J Anesth (2000) 14:91–97

Journal of Anesthesia

Review

Managing perioperative hypothermia

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Key words: Hypothermia, Temperature, Hyperthermia, Anesthesia

Introduction

Mild perioperative hypothermia, defined as a core temperature less than 36°C, occurs in 50%–70% of patients during anesthesia and surgery [1]. Normally, core temperature varies among individuals between 36.2° and 37.5°C [2]. The anterior hypothalamus integrates thermal input from other parts of the brain, the spinal cord, and thermal receptors throughout the viscera and the skin. Cold signals travel to the CNS via A-δ fibers, and information about warmth travels in unmyelinated C-fibers. The temperature of the hypothalamus itself also contributes roughly 20 percent of the information used in thermoregulatory control [3]. The body temperature follows a circadian rhythm; it is usually lowest at 3 A.M. and maximal near 3 P.M. Women have a slightly higher core temperature than men, and there is a cyclical increase associated with ovulation. The mean temperature in the elderly is approximately 0.5°C lower than that of younger people.

Humans are warm-blooded animals (homeotherms). This implies that the core temperature is maintained at about 37°C irrespective of environmental temperature. Behavioral responses, such as appropriate clothing, are an efficient means of adapting to variations in environmental temperature. The thermal core is made up of the heat-producing viscera, the central nervous system, and the great vessels, which comprise about one half of the body mass [2]. A peripheral shell of skin, fat, and muscle surrounds this thermal core. The peripheral temperature ranges between 31° and 35°C, whereas skin temperature is generally 28° to 32°C [2,4]. The peripheral shell protects the thermal core by either absorbing heat from or releasing heat to the environment. The range of core temperatures that are tolerated without triggering a thermoregulatory response is known as the interthreshold range. This range is normally 0.2°C. Within this range, no autonomic responses to cold or warmth occur. Below the hypothermia threshold, vasoconstriction is triggered, followed by shivering as the temperature decreases further. Peripheral vasoconstriction takes place in arteriovenous shunts located primarily in the fingers and toes. These are controlled by centrally mediated α_1-adrenergic receptors, but the vasoconstriction triggered by local hypothermia is augmented by α_2-adrenergic receptors [3]. Shivering is an involuntary muscular activity that increases metabolic rate and oxygen consumption. The response to body temperatures above the hyperthermia threshold is perspiration.

Reliable sites for monitoring the core temperature include the tympanic membrane, the nasopharynx, the distal esophagus, the rectum, and the pulmonary arteries. These reflect core temperature even during rapid cooling or rewarming [5]. The tympanic membrane temperature reflects that of the blood supplying the hypothalamus [6]. Measurement of temperature in the ear canal avoids the risk of tympanic membrane perforation. Esophageal probes are a popular means of temperature monitoring, and the results correlate well with tympanic membrane temperature [7]. It is important to note that the inspired air temperature affects the esophageal temperature and that the esophagus has a large temperature gradient along its length [8]. For investigative purposes, the esophageal probe is placed 12 to 16 cm distal to the best heart–lung sounds [9], but for clinical use it should be placed at the point of maximal heart sounds. Rectal probes have slow response rates and may give inaccurate readings.

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Received for publication on July 12, 1999; accepted on October 27, 1999

In the operating room, mild hypothermia may result from any or all of four physical mechanisms of heat transfer. Radiation is the major source of heat loss in anesthetized patients. It is proportional to the temperature difference between the patient and the environment, and is a function of the body surface area. The next most important means of heat loss is convection, the quantity of which is determined by the temperature gradient between the body and any immediately surrounding fluid or air, and the velocity at which these materials are moving. Conductive heat loss is proportional to the temperature difference between adjacent surfaces, and the properties of any thermal insulation separating them. Evaporation of water from the skin or exposed viscera to the environment is influenced by the degree of patient hydration, and the humidity and rate of air exchange in the room.

Numerous studies have evaluated the physiologic effects of hypothermia and its effects on surgical outcome. This article provides an overview of the effects, followed by recommendations to assist the practitioner in making decisions about the prevention and treatment of mild hypothermia.

Adverse and beneficial effects of hypothermia

Hypothermia produces numerous metabolic and physiologic effects, which may have adverse or beneficial consequences. Oxygen consumption and carbon dioxide production decrease by 7%–9% for each degree centigrade of decrease in temperature [10]. Mild hypothermia thus reduces the metabolism of drugs such as muscle relaxants and proposal; a prolonged postoperative recovery period may result. This temperature decline can also reduce resistance to surgical wound infection by impairing immune function [3]. Effects on the hematological system include platelet dysfunction and impaired activation of the coagulation cascade [3,10]. Blood viscosity increases by 2%–3% per degree of decrease in temperature [10].

The cardiovascular effects of hypothermia include a decrease in heart rate and cardiac output, associated with an increase in systemic vascular resistance and central venous pressure. Electrocardiographic changes include sinus bradycardia, prolonged PR and QT intervals, and widened QRS complexes. Arrhythmias may occur at temperatures below 28°C [10]. Ventricular fibrillation and asystole are likely at temperatures below 20°C [10]. The decrease in hepatic blood flow resulting from decreased cardiac output diminishes liver function, and thus the metabolism and elimination of its normal substrates and many drugs. Hypothermia causes a direct depression of hepatic enzymatic activity, contributing to decreased drug metabolism. Respiratory effects include depression of hypoxic pulmonary vasoconstriction, which can increase intrapulmonary shunting; depression of hypoxic respiratory drive; and an increase in pulmonary vascular resistance [10]. Renal function is affected by a reduction in renal blood flow and by an impaired ability to concentrate or dilute urine.

Shivering commonly occurs as a hypothermic patient emerges from anesthesia, and produces an increase in oxygen consumption and carbon dioxide production. A decrease in arterial oxygenation may trigger myocardial ischemia in patients with underlying coronary artery disease [2].

Hypothermia may be intentionally induced during cardiovascular and neurosurgical procedures. Mild hypothermia may offer some degree of neuronal protection in areas of ischemia by decreasing cerebral electrical activity, metabolism, and blood flow. These effects are nonspecific and may result from suppression of excitatory neurotransmitter release and intraneuronal calcium mobilization, preservation of high-energy phosphates, reduced accumulation of toxic metabolites, prevention of blood-brain barrier disruption, and decreased free radical production [11].

General anesthesia and mechanisms of hypothermia

General anesthetics increase the interthreshold temperature range to about 4°C. As a result, anesthetized patients are poikilothermic; the environment essentially determines the body temperature. Initially, this loss of thermoregulation causes a redistribution of body heat from the core to the periphery, which decreases the core temperature by 1° to 1.5°C during the first hour. Unless steps are taken to prevent it, after the first hour the temperature decreases further because the heat loss exceeds the metabolic heat production [3]. If hypothermia is allowed to progress, the temperature will stabilize by the activation of thermoregulatory vasoconstriction, which holds metabolic heat in the body core. Vasoconstriction occurs during anesthesia, but not until the core temperature reaches about 34°C [3]. This effect may be detrimental, since the mean temperature and the total heat content of the body continue to decrease even though the measured core temperature remains constant [3].

Regional anesthesia and mechanisms of hypothermia

Neuroaxial regional anesthesia impairs both peripheral and central thermoregulation. The cold threshold is reduced by 0.5°C, whereas the warm threshold is increased by 0.3°C [12]. The onset of spinal or epidural anesthesia blocks afferent input from cutaneous cold receptors. Sympathetic blockade and vasodilatation increase perfusion to peripheral tissues, producing heat transfer from the core to the periphery, as occurs during general anesthesia [12]. This causes the thermoregulatory system to "see" the skin temperature in the blocked area as increased. This overall perception of warmth results in tolerance for a degree of hypothermia that would normally trigger shivering [12]. Therefore, shivering will stop in a cool environment after the onset of spinal anesthesia, even in the presence of a core temperature that has decreased by 1°C [13]. Patients under epidural anesthesia may report feeling warmest when their core temperature is at its lowest [14]. If a patient becomes sufficiently hypothermic during spinal or epidural anesthesia, shivering will occur cephalad to the block. In contrast to the effects of general anesthesia, patients under neuroaxial blockade cannot establish a thermal plateau, because peripheral vasoconstriction is inhibited. Thus a decline in temperature may take place throughout surgery [2].

Techniques and devices to prevent and treat perioperative hypothermia

As we have discussed, mild hypothermia is common after the induction of general or regional anesthesia because these techniques block normal mechanisms that maintain a stable body temperature. Behavioral responses are removed, and only autonomic responses remain. Anesthesiologists have several ways at their disposal of preventing and treating this problem. The following is a list of devices and techniques widely available in most practice settings. The items are listed in the order of increasing expense.

Room temperature

The operating room temperature is the most critical factor in heat loss. The rate of heat loss is determined by radiation and convection from the skin and by evaporation from the surgical incision. Normothermia can be maintained by providing ambient temperatures greater than 21°C [15]. This temperature may be uncomfortable for gowned personnel in the operating room. The holding area and operating room can be maintained at room temperature until skin preparation is completed, since this will limit the initial drop in temperature caused by redistribution.

Blankets

Skin temperature contributes 10%–20% of the autonomic thermoregulatory response [12,16]. Thus, cutaneous warming is an effective treatment for shivering, even in the presence of core hypothermia [17]. Furthermore, skin surface warming prevents redistributive hypothermia and increases total body heat content [18].

Passive insulation creates a layer of trapped air between the covering material and the skin. A single cotton blanket reduces heat loss by approximately 30% and increases the mean skin temperature by 1°–2°C [19]. Multiple layers of blankets decrease heat loss only slightly, to approximately 50% [19]. Heated blankets may increase the perception of warmth; however, since the heat capacity of cotton is low, the efficacy of a warmed blanket is only slightly greater than that of than an unwarmed one. The heat is redistributed to the environment and the benefit dissipates in about 10 min. The patient's overall perception of warmth is similar whether he or she is covered with three blankets or one and whether these are warmed or unwarmed [18,19].

Low-flow delivery of anesthetic gases

The minimum recommended humidity for the anesthesia circuit is 60% or $12\,\mathrm{mg \cdot l^{-1}}$; the optimum values are between 14 and $30\,\mathrm{mg \cdot l^{-1}}$. No significant cellular change occurs in the tracheobronchial epithelium when gas is humidified to 60% at room temperature (22°–26°C) or saturated with moisture at body temperature [20]. Most of the heat loss from the body during breathing of dry gases is due to evaporation. The relative humidity of inspired gases in a circle system can be manipulated by changes in fresh gas inflow (FGI) and minute ventilation [21]. Other factors that contribute to the system humidity include the water generated from carbon dioxide neutralization in the absorbant (sodalime or baralyme). The initial humidity in every fresh-gas system is derived from the water content of the barium or calcium hydroxide granules. In a previously used system, which contains water of condensation, the original humidity is naturally higher [20]. The time required to reach steady-state humidity depends on the time needed to saturate the gases in the ventilator with water vapor. Increasing the FGI decreases the humidity on the inspiratory side by diluting the gases already in the circuit. A fresh-gas inflow of $1\,\mathrm{l \cdot min^{-1}}$ produces a system humidity of $18\,\mathrm{mg\ H_2O \cdot l^{-1}}$, whereas a fresh-gas inflow of $6\,\mathrm{l \cdot min^{-1}}$ produces a system humidity of $12\,\mathrm{mg\ H_2O \cdot l^{-1}}$ with no ancillary humidification [21]. Decreasing the minute ventilation decreases the amount of warm humidified gases exhaled by the patient into the circle system. A series of experiments demonstrated the effect of variations in FGI, CO_2 inflow, respiratory rate, and tidal volume in a circle system [20]. In the "standard adult" model (FGI $5000\,\mathrm{ml \cdot min^{-1}}$, VCO_2 $200\,\mathrm{ml \cdot min^{-1}}$, VT $500\,\mathrm{ml \cdot min^{-1}}$, rate $12 \cdot \mathrm{min^{-1}}$), the initial humidity ranged from 29% to 32%, and a mean humidity of 61% was reached in 90 min. When the FGI was reduced to $500\,\mathrm{ml \cdot min^{-1}}$, the initial humidity was 47.5%, increasing to 93% and stabilizing in 100 min. Removing a humidifier from the system does not change the period of stabilization, which remains at 90 min, but delays the initial increase in humidity by 20 min. On the basis of the data above, the use of low flows of inhaled gases can maintain circuit humidity but it is not enough to increase body heat content.

Warmed-water mattress

Warmed-water mattresses have been shown to be effective in children under 10 kg but are of little value in adults unless the patient is wrapped in the blanket [22,23]. Warming mattresses used alone are ineffective in countering heat loss during anesthesia and surgery, because little heat is lost from the back. In addition, the heat transfer is limited by the surface area, poor perfusion of dependent areas, and the relatively low water temperatures that must be used to avoid causing burns [24]. The amount of body heat gained from a warming mattress has not been evaluated. Warming mattresses work best if they are placed over the patient, but this is obviously usually impractical during surgery [22]. Prolonged exposure to warming mattresses has been associated with thermal injury in all age groups, even at water temperatures as low as 37°C [1]. The maximum blanket temperature recommended is 40.5°C. There are two case reports of second and third degree burns corresponding to the area of contact and to the fluid channel spacing in the warming blanket [25]. Among a total of 3000 claims in the American Society of Anesthesiologists (ASA) Closed Claims database, there were 54 burns, of which 28 resulted from materials or devices used to warm patients [26]. Electrically powered warming equipment represented 29% (eight cases) of the total cases. Five of these resulted from the use of circulating warmed-water mattresses. In only one case was the device noted to be defective, resulting in overheating. Analysis of risk factors for hypothermia and burns included the extremes of age (one infant and four adults older than 60 years), the presence of vascular disease or diabetes, and prolonged surgery. In all cases the burns were over bony prominences and resulted from a combination of heat and pressure. The probability of cutaneous burns depends directly on factors such as the applied temperature and the duration of exposure, and is inversely related to tissue perfusion. Normal tissue perfusion dissipates applied heat, but perfusion may decrease as a result of vascular insufficiency, clamping of vessels, or extrinsic pressure. Warmed-water mattresses also have an uneven surface, which may compound the injury by causing pressure over bony prominences. Before the device is used, any predisposing patient conditions (diabetes or vascular disease), the length of the procedure, and the patient's weight, position, and age have to be considered. If any of these risk factors are present, the lowest temperature setting should be used and the device should be turned off intermittently.

Heat lamps

Radiant heat lamps are the least effective active warming devices, since in adults they can heat only a relatively small surface area. Since the skin must be exposed to the lamp to be effective, convective heat loss continues. However, with this device it is possible to stop shivering and thermal discomfort despite low core temperatures because of activation of warmth receptors that are distributed in the blush region (face, neck, and upper thorax), and alteration of thermal signals reaching the nervous system [17]. The sensitivity to warmth varies in different regions of the body. Each region differs in its capacity to influence the thermoregulatory response and the subjective appreciation of cold or warmth. The major benefit of radiant heating is suppression of shivering [17]. The application of radiant heat lamps located 18–24 cm above the sternum illuminating the upper thorax to the suprapubic area resulted in the complete cessation of shivering in an average time of 60.6 ± 9.8 s. When the lamps were turned off, patients resumed shivering within 42.8 ± 6.9 s. When heat was reapplied, patients stopped shivering again in an average of 59.5 ± 10.2 s. Radiant heat lamps are superior to warmed blankets for the control of postanesthetic shivering. Radiant heating suppressed shivering in a group of patients ($n = 15$) after 10 min of continuous treatment, but 67% of the warmed-blanket group ($n = 15$) continued to shiver after 30 min. This indicates that localized radiant heat applied to the neck, chest, and abdomen triggers cutaneous neuronal input to the central nervous system that can inhibit the physiologic response [17].

Plastic bags

The use of plastic bags to cover the patient's head is a common practice. Prevention of heat loss by this method has not been demonstrated in prospective studies in adults. Unlike infants, the adult head does not contribute to a large proportion of heat loss; the legs are the most important component of the peripheral thermal compartment [27].

Passive airway humidifiers (Pall Filters/Humid-Vent 1 Heat-Moisture Exchanger)

Passive airway humidifies provide efficient humidification and work almost as well as active heater humidifiers in preventing respiratory heat loss [28]. In one study, 27 infants and children were randomly assigned to active, passive, or no intraoperative airway humidification and warming [28]. The humidity of inspired gases was 90% with the use of active airway humidification, 50% with passive heat and moisture exchangers, and 30% with no device. After 80 min of anesthesia, the inspired humidity due to the heat and moisture exchanger did not differ significantly from that produced by active airway humidification. The humidification with either device was significantly greater than that with unconditioned gases. The clinical benefit is related to the maintenance of ciliary function rather than to heat conservation. They do not prevent core hypothermia.

Metallized plastic blankets and head covers

There are no clinically important differences in efficacy among the various types of passive thermal barriers. These devices are no more effective than paper surgical drapes or cotton blankets, and are of little value in preventing intraoperative heat loss [29].

Active heater humidifiers

Only 10%–15% of metabolic heat is lost via the respiratory tract, even during inhalation of cold, dry anesthetic gases [30,31]. Airway humidifiers have been shown in several studies to be inefficient in raising total body heat content in adults, because heat loss via the tracheobronchial tree is small. Respiratory heat loss is estimated to be about 12 W (19 $\mathrm{kcal \cdot h^{-1}}$). On the basis of these data, after 3 h of anesthesia the heated humidification of inspired gases can increase body heat content a maximum of 30 kcal and increase mean body temperature by about 0.5°C [22]. Pediatric patients (5–30 kg) undergoing minor procedures (with minimal body cavity exposure) may benefit from airway heating and humidification, which can increase the steady-state temperature [32]. These devices may spuriously increase nasopharyngeal and esophageal temperatures, resulting in an overestimation of their efficacy. Although heater-humidifiers are recommended for prolonged ventilation, they are unnecessary for routine intraoperative use. Furthermore, they increase the risk of thermal injury to the airway and are an added expense. They do not prevent core hypothermia.

Forced-air warming

Forced-air warming is the most effective means of rewarming hypothermic patients intraoperatively [2]. It is superior to circulating water mattresses [23,24] or warmed cotton blankets [33]. The highest skin temperatures attained during forced-air warming approach 38.5°C. Although air has a heating capacity of only 1 $\mathrm{J \cdot g^{-1} \cdot C}$, forced-air warmers transfer large amounts of heat to the patient because of their high rates of airflow. These devices can reverse hypothermia during anesthesia and prevent further cutaneous heat loss. The only contraindication to the use of these devices is when circulation is impaired, such as during aortic cross-clamping, because excessive heating of the lower extremities may lead to an imbalance of oxygen supply and demand [31].

After the patient emerges from anesthesia, the hypothalamic thermoregulatory responses usually return to the normal interthreshold range within 15 min [34]. Peripheral vasoconstriction and shivering are common at this time. This mechanism preserves the central heat content at the expense of the periphery. Forced-air warming actively warms the skin, but this heat cannot reach the core because vasoconstriction isolates it from the periphery. Thus, this technique is inefficient for rewarming the patient in the immediate postoperative period.

Countercurrent fluid warmers

Intravenous fluid administration results in convective heat loss, especially when large volumes and rapid flow rates are used. A unit of refrigerated blood or 1 l of crystalloid solution at room temperature may decrease mean body temperature by 0.25°C if administered over a short period of time. Fluid warmers are essential during massive transfusion and in cases involving large amounts of insensible fluid loss. Fluid warmer technology includes dry heat, water bath, or countercurrent heat exchange. These devices warm intravenous fluid through a coil or sleeve in contact with a heat source. The efficacy of these devices is similar at flows of approximately 50 $\mathrm{ml \cdot min^{-1}}$; at this rate the fluid temperature increases, but this has no effect on the body's core temperature. Only countercurrent systems can warm blood from 4° to 33°C or more at flow rates greater than 100 $\mathrm{ml \cdot min^{-1}}$, reducing the convective heat loss. Fluid warming is not a substitute for surface insulation or warming [19]. These devices can prevent fluid-induced hypothermia but cannot rewarm an already cold patient [31].

Practical guidelines for treatment and prevention of mild perioperative hypothermia

Prevention of hypothermia should begin when the patient enters the surgical suite. The operating room should be maintained at a comfortable ambient temperature at this time in order to decrease heat loss prior to induction of anesthesia. Radiant heat loss can be reduced by the application of a single blanket covering as much surface area as possible. Pediatric patients (5–30 kg) can benefit from radiant heaters applied to the exposed skin surface and by maintaining room temperature at 21°–24°C prior to induction. If general anesthesia is employed, a passive heat and moisture exchanger should be attached to maintain circuit humidity. Low anesthetic gas flows can also help maintain the moisture content of the circuit. Forced-air warmers should be used if the procedure is anticipated to be longer than 60 min. These devices can reverse the redistributive hypothermia that takes place during the first hour after induction of anesthesia and prevent further cutaneous heat loss. They are effective even when applied over a small surface area. If spinal or epidural anesthesia is employed, the warming device should be applied above the level of the block. For reasons we have discussed, forced-air warming devices are less useful to treat established hypothermia in the postoperative period.

A countercurrent fluid warmer should be used if more than 2 l of blood or fluid per hour is administered to an adult. At lower rates the benefits do not exceed the cost, and warmed fluid cools to room temperature as it passes through the tubing. Irrigation fluids should also be warmed. Shivering will not occur during emergence from anesthesia if intraoperative hypothermia has been avoided. If the patient does shiver, appropriate medications may be administered, the room temperature should be increased to a comfortable level, a blanket may be applied, or forced-air warming may be continued if it has been used. Radiant heaters are effective for infants at this time.

Intravenous opioids suppress shivering. Meperidine (12.5–25 mg) is the most commonly used agent; it can be administered intravenously or epidurally [2]. Intravenous clonidine (75–100 µg) or epidural sufentanil (50 to 100 µg) may also be employed [35,36].

These guidelines can be used in a majority of surgical cases. Obviously, they may need to be modified depending on clinical needs and constraints. In general, however, they are capable of improving both patient comfort and patient safety in a cost-effective manner.

Acknowledgment. The author thanks Drs. Sanford Miller and Charles Fermon for their assistance.

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