Autonomic Neuroscience: Basic and Clinical 196 (2016) 91–104

Contents lists available at ScienceDirect

Autonomic Neuroscience: Basic and Clinical

journal homepage: www.elsevier.com/locate/autneu

Review

# Thermoregulatory disorders and illness related to heat and cold stress

William P. Cheshire Jr.

*Department of Neurology, Mayo Clinic, 4500 San Pablo Rd., Jacksonville, FL 32224, United States*

ARTICLE INFO

*Article history:*
Received 22 October 2015
Received in revised form 17 December 2015
Accepted 5 January 2016

*Keywords:*
Thermoregulation
Heat stroke
Heat exhaustion
Hypothermia
Rewarming
Hypohidrosis
Small fiber neuropathy

ABSTRACT

Thermoregulation is a vital function of the autonomic nervous system in response to cold and heat stress. Thermoregulatory physiology sustains health by keeping body core temperature within a degree or two of 37 °C, which enables normal cellular function. Heat production and dissipation are dependent on a coordinated set of autonomic responses. The clinical detection of thermoregulatory impairment provides important diagnostic and localizing information in the evaluation of disorders that impair thermoregulatory pathways, including autonomic neuropathies and ganglionopathies. Failure of neural thermoregulatory mechanisms or exposure to extreme or sustained temperatures that overwhelm the body's thermoregulatory capacity can also result in potentially life-threatening departures from normothermia. Hypothermia, defined as a core temperature of <35.0 °C, may present with shivering, respiratory depression, cardiac dysrhythmias, impaired mental function, mydriasis, hypotension, and muscle dysfunction, which can progress to cardiac arrest or coma. Management includes warming measures, hydration, and cardiovascular support. Deaths from hypothermia are twice as frequent as deaths from hyperthermia. Hyperthermia, defined as a core temperature of >40.5 °C, may present with sweating, flushing, tachycardia, fatigue, lightheadedness, headache, and paresthesia, progressing to weakness, muscle cramps, oliguria, nausea, agitation, hypotension, syncope, confusion, delirium, seizures, and coma. Mental status changes and core temperature distinguish potentially fatal heat stroke from heat exhaustion. Management requires the immediate reduction of core temperature. Ice water immersion has been shown to be superior to alternative cooling measures. Avoidance of thermal risk and early recognition of cold or heat stress are the cornerstones of preventive therapy.



**Contents**



*E-mail address:* cheshire@mayo.edu.

http://dx.doi.org/10.1016/j.autneu.2016.01.001

## 1. Introduction

Temperature is a critical variable in health and disease. Constraint of human body core temperature within a degree or two of 37 °C, which is the optimal temperature for normal cellular function, occurs in three ways. The first is stable climate, which maintains temperatures across most of the surface of planet Earth within a range compatible with human life. The second is the autonomic nervous system, which reacts robustly to thermal challenges by orchestrating a complex array of neural responses below the level of conscious awareness. The autonomic responses to cold stress include cutaneous vasoconstriction to retain bodily heat as well as metabolic and shivering thermogenesis. The autonomic responses to heat stress include cutaneous vasodilatation, which liberates heat by radiant and convective heat loss, and sweating, which liberates heat by evaporation. The third and perhaps least predictable is human behavior, which responds to thermal sensory input by seeking warmth or coolness, but which also is responsible for getting people into situations of cold or heat stress, some of which can threaten life or health. Another aspect to human behavior is the healthcare professional's response to thermoregulatory disorders, which draws from knowledge of autonomic physiology to treat patients who have been rescued from circumstances that challenge their capacity for thermoregulation.

This clinical review has a dual emphasis. The first is thermoregulatory disorders, which are disorders of the autonomic nervous system that impair the pathways involved in thermoregulation. Whereas these disorders sometimes present with symptoms related to heat or cold stress, more often the thermoregulatory deficit is incidental to symptoms and provides colocalizing information that is helpful to reaching an accurate diagnosis. The second is illness related to heat stress or cold stress, which encompasses common clinical presentations in which autonomic thermoregulatory function or dysfunction plays a role. Environmental conditions of extreme or prolonged heat or cold stress can overwhelm human thermoregulatory capacity, even in healthy persons, but especially for those whose capacity is impaired. Each year in the United States, for example, approximately 2000 people die from weather-related causes of death (Berko et al., 2014). The National Center for Health Statistics found that 63% of these were attributed to exposure to excessive or prolonged natural cold, hypothermia, or both; whereas 31% were attributed to exposure to excessive natural heat, heat stroke, or sun stroke. As these statistics were gathered from death certificates, the numbers may underestimate the true incidence of fatal thermoregulatory catastrophe (Berko et al., 2014).

## 2. Measurement of body temperature

The bodily temperatures most relevant in medicine are those of the internal organs, particularly the brain, heart and liver. The temperature of the vital internal organs is referred to as the core temperature. The clinical importance of the core temperature relates to the fact that the central nervous system, especially the cerebellum, and the liver are especially sensitive to heat stress (Atha, 2013; Kiyatkin, 2010). Heat-related injury also impacts the kidneys, gastrointestinal tract, and myocardium (Atha, 2013; Jardine, 2007; Wexler, 2002). A number of methods are available in clinical practice, and each has its advantages and disadvantages (Table 1).

### *2.1. Invasive techniques*

Whereas direct measurement of brain temperature in clinical settings is impractical, the pulmonary artery temperature, as measured by a thermistor in a pulmonary artery catheter, is considered the gold standard for accurate determination of core temperature in clinical settings where invasive measurements are possible (Pearson et al., 2012; Lefrant et al., 2003). Other internal sites at which core temperature has been measured include the esophagus, intestines, rectum, and bladder (Lefrant et al., 2003; Robinson et al., 1998). Monitoring of esophageal temperature during left atrial radiofrequency procedures for atrial fibrillation, for example, has been shown to reduce the risk of thermal injury to the esophagus (Liu et al., 2012; Leite et al., 2011).

For the vast majority of patients who do not have indwelling catheters, rectal thermometry has evolved as the standard method for determining core temperature (Lefrant et al., 2003; Robinson et al., 1998). Rectal thermometry is not ideal, however, as rectal temperatures may lag changing temperatures in the blood and other deep organs (Robinson et al., 1998; Eichna et al., 1951). Rectal thermometry also involves physical and psychological discomfort, and there have been documented cases of nosocomial transmission of stool-borne pathogens (Livornese et al., 1992; McAllister et al., 1986) and, very rarely, traumatic injury to the rectum (Al-Qahanti et al., 2001).

### *2.2. Noninvasive techniques*

In common clinical practice, noninvasive methods approximate core temperature indirectly. The traditional method of taking oral temperature with a sublingual mercury-in-glass thermometer has, in recent decades, yielded to new technologies that avoid the potential hazards of broken glass and liquid mercury (Zhen et al., 2014; Apa et al., 2013; Batra and Goyal, 2013; El-Radhi and Patel, 2006; Gasim et al., 2013; Jefferies et al., 2011; Penning et al., 2011). The most sensitive temperature sensors are thermistors, which are semiconductors, the electrical resistance of which varies in proportion to temperature (Bhavaraju et al., 2001). Other types of contact sensors include thermocouples, which are constructed with a pair of dissimilar metal wires joined at one end, resistance temperature detectors, which are wire windings or film serpentines, and liquid crystal strips. These have in common a temperature-dependent physical property that translates to a measurable change in an electric circuit to which the sensor is connected (Jones, 2009). Temperature can also be measured remotely by an infrared sensor pointed at the skin or tympanic membrane surface (Tse et al., 2015).

Numerous studies have compared the clinical use of rectal, oral, axillary, tympanic membrane, and temporal artery thermometry, with varying and at times conflicting results (Allegaert et al., 2014; Bodkin et al., 2014; Charafeddine et al., 2014; Odinaka et al., 2014; Zhen et al., 2014; Apa et al., 2013; Batra and Goyal, 2013; Gasim et al., 2013; Huggins et al., 2012; Edelu et al., 2011; Penning et al., 2011; Jefferies et al., 2011; El-Radhi and Patel, 2006; Craig et al., 2002; Greenes and Fleisher, 2001). Considering these studies as a whole, it may be concluded that the appropriate choice of method depends on the clinical context, as physiologic conditions vary considerably depending on whether the patient is hyperthermic or hypothermic, the external environment, the rate of thermal change, and the age and medical acuity of the patient.