Short Technical Report on Thermoregulation in Dogs and the Pathophysiology of Hyperthermia

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July 24, 2011

Stationary cars or other enclosed areas in that are in direct sunlight heat up vary rapidly and stay heated even though there may be some slight ventilation. This is sometimes called the "hot house" effect. Basically the windows allow the sun's rays to enter but preclude the heat waves to exit. The whole interior of the car heats up quite quickly (seats, steering wheel, dash board) and hold the heat. Putting an animal into this situation is like putting an animal into an oven and turning on the heat. (Grundstein, Dowd, John, & Meentemeyer, 2010) (McLaren, Null, & Quinn, 2005)

Importance of Thermoregulation

An animal's body is made up of cells which contain a vital fluid known as protoplasm. This protoplasm contains proteins and vital nutrients, enzymes, and hormones necessary for life function. Chemical reactions necessary for life are occurring in the cells. Cells operate in a defined temperature spectrum which varies among species. Mammals have built in metabolic mechanisms to maintain body temperature within that optimal range. (Neutral range)

Maintenance of normal core body temperature in dogs (and all mammals) is a very complex mechanism which is part of physiological homeostasis. This regulation involves multiple body systems – respiratory, cardiovascular, endocrine, nervous, urinary, and even integumentary systems – i.e. the amount and type of hair on the animal. The goal of these mechanisms is to keep the core body temperatures within optimal range for cell function. The homeostatic mechanisms are most efficient in adult animals and less efficient in young or old animals. The mechanisms also allow for acclimatization to extreme temperatures if changes occur gradually. This acclimatization may take from 10 to 60 days.

Physiological Responses to Heat (Hardy, 1961)

When the ambient temperature rises above the neutral range, temperature sensors in the central nervous system (hypothalamus) respond by stimulating the systems involved with thermoregulation to maintain core body temperature. Heat is dissipated by four physical mechanisms: conduction, convection, radiation, and evaporation. Conduction occurs when the body is in contact with a cooler surface, thereby allowing heat to be transferred from the animal to that surface (e.g., placing a hyperthermic animal on a cold steel table). Convection is the transference of heat from the body as air passes over it, as is seen with a fan or with wind. Radiation is the natural process of the body releasing heat into the environment. Evaporation is the endothermic process of a fluid changing to a vapor. As the environmental temperature increases above 32^{o}C (89.61F), evaporation becomes the most important mechanism for dissipating body heat.

The transportation of heat by convective transfer from the interior of the body to the body surface is an important homeostatic function of the cardiovascular system. During exercise or upon exposure to temperatures higher than neutral (~ 80^{O} F.), there is a dilation of blood vessels in the skin to bring the

hot core temperature to the surface of the body. This accompanied by sweat production and the evaporation of sweat also cools the body. In dogs, this vasodilation is limited to the tongue and areas with little hair such as ears. Haircoats limit the effectiveness of vasodilation elsewhere and dogs have no sweat glands except in their foot pads. As the convective mechanism increases blood flow to the surface it is decreasing blood renal and splanchnic blood flow.

In dogs, who don't sweat, water evaporation in occurs on the mucous membranes of the upper respiratory system and mouth and is increased by panting. The panting pattern changes depending on the needs of the body. Inhalation and exhalation first occurs first occurs through the nose entirely (rate is increased), then inhalation through the nose and exhalation through the nose and mouth, and, finally, both inhalation and exhalation through the nose and mouth with the tongue further extended as cooling needs demand. In a well hydrated, healthy dog this evaporation will efficiently work to cool the body. Brachycephalic dogs have reduced nasal and pharyngeal areas and often have elongated soft palates and cannot dissipate heat a nearly as well as other breeds. (Reece, 2005) It should be noted, that heavy panting utilizes much energy and increases water loss as does an increase in exercise. Exertion in the form of frantically trying to get out of a hot car would also decrease the effectiveness of thermoregulation by evaporation.

Tachycardia and increases in cardiac output and minute ventilation also occur to increase blood flow and respiratory rate. Dehydration, previous to heat exposure or as a result of prolonged panting, can impair thermoregulation because less water is available for the respiratory system and by decreasing heat dissipation through radiation and convection because of decreased blood flow to the periphery of the body. High humidity along with high temperatures increase the intensity of the thermoregulatory response mechanisms because evaporation is impeded. (The heat index is a measure of temperature and humidity. As the heat index rises, so does the demand on the thermoregulatory mechanisms.)

Pathophysiology of Heat Stress

If the animal has not been acclimated to heat and/or humidity and is forced to endure high heat for a period of time, (This amount of time is variable according to specific animal idiosyncrasies and actual conditions.) hypovolemia, and dehydration occur and lead to vasoconstriction and decreased cardiac output. Eventually, vasoconstriction and decreased cardiac output (secondary to ongoing heat dissipation) result in decreased tissue perfusion and tissue hypoxia that can lead to complications such as hemorrhagic diarrhea, disseminated intravascular coagulation (DIC), arrhythmias, and renal failure. Renal failure is a common sequel of heatstroke because severe dehydration, hypotension, hypoxia, rhabdomyolysis that causes myoglobinurina, direct thermal damage, acidosis, and DIC all contribute to glomerular damage and tubular necrosis. (Johnson, 2006)

Essentially, the mechanisms attempting to regulate core body temperature become ineffective and the now stressed physiological systems and cellular metabolism begin responding negatively. Cells and tissues are damaged and a dangerous cycle begins that can cause the death of the animal even as the core body temperature is returned to normal. Veterinary care should always be sought in cases of prolonged heat exposure – whether or not there are obvious clinical signs.

Clinical signs of heatstroke may include profound depression, prostration, panting, tachycardia, hyperemia, dry mucous membranes, rapid to nonexistent capillary refill time (CRT), and/or hyperdynamic to weak femoral pulses (with or without pulse deficits). The presence of pulse deficits is indicative of cardiac arrhythmias. Neurologic abnormalities may include ataxia, cortical blindness, seizures, and coma. Other clinical signs may include petechiations and echymoses on the mucous membranes, ear pinnae, or on the skin after clipping hair for the placement of an intravenous (IV) catheter. Bloody diarrhea may be present or may develop during the course of therapy. Clinical laboratory findings may include elevations of the hematocrit, total solids, alanine aminotransferase, bilirubin, blood urea nitrogen, creatinine, creatine kinase, and decrease in blood glucose.

Aggressive treatment is often necessary for dogs that have experienced prolonged heat exposure.

Predisposing factors that decrease heat dissipation: (Johnson, p.114)

Predisposing factor	**Mechanism of action**
Exogenous	
Lack of acclimatization	Decreased neurohormonal responses
Confinement and/or poor ventilation	Decreased conduction, convection, radiation, and evaporation
Increased humidity	Decreased evaporative heat loss
Water deprivation	Decreased blood volume that leads to decreased cutaneous vasodilation and cooling
Endogenous	
Brachycephalic anatomy	Inadequate ventilatory capacity
Obesity	The insulating effect of fat leads to decreased heat dissipation and decreased ventilation
Cardiovascular disease	Decreased cardiac output
Neurological/neuromuscular	Altered thermoregulatory function; decreased ventilatory capacity
Age (geriatric); Age (very young)	As extrapolated from humans, poor acclimatization, compromised cardiovascular response, and deficient voluntary control
Hair coat and color	Darker coats absorb more heat Thicker coats decrease radiation and convection

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