutrition, bacterial infection, and thyroid disease may contribute to hypothermia in people with spinal cord injury. Thus the first and most important approach is to keep the patient warm with proper clothing and avoid drugs that can aggravate hypothermia. Hyperthermia, on the other hand, may be caused by excessive heat production, diminished heat dissipation, or malfunction of the hypothalamic thermostat. Hence the most important step in the management of hyperthermia is to diagnose and treat the underlying disorder while providing appropriate cardiovascular and metabolic support. In contrast to patients with fever, patients with hyperthermia derive no benefit from centrally active antipyretic agents. Instead, physical cooling is appropriate with the use of techniques such as removing bedclothes, using bedside fans, and sponging the patient with tepid water. More rapid reductions in body temperature can be achieved by using hypothermic mattresses or ice packs.

Based on termal instability in SCI patients, the presence of fever is not necessarily a reliable indicator of infection. However, an elevation of temperature 38°C or more should always necessitate a search for an infectious cause thermoregulatory disturbances be assigned as the cause of fever in SCI patients only when other etiological causes have been excluded. Most febrile episodes caused by thermoregulatory disturbances are usually self-limited and resolve sponteneuously within hours to days.

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