Thermoregulation Physiology

Animals attempt to tightly regulate their core body temperature to within a very narrow, species-specific range called a ‘set-point’. Thermoregulation occurs when the body’s thermal receptors detect temperature changes in the peripheral zone (e.g., skin, extremities and subcutaneous tissues) and core zone regions (e.g., brain, heart and great vessels). These thermal variations are then transmitted from the thermal receptors to the posterior hypothalamus via the spinal cord. Since heat travels from high to low temperatures, thermal homeostasis (or maintaining the set-point) is achieved by modulating the distribution and flow of blood to organs, viscera and skin by way of either vasoconstriction or vasodilation. Initial heat loss induces cutaneous vasoconstriction in an attempt to limit heat loss and maintain core temperature. When vasoconstrictive efforts fail to resolve hypothermia, heat production is augmented via increasing muscle tone and shivering. Furthermore, non-shivering thermogenesis occurs with epinephrine secretions.

Hypothermia may be the result of heat loss, decreased heat production, or thermoregulation alterations due varying clinical problems, and can occur as a primary (accidental), secondary (e.g., due to sepsis, trauma, or disease) or therapeutic (induced) condition. Hypothermia is most commonly associated with anesthetized patients as well as emergent shocky or hemorrhaging patients. Other factors that can influence thermoregulation include age (e.g., pediatric or geriatric), body condition, hormones, or circadian rhythm.

Factors Influencing Thermoregulation

The body is protected from heat loss by 3 tissue layers: skin, subcutaneous fat, and hair. Additionally, the thickness of these 3 layers can vary from patient to patient. (e.g., they are the least thick in most pediatric patients.) Heat loss occurs from the insulating layers to the environment in 2 stages. Stage 1 occurs when heat is transferred from the core to the skin. Stage 2 occurs when heat is ultimately lost to the environment by conduction, convection, radiation, evaporation, and by the excretion of urine and feces. Conduction is the process that occurs when heat is transferred away from an animal’s body as a result of direct contact with a cooler object or surface such as a stainless steel table or electrocautery plate. Convection may be referred to as the ‘wind chill’ effect, relying on circulating air or liquid to carry heat away from or towards an object. Convection may be influenced by the ambient room temperature, air conditioning or furnace settings. Radiation occurs in a similar fashion, but instead relying on passive dissipation of thermal energy through air or space and into the environment. Seventy-percent of the body’s dissipation of heat can be attributed to radiation and convection. Evaporation may be due to heat and moisture loss from the skin and respiratory tract, open body cavities, or after the use of surgical prep solutions (e.g., alcohol or scrub solutions.)

Hypothermia’s Adverse Effects

Almost every major organ and system is adversely affected by hypothermia. Hypothermia can cause decreased cardiac output, resulting in an increased risk of arrhythmias and hypoxia, and leading to reduced tissue perfusion. Hypothermia-induced bradycardia is typically non-responsive to anticholinergics. Hypothermia also diminishes the effect of positive inotropes on blood pressure, heart rate and cardiac output. Delayed drug metabolism, hypomotility, and decreased hepatic metabolism result in a prolonged recovery and potential drug toxicity. Clotting times can be prolonged due to impaired platelet function and hemoconcentration with sludging. A suppressed immune function can lead to increased infection rates and delayed wound healing.

Even moderate hypothermia (<95°F), (e.g., due to trauma, shock, or as observed in the postoperative period) is associated with a significant stress response. There is a 2- to 7-fold increase in the release of catecholamines associated with hypothermia, resulting in vasoconstriction and hypertension, and causing bradycardic patients to become tachycardic. Severe hypothermia (<86°F) results in an increased risk of atrial fibrillation. Profound hypothermia (75.2°F to 82.4°F) can result in refractory ventricular fibrillation and death. Subsequently, the net effect of hypothermia results in an increased incidence of morbidity and mortality.

Hypothermia is not only one of the most common anesthetic complications, but also the easiest to document without special equipment. Tympanic membrane temperatures are the most accurate due to the shared blood supply by the middle ear and hypothalamus. However, ear thermometers are relatively expensive and can be technically challenging to use properly.
Almost all anesthetized or sedated patients will lose body heat under general anesthesia, with the exception of adult Nordic breeds (e.g., Samoyed, Siberian husky, Alaskan malamute), which can actually become hyperthermic. Initially, general anesthesia-induced vasodilation allows for core body heat to be redistributed to the skin and extremities. This results in hypothermia-induced vasoconstriction that limits the amount of blood and heat delivered from the core to the periphery. Ultimately, this cascade of events cannot restore the core body temperature. Small patients are at the greatest risk, due in large part due to their small body-surface-to-mass ratio.

The majority of heat loss occurs within the first 20 minutes of general anesthesia for a multitude of reasons—the presence of cooler ambient temperatures and stainless steel induction tables, drug-induced vasodilation, breathing of dry anesthetic gases, shaving and surgical preps. Hypothermia is exacerbated by prolonged surgical procedures, especially those in which open body cavities remain exposed or when cold lavage solutions are utilized. In fact, one study demonstrated that the risk of skin infection increased by 0.5% for each additional minute of anesthesia time. This equates to a 30% increase in skin infections for each additional hour of anesthesia time!

Hypothermia is also considered a form of general anesthesia, as it increases the solubility of inhalants in the body, thereby effectively increasing the dose delivered. When using volatile anesthetics, for every 1.8oF decrease in body temperature there is a 5% decrease in MAC requirements. Critically ill or otherwise compromised patients may face adverse challenges when core body temperature decreases by as little as 2oF.

Although shivering is very effective in restoring body temperature, it is also associated with a significant increase in metabolic oxygen demand (40% to 200%, or more)! As this phenomenon may result in an oxygen debt, it may be prudent to administer all recovering shivering patients with supplemental oxygen.

**Treating Hypothermia**

The body obtains heat from 2 sources: endogenously, as described above, or exogenously, from environmental sources. Although there is controversy regarding the optimal methods, duration and rates for rewarming, there is no question that preventing hypothermia is easier and more efficient than treating it. Important considerations for evaluating rewarming systems include the heating element itself as well as the body surface area in contact with said heating element, and tissues in contact with the heating element. Furthermore, all cutaneous warming methods designed to transfer heat into the thermal core will rely on skin temperature, tissue insulation, and the body’s ability to circulate the heat (convection.) Since the core body surfaces (e.g., thorax and abdominal cavities) are relatively isolated from distal skin surfaces (e.g., extremities, tail), the efficacy of various warming devices can be unpredictable. Nonetheless, skin temperature is an important variable in regards to delivering effective cutaneous heat transfer.

Rewarming should be considered when hypothermic patients are less than 97.6oF. There are 3 techniques for rewarming chilly patients: 1, Passive external rewarming (PER), 2, Active external rewarming (AER), and 3, Active core rewarming (ACR).

**PER** is typically used to treat mild hypothermia and involves placing the patient in a warm environment and providing towels, blankets, or articles of clothing (e.g., sweaters) to help the patient regain thermal homeostasis. Patients treated with PER must be able to generate heat (e.g., shiver) to be effective. PER is the slowest method for treating hypothermia.

**AER** involves the application of external heat sources such as heating blankets, radiant heat lamps, heated rice bags, or immersion in warm water. Overall these methods tend to be non-invasive, inexpensive, readily available, and are easily employable rewarming methods. There are a variety of ways to maintain an envelope of warm air around hypothermic patients. Convection-type warm air devices (e.g., BAIR Huggers®) and electrically conductive fabric warmers such as the HotDogWarmer® (Augustine Biomedical + Design) are the most effective, followed by other warming units such as carbon-based conductive polymers by PetTherm (Inditherm plc), and circulating warm water blankets. At least 60% of the body surface area must be in contact with the external heat source for rewarming efforts to be most effective.

Other methods of maintaining body temperature during anesthesia include decreasing the oxygen flow rate (e.g., low flow anesthesia), utilizing a Humid-Vent adapter on the endotracheal tube, or using a coaxial (F-circuit) anesthesia hose. The coaxial design of the latter allows the patient’s exhaled breath to warm the incoming cold, fresh gases (e.g., oxygen, +/- an anesthetic agent.)

If latex gloves or bottles of warm water are to be used for smaller patients, it is essential that they are initially warmed to a temperature of <107oF and removed once they cool to the temperature of the patient, as at that point they begin contribute to heat loss rather than a heat gain. As such, these items are considered rather ineffective for raising body temperature, and pose an increased risk of thermal burns along the contact site.
Extreme caution is essential when using a microwave to warm rice bags, water bottles, lavage or intravenous solutions since ‘hot spots’ may occur due to uneven heating. Commercially available wire electric heating-pads and heat lamps have been associated with thermal injury and/or electrocution and should be avoided.

‘After-drop’ is another potential disadvantage of AER and occurs when heat is transferred from the core to the periphery of a hypothermic patient, thereby creating a large temperature gradient when colder peripheral blood is subsequently transferred to the relatively warmer core. The overall effect of an ‘after-drop’ results in a reduced core temperature. As a result, it has been suggested that warming the torso region while the (cooler) extremities remain vasoconstricted can be advantageous.

Although ACR is the most rapid method of rewarming, it is also considered the most invasive and therefore reserved for patients with severe hypothermia or with an arrest cardiac rhythm. ACR involves heat application to the body’s core via methods such as heat humidified oxygen, heated intravenous fluids, or warmed peritoneal, thoracic, gastric, rectal or urinary bladder lavage. One study demonstrated that when abdominal lavage fluids were warmed to 110°F and left in the abdomen for as little as 2- to 6-minutes, the patient’s temperature increased from 94°- to 97°F. However, the efficacy of warmed gastric, rectal or bladder lavage has not been well documented. Furthermore, warm fluid enemas will preclude the use of a rectal thermometer, necessitating the use of an ear thermometer instead. Esophageal warmers (Gaymar 800.828.7311) are also available to help warm hypothermic patients ‘from the inside out.’

The simplest core rewarming method entails warmed, humidified, inhaled oxygen (104°- to 107.6°F), but this technique results in only a mild to modest heat gain. It should also be noted that the efficacy of warmed intravenous fluids is greatly dependent on the fluid rate and volume administered. Therefore severely hypothermic patients should be treated with multiple rewarming techniques such as combined truncal AER and ACR (e.g., warm peritoneal lavage or warm fluid enemas) methods.

Other investigational techniques being explored for the treatment of hypothermia include high temperature intravenous fluids and diathermy. Studies performed utilizing intravenous fluids heated to 149°F demonstrated rewarming rates of 37.22°F to 38.66°F per hour with minimal intimal injury. Diathermy involves delivering heat to deep tissues via ultrasound, low-frequency microwave radiation, or energy waves.

An important consideration when employing any rewarming technique is to taper or step-down the rewarming efforts as the patient’s temperature approaches normal parameters. This approach can help avoid causing a rebound hyperthermia, especially in cats and small dogs. Therefore it is prudent to monitor the temperature of hypothermic patients every 30 minutes.

Combating hypothermia should be paramount for every hospitalized patient; it’s easy, non-invasive, inexpensive, and a vital component of providing good patient care.

References


See also: *National Association of Veterinary Technician in America (NAVTA) Journal* Hypothermia—What’s the Hype? (June/July 2013)