

Adam B. King and Jesse M. Ehrenfeld

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## Introduction

Hypothermia is a common iatrogenic complication in acute care environments due to environmental exposure, illness, and the effects of anesthesia or other drugs. For example, during surgery the prevalence of hypothermia is estimated at 50–70 % [1]. Unintended hypothermia is associated with a number of notable adverse events. Intraoperatively, hypothermia may cause increased blood loss and can contribute to increased transfusion requirements [2], prolonged neuromuscular blockade, and increased cardiac morbidity [3]. In the postoperative period, perioperative hypothermia can lead to prolonged recovery in the postanesthesia care unit (PACU) and postoperative shivering, in addition to the aforementioned increased cardiac risk. Iatrogenic consequences can continue to affect the patient in the recovery period as well as unintended perioperative hypothermia is associated with longer surgical wound healing times and increased wound infections. Most medical

specialty societies, including The American Society of Anesthesiologists, recommend temperature monitoring when clinically significant changes in body temperature are intended, anticipated, or suspected in an acute care environment [4].

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## Normal Body Temperature

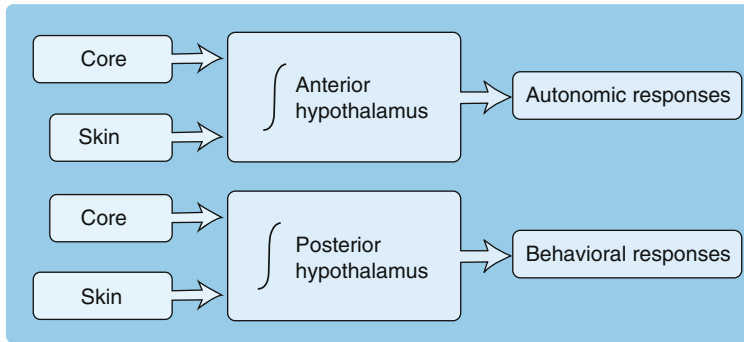
Normal body temperature is considered to be 36.8 °C with a normal range between 36.2 and 37.5 °C [5]. There is a diurnal variation in body temperature with a low point early in the morning and a peak in the evening. The sympathetic and parasympathetic nervous work in concert to maintain core body temperature within this typical range as shown in Fig. 39.1. Hypothermia is defined as an oral temperature less than 36 °C. Hyperthermia is defined by a core temperature greater than 38 °C.

Body temperature is thought to be closely regulated by set point theory using a central thermostat. Thermal receptors are located throughout the body. Cold signals are transmitted using small, thinly myelinated A $\delta$  fibers. These A $\delta$  fibers are also responsible for transmission of pressure and nociceptive information. They are involved in the first, sharp pain transmission and sensation of cold. Warm signals are transmitted using small, unmyelinated C fibers. C fibers also transmit nociceptive information but are involved in second pain sensation that is burning in nature. All of these afferent temperature signals converge

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A.B. King, MD  
Department of Anesthesiology,  
Vanderbilt University, 1211 Medical Center Drive,  
Nashville, TN 37232, USA  
e-mail: adam.b.king@vanderbilt.edu

J.M. Ehrenfeld, MD, MPH (✉)  
Department of Anesthesiology, Surgery,  
and Biomedical Informatics, Vanderbilt University  
School of Medicine, 1301 Medical Center Drive,  
Suite TVC 4648, Nashville, TN 37232, USA  
e-mail: jesse.ehrenfeld@vanderbilt.edu



**Fig. 39.1** Skin and core temperature contributions to central thermoregulatory control. Core temperatures contribute approximately 80 % to the control of autonomic thermoregulatory responses; mean skin temperature contributes the remaining 20 %. Changes in core temperature are, thus, far more important than those in skin temperature; however, skin temperatures change far more than core temperature

and remain important. In contrast to autonomic thermoregulatory responses, which are integrated in the anterior hypothalamus, behavioral responses (e.g., putting on a sweater, opening a window) are integrated largely in the posterior hypothalamus and are determined largely by skin temperature (Reproduced from Sessler et al. [31]; kind permission from Springer Science+Business Media BV)

in the spinothalamic tracts of the anterior spinal cord where they travel to the hypothalamus. The preoptic area of the hypothalamus is believed to be the coordinator of temperature regulation in the brain [6].

In response to hypothermia, cutaneous vasoconstriction occurs which is regulated by the sympathetic nervous system. As a protective mechanism, shivering begins to occur as the body's core temperature continues to decrease. Shivering increases the body's metabolic heat production by an impressive 200–500 % [7].

On the opposite end of the spectrum, the body has also developed innate responses to hyperthermia. An increase in core temperature leads to two different but integrated autonomic responses. The first is sweating and the second is vasodilation of the cutaneous blood vessels. These two mechanisms work in concert to promote heat loss from the surface of the body.

## Methods of Heat Transfer

There are four mechanisms of heat transfer across a temperature gradient: *conduction*, *convection*, *evaporation*, and *radiation*. The most common source of heat loss is through radiant heat losses. Radiant heat exchange is a function of surface area. This becomes especially important to take

into consideration in the field of pediatrics. Compared to adults, infants have a high surface area to body mass ratio, which makes them particularly vulnerable to radiant heat losses.

The second most common cause of heat loss is through convective losses. Convective losses involve the movement of molecules from a warm to cool area. It is dependent on a temperature differential; an example of this phenomenon is the wind chill effect.

The other two mechanisms of heat transfer are evaporative and conduction. Evaporative heat loss is particularly important during long surgeries with exposed viscera. This causes water to be lost to the surrounding environment. Conduction involves the transfer of heat through direct contact. This can be used to our advantage through the use of heating and cooling blankets.

## Effects of Anesthesia on Temperature Regulation

After induction of general anesthesia, unless intentionally intervened upon, a core temperature decrease of 1 °C can occur within the first 40 min. This is thought to occur secondary to peripheral vasodilation leading to heat loss in the extremities [8]. Additionally, during the time period after induction, the patient is usually uncovered and

**Table 39.1** Temperature monitoring sites

Temperature monitoring sites	
Core	Peripheral
Pulmonary artery catheter	Skin
Tympanic membrane	Rectal
Esophageal	Bladder
Nasopharyngeal	Axillary

exposed to the cold ambient temperature of the operating room. The combination of these two factors leads to inadvertent hypothermia shortly after induction. In addition, general anesthesia inhibits the ability of the hypothalamus to regulate body temperature.

Intraoperative hyperthermia usually is due to overwarming of the patient. However, more serious causes of hyperthermia such as malignant hyperthermia, mismatched blood transfusions, or an infectious etiology must be considered. Due to the risk for significant morbidity or mortality should these sources of intraoperative hyperthermia go unrecognized, monitoring for hyperthermia is just as important as monitoring for hypothermia.

## Temperature Monitoring Devices

There are multiple devices and anatomic sites available for perioperative temperature monitoring. Measurement of core temperature is the best indicator of body temperature. Accurate measurement of temperature is of utmost importance because it may lead to early recognition of hypothermia or even hyperthermia. Most devices used currently are thermistors and thermocouples. See Table 39.1 for temperature monitoring sites.

Thermistors are temperature sensitive thermoconductors. Thermocouples measure the current generated when different metals are joined. Both have been adapted to clinical practice for the measurement of temperature. Additionally, infrared sensors can also be used to detect temperature. Infrared sensors sense the infrared energy emitted from a surface at all temperatures above absolute zero.

## Core Temperature Monitors

The pulmonary artery catheter is considered the gold standard for measurement of core body temperature. However, due to the high cost and invasiveness of placement of the catheter, they are reserved for patients that would otherwise require them for hemodynamic monitoring.

Esophageal temperature can be monitored using a thermocouple or thermistor that is incorporated as part of an esophageal stethoscope. It reflects core temperature in a more cost-effective and less invasive method than the pulmonary artery catheter. The optimal position is approximately 45 cm measured from the nose in adults [3]. In addition, they should be positioned at the point of maximal heart sounds for maximum accuracy [9].

Due to their proximity to the brain, nasopharyngeal temperature probes reflect brain and core temperature with reasonable accuracy. Interestingly, in a study of patients undergoing cardiopulmonary bypass, nasopharyngeal temperature was more accurate at reflecting brain temperature during rewarming than cooling [10]. This was thought to be because rewarming is a slower process than cooling.

Tympanic membrane temperatures may be measured using thermocouples or thermistors manually placed against the tympanic membrane. While less invasive than some other core temperature monitoring techniques, this can be uncomfortable in awake patients and even proves at times difficult in patients who are not. Tympanic membrane temperatures can also be taken using an infrared sensor. However, these thermometers usually get directed at a shallow part of the ear canal and do not provide an accurate measurement of core temperature [11]. However, tympanic membrane temperatures can accurately reflect core temperatures if taken correctly.

## Peripheral Temperature Monitors

Skin temperature monitors can be used to estimate core body temperature. However, because of the differential between core and peripheral

blood flow, skin temperatures tend to underestimate core temperature. These monitors are also affected by changes in ambient temperatures. Thermoregulatory changes in vasomotor tone leads to cutaneous vasoconstriction, a reduction in skin blood flow and reduction in skin temperature. Additionally, skin and rectal temperatures are unreliable in detecting temperature changes during malignant hyperthermia in swine [12]. One must take this propensity to underestimate core temperature into account when using these peripheral temperature monitors in clinical practice.

Axillary temperature can be an accurate estimate of core temperature. However, the probe must be placed over the axillary artery and the arm must be abducted at all times to maximize precision [13]. This can be a definite drawback to the axillary temperature probe, as maintaining the position of the probe can prove difficult.

Bladder temperature can be measured using a Foley catheter with an attached thermistor or thermocouple. Bladder temperature can give an accurate representation of core temperature. However, during times of low urine output or during surgeries involving the lower abdomen, the accuracy of this site may decrease.

Rectal temperature can be measured by insertion of a thermistor or thermocouple into the rectum. Rectal temperatures are affected by the presence of stool and bacteria in the rectal vault [14]. These confounders tend to cause rectal temperatures to overestimate the true core temperature.

Skin, bladder, rectal, and axillary temperature monitoring can give a reasonable estimate of core body temperature in certain appropriate clinical scenarios. However, if rapid changes in temperature are anticipated, a more accurate measurement of core temperature might be of benefit and preferred to maximize outcomes.

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## Complications of Hypothermia

Hypothermia affects multiple organ systems within the body and has been shown to correlate with increased mortality rates in trauma patients [15, 16]. This has been further confirmed by a

review of 100 noncardiac surgical patients that found that postoperative hypothermia was associated with an increase in mortality [17].

Hypothermia affects the cardiovascular system in multiple different ways. It predisposes the heart to arrhythmias, notably ventricular fibrillation. There is an increase in systemic vascular resistance and therefore afterload with hyperthermia, which increases the work of the heart. One notable study found that the incidence of myocardial ischemia is increased in patients undergoing revascularization of the lower extremity when they experience perioperative hypothermia [18]. The study ultimately concluded that perioperative hypothermia was an independent risk factor for myocardial ischemia. Frank et al. showed that norepinephrine levels were 1.5 times higher than controls in patients with perioperative hypothermia than those who maintained normothermia [19]. Interestingly, these patients also had increased systolic, diastolic, and mean arterial blood pressures upon arrival to the postanesthetic care unit. Frank et al. proposed that the increase in norepinephrine concentrations in hypothermia patients could be responsible for the increase in perioperative myocardial ischemia [19].

Oxygen consumption and whole body metabolic rates are decreased with decreasing temperature. Additionally, there is a leftward shift of the oxyhemoglobin curve with a decrease in body temperature. This shift decreases the amount of oxygen that is off loaded from hemoglobin in the tissues. The decrease in oxygen demand is usually greater than the decrease in supply cause by the shift in the oxyhemoglobin curve. Oxygen consumption decreases about 7 % per °C that core temperature decreases. This can be used to the patient's advantage during cerebral or myocardial ischemia. Induced hypothermia after cardiac arrest has been shown to improve outcomes in select patients [20, 21]. In addition, core temperatures of 18 °C are used during aortic arch surgery to provide cerebral protection [22].

As temperature decreases, there is a prolongation of the prothrombin and partial thromboplastin times. This in addition, the platelet dysfunction caused by decreases in core temperature can lead to coagulopathy [7].

There is triple incidence of wound infections in patients experiencing intraoperative hypothermia [23]. This is thought to occur because of vasoconstriction caused by the decrease in core temperature. This vasoconstriction leads to a decrease in subcutaneous oxygen tension, which has been associated with increased wound infections [24]. A second reason for the increase in wound infection rates is that hypothermia impairs T-cell-mediated antibody production and oxidative bacterial killing by neutrophils [25, 26].

The above complications can lead to significant morbidity. In addition, to these complications, there are also minor complications that can arise. The pharmacology of drugs changes during hypothermia. The duration of action of vecuronium is more than doubled in patients experiencing core hypothermia [27]. Hypothermia also decreases the minimum alveolar concentration of volatile anesthetics by 5 % per °C below normal body temperature [28]. Mild hypothermia is associated with postoperative thermal discomfort and can delay discharge from the PACU [29, 30]. This can lead to a significant increase in hospital costs and decreased operating room efficiency.

### Conclusion

Temperature is tightly controlled by the body's autonomic regulatory system to optimize its function from the cellular to organ system level. Derangements in temperature, be it hypothermia or hyperthermia, can cause significant harm and thus needs to be monitored closely. Loss of heat most commonly occurs via radiant and convective losses. Excessive temperature is usually the result of rewarming but can be a red flag for a more ominous condition such as malignant hyperthermia or infection. A number of devices and anatomic locations are available for monitoring purposes, but those reliably reporting core temperature remain standard for cases in which temperature fluctuations are anticipated. Normothermia should be maintained unless otherwise indicated to minimize the impact of temperature derangements on the perioperative well-being of patients.

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