Review on Hypothermia during anesthesia

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Abstract

Background: **Perioperative hypothermia is a preventable decline in core body temperature (below 36.0°C) during anesthesia. This can lead to adverse outcomes and increased healthcare costs.**
Objective: **To investigate perioperative hypothermia, its physiological mechanisms, risk factors, and preventative measures during anesthesia.**
Methods: **We performed a review of literature on thermoregulation, impact of different anesthesia types, risk factors, complications, and management strategies for perioperative hypothermia.**
Results: **Perioperative hypothermia, defined as a core body temperature below 36.0°C, affects up to 72.5% of surgical patients and leads to adverse outcomes such as increased infection rates, blood loss, and prolonged hospital stays. General and regional anesthesia compromise thermoregulation, with certain anesthetics lowering the vasoconstriction and shivering thresholds. Risk factors include advanced age, low body mass index and the use of unwarmed fluids. Effective preventive measures include active warming devices, such as forced air systems, and prewarming protocols. Core temperature monitoring is essential, with various reliable techniques available, including nasopharyngeal and esophageal measurements.**
Conclusion: **Perioperative hypothermia is a common, preventable issue that significantly impacts patient outcomes and healthcare costs. Proactive temperature monitoring and the use of warming devices are critical for preventing hypothermia and its associated complications. Implementing best practices in perioperative temperature management can enhance patient safety and reduce healthcare expenses.**

Keywords: **Perioperative, hypothermia, anesthesia, core body temperature, thermoregulation.**

Introduction

Hypothermia is a physiological state wherein the body's core temperature drops below a defined threshold, typically set at 36,0°C[1,2]. Perioperative hypothermia is a preventable complication during general and regional anesthesia. Affecting up to 72,5% of cases, it is a widespread problem adversely affecting patient's outcome[3,4]. Even mild hypothermia can lead to unwanted outcomes, decreasing patient's satisfaction and increasing healthcare costs. Anesthesiologists should be aware of the potentially serious complications caused by perioperative hypothermia and should monitor a patient's body temperature during all phases of perioperative care[2]. Methods to prevent hypothermia are easy to use, low cost and very effective.

Physiology of thermoregulation

General

Thermoregulation is a homeostatic process by which the body's temperature remains within a narrow range -usually around 37,0°C- despite external fluctuations[5,6]. Core temperature follows circadian fluctuations and is subject to hormonal changes[6,11]. Thermoregulation is mediated by specific transient receptor potential (TRP) receptors located on afferent Aδ and C-fibers[11]. These thermal signals are transmitted to the central nervous system through the anterior spinal cord. The body's primary thermostat - the hypothalamus - receives these signals and plays a central role in regulating the body's temperature through a variety of autonomic and behavioral responses[5,11]. Autonomic responses to an increased body temperature include precapillary vasodilatation and sweating facilitating heat loss to the environment. Autonomic responses to a drop in core temperature initially triggers vasoconstriction in the extremities reducing blood flow to minimize heat loss. If the temperature continues to decrease, the shivering threshold will be reached. This threshold is usually 1°C lower than the threshold for vasoconstriction[5]. Shivering is a mechanism leading to an increase in metabolic heat production through involuntary muscle contractions[5,11]. In infants heat can be produced by non-shivering thermogenesis in brown adipose tissue[5]. Each response has its own threshold, a few tenths of a degree above or below the core temperature[5]. Behavioral responses include a variety of voluntary actions taken to adapt to the environmental temperature and are the most effective respons[5]. Failure of the thermoregulatory process can either result in hyper- or hypothermia, each one with its own clinical signs and consequences. Hyperthermia is an elevation in core temperature caused by excessive heat, heat production or inadequate heat loss. It is usually treated by measures to promote heat loss. Fever, on the contrary is a regulated form of increased body temperature originating from the hypothalamus and driven by pyrogenic cytokines. Managing fever is more difficult since cooling is ineffective as the body is programmed to increase metabolic heat production. Diagnosing and treating the underlying cause is primordial[5,11].

During general anesthesia

During general anesthesia, central control of the body's core temperature is impaired because both behavioral and autonomic pathways are altered. Once the patient becomes unconscious, behavioral responses lose significance. Anesthetic drugs, such as propofol for intravenous use and volatile agents like sevoflurane and desflurane, significantly lower the threshold for shivering and vasoconstriction, thus impairing the body's autonomic responses to a lower core temperature. While the precise physiological mechanism responsible for these alterations is not fully understood, some volatile anesthetic may directly inhibit TRP receptors[5]. This impairment causes the vasoconstriction threshold to drop to 34,5°C[5]. Combined with decreased metabolic heat production and some typical external environmental factors in the operating room (cold temperature, laminar airflow, and exposure of body parts) makes patients susceptible to hypothermia[6].

Following the onset of general anesthesia, core temperature exhibits a characteristic decline with several distinct phases (Figure 1)[7]. In the first phase the core temperature rapidly drops by about 1°C, caused by redistribution of heat within the body[5,8,9]. This heat redistribution is due to the vasodilatation accompanying the inhibition of the autonomic nervous system by intravenous or inhalational anesthetics[5]. The blood volume of the warmer core will be mixed with the blood volume of the colder peripheral compartments. This initial drop of core temperature is almost inevitable in anesthetized patients. The second phase is a much slower linear decrease in core temperature due to heat loss to the environment, primary through

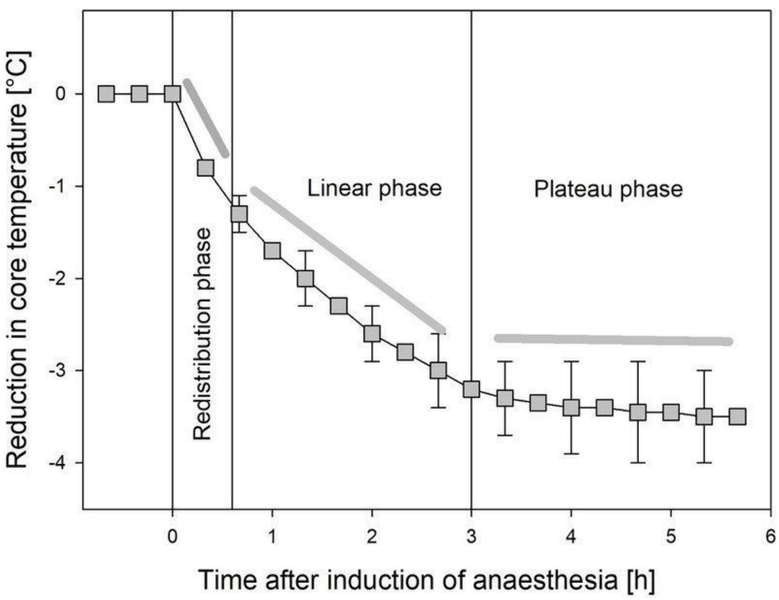

Fig. 1 — The impact of general anesthesia on core temperature. In the first phase, core temperature drops about 1°C due to heat redistribution. The second phase involves a slower, continuous decrease in core temperature. In the third phase, also called plateau phase, heat loss and production balance out, stabilizing the core temperature.

radiation and convection, that exceeds the inherent heat production of the body[5,9,10]. Eventually, the heat dissipated to the surroundings equals the heat generated, leading to the stabilization of the core temperature, known as the plateau phase.

During regional anesthesia

Neuraxial anesthesia is known for blocking the autonomic nervous system, responsible for regulating vascular tone during activation, and thermal input from the anesthetized parts of the body[11]. This effect will cause a similar drop in core temperature as seen in general anesthesia. Since the lack of thermal input of the anesthetized body part often is interpreted as a subjective "warm" sensation in an awake patient, patients under neuraxial anesthesia often are not aware of becoming hypothermic[9,12]. The more centrally a locoregional block is placed, the greater its effect on thermoregulation[5]. Since locoregional anesthesia typically affects only a part of the body, patients receiving combined locoregional and general anesthesia are more susceptible to hypothermia, as the autonomic thermoregulatory impairments are additive. Although pre-heated cotton blankets are frequently used in perioperative environments, they do not effectively prevent neuraxial anesthesia-induced hypothermia[12]. Therefore, active warming should be carried out in all patients undergoing neuraxial anesthesia, even if they do not report thermal discomfort. As hypothermia is often aggravated due to vasodilatation, a continuous infusion of vasoactive drugs like phenylephrine could partially counteract redistribution hypothermia[13,14].

During sedation

Light to moderate sedation does not seem to significantly impair thermoregulation[5]. Since thermal input to the (partially) conscious patient remains intact and adequate, the anesthesiologist can rely on the thermal comfort or discomfort the patient will report. Since the adverse effect of anesthetic drugs on thermoregulation is dose-dependent, hypothermia is more likely to occur in patient with increasing depths op sedations[5].

Risk factors for developing perioperative hypothermia

The vast majority of patients develop hypothermia during surgery, but this occurrence is not evenly distributed among patient populations and types of surgeries. Understanding the risk factors is crucial in preventing hypothermia and its consequences. Patients older than 60 years[15] and higher ASA-scores are at greater risk of becoming hypothermic, because of inherent impairment of thermoregulation and increased level of comorbidities[10,16]. Lower temperature in the operating room will increase the temperature gradient leading to an increased incidence and faster onset of hypothermia[17,18]. Low body mass index provides less natural insulation, also increasing the risk[10,19]. Combining general anesthesia with regional or neuraxial anesthesia heightens the risk for hypothermia development in comparison to the independent administration of each anesthetic technique[10]. Infusion of large volumes of unwarmed fluid should be avoided as it contributes to cooling down the patient[18]. Guidelines recommend using a fluid warmer when administering more than 500 ml/h of fluids[10,20]. A low perfusion index (PI) prior to the induction of anesthesia is an independent risk factor for developing lower core temperatures during the redistribution phase. The PI is the ratio of pulsatile blood flow versus nonpulsatile blood in peripheral tissues. Diminished peripheral perfusion, indicated by a low PI, leads to lower temperatures in the peripheral regional of the body, thereby increasing the temperature gradient between the core and peripheral body parts. As a result, the heat redistribution is more pronounced, contributing to a greater drop in core temperature after anesthesia induction[21]. Surgery related factors that are at greater risk of developing hypothermia include laparoscopic procedures with unwarmed gas[19], laparotomies and procedures which include exposing large body areas[18]. Operating time has been identified as an independent risk factor for intraoperative hypothermia, in particular when no measures for patient warming were implemented[18,22].

Perioperative hypothermia in children

Children are more vulnerable to intraoperative hypothermia due to their physiology. Firstly, children have a higher surface area to mass ratio and a proportionally larger head compared to the size of their body, favoring heat loss to the environment[23]. Secondly, a child's thermoregulation is less effective than in adults. And additionally, children have less adipose tissue for thermal insulation[23]. These factors make it even more important in infants and children to optimize operating room temperature. An insulating cap can be of great importance since a lot of heat loss comes from the large head[23].

Therapeutic perioperative hypothermia

Not all cases of intraoperative hypothermia are inadvertent. Few indications exist for therapeutic hypothermia, mostly ischemia-inducing surgeries and conditions[24]. This is used to protect vital organs (such as brain, heart and kidneys) from severe ischemia and dysfunction as a consequence. Hypothermia induces a decrease in metabolic demands, thereby preserving energy stores more effectively and engaging in neuroprotection[24]. Evidence about the benefits of neuroprotective hypothermia remains conflicting after the POLAR RCT failed to demonstrate improved neurological outcomes in traumatic brain injury (TBI) patients with hypothermic management compared to the normothermic group[25].

Body temperature monitoring

To prevent hypothermia, it is important to closely monitor a patient's body temperature with the different types of anesthesia. Hypothermia can occur in general anesthesia, but also in regional anesthesia and even in patients who are moderately to deeply sedated. Since there is a temperature gradient between the core temperature and the peripheral temperature, it is important to know what type of monitoring is being used at which body site. Most recent guideline advise to monitor core temperature during all phases of perioperative care[2]. Whereas standard-of-care a few years ago was to monitor body temperatures in general anesthesia lasting for more than half an hour[5].

A survey conducted in 2007 in 17 European countries, revealed that intraoperative temperature monitoring and active patient warming practices are not yet standard, with monitoring occurring in a minority of cases and active warming of patients in only 43%. The authors emphasized the necessity of heightened awareness of perioperative hypothermia, advocating for the establishment of a European practice guideline for perioperative patient temperature management to maintain normothermia throughout surgery[26].

A non-randomized multicenter observational study was conducted in France in 2019 to assess the occurrence of perioperative hypothermia. 53,5% of 893 involved subjects exhibited hypothermia, meaning that the incidence of hypothermia remains high despite increased awareness, guidelines and therapeutic interventions[27].

Both invasive and non-invasive measurement techniques exist. Four sites of measurement are considered to reliably monitor the core temperature of a body: the tympanic membrane, nasopharynx, esophagus and the pulmonary artery[5,28]. Tympanic membrane is a relatively easy and quick method to use but must be carried out with the necessary care and attention. The performer should be aware that any obstruction of the auditory canal or mispositioning of the thermometer can lead to repetitive bias and/or incorrect measurements. This technique can be used in awake patients without discomfort. Nasopharyngeal and esophageal measurement methods are considered very reliable and easy to perform, although the patient should be unconscious due to discomfort when inserting the probe. This technique is generally a safe way to estimate core temperature, but insertion of the probe should be performed carefully to prevent bleeding[28]. Recently a new method has been developed. The SpotOn™ thermometer, which is attached to the forehead of the patient and uses zero-heat-flux technology, accurately estimated core temperature. Showing a mean difference of -0.06 °C compared to the pulmonary artery catheter thermometer, it demonstrates its reliability and potential as an alternative in general anesthesia for core temperature assessment[29]. The most precise way to measure core temperature is a pulmonary catheter. Although it is considered as the golden standard, it is an invasive technique that is only used in critical care patients and patients undergoing cardiac surgery[28].

Temperature measurement methods that are considered less reliable are axillar, oral, rectal and bladder measurements due to high environmental influence and bias[28]. Axillar measurement is safe, easy, quick and inexpensive to perform which makes it very attractive to use. Disadvantages of this method include the underestimation of the core temperature and highly prone to environmental changes, which makes it not suitable during perioperative care[28]. Oral measurement can be an alternative, if measured in the sublingual pocket. This is the most temperature stable location in the mouth. Rectal temperature has a poor correlation with core temperature and can be severely delayed, moreover there is a small but severe risk of rectal perforation[28]. Urinary bladder temperature can be a good estimate of core temperature if urinary output is adequate. Since urinary catheters are common in awake and conscious patients, this is a relatively non-invasive and reliable method for continuous temperature monitoring[28].

In certain medical situations, such as maxillofacial surgery, reliable temperature measurement can be challenging due to limited access to standard measurement sites like the nasopharynx or esophagus. This limitation highlights the need for alternative methods that are both accurate and non-invasive. The SpotOn™ thermometer offers a promising solution by providing accurate core temperature readings, even in patients where traditional techniques are impractical. Additionally, urinary bladder temperature measurement, while less precise, can be a viable option if urinary output is adequate, offering a continuous and relatively non-invasive temperature monitoring.

Complications of perioperative hypothermia

Surgical site infection (SSI)

In colorectal surgery the odds ratio of serious infectious complication increased to 1,38 in patients with a core temperature lower than 35,5°C compared to the normothermic group. Below 35,4°C the risk of post-operative infection progressively increased[30].

Although abundant evidence and studies were able to identify hypothermia as a risk factor for SSI, a retrospective study from Baucom et al. conducted in 2015 concluded that there was no association between intraoperative hypothermia and 30-day postoperative SSI development[31]. This study is limited due to is retrospective aspect and its relative small number of patients as well as its definition of hypothermia. Hypothermia was defined as an average core temperature below 36 degrees Celsius, but no subdivisions were made. Discussion remains if hypothermia has a significant impact on SSI, it is likely that other factors exist which have a much greater effect, such as surgical asepsis and antimicrobial prophylaxis.

Blood loss and blood transfusion (hypothermia induced coagulopathy)

Normal core temperature and preventing hypothermia is an important factor in reducing blood loss and consequently blood transfusions in major surgeries like open thoracic surgery and hip replacements. This was concluded by Yi et al. in a randomized controlled clinical trial[32]. Increased bleeding that occurs with hypothermia can be explained with the physiological inhibition of clotting factors and impaired platelet function due to hypothermia-induced impairment of thrombin[33].

Myocardial injury

The PROTECT study conducted in 2021 by Sessler et al. is a multicentre, parallel group trial which investigated differences in outcome on major perioperative complications between aggressive core temperature control (37 degrees Celsius) and routine thermal management (35,5 degrees Celsius). Major perioperative complications were defined as myocardial injury, non-fatal cardiac arrest and all-cause mortality within 30 days of surgery. The incidence of these complications did not differ significantly between the 35,5°C group and the 37°C group[34]. It is likely that major perioperative complications increase with decreasing core temperature, and that mild hypothermia (35,5°C) is not a significant risk factor. This trial supports the conclusion of a retrospective study performed by Schacham et al. who failed to observe an association between mild perioperative hypothermia and mortality or myocardial injury in adults having noncardiac surgery[35].

Postoperative shivering (patient satisfaction, increased oxygen consumption)

Shivering is defined as uncoordinated spontaneous contractions of skeletal muscles. It is often a sympathetic response to increase basal metabolism and augment core temperature in hypothermic patients. Postoperatively it's a major determinant of patient satisfaction and subjective well-being[36]. Shivering is known to cause a rise in metabolic rate that increases oxygen requirements and carbon dioxide and lactic acid production, which may increase complications in patients with poor cardiopulmonary reserve[37]. Shivering can be easily prevented by prevention hypothermia or by administering intravenous medications such as pethidine and ketamine[36,38].

Healthcare costs and hospital stay length

In 2017 a large national observational study in China concluded that patients with hypothermia are associated with more postoperative ICU admit, longer PACU and more postoperative hospital days18. Inevitable this increases health care cost. Although healthcare cost is very variable among different countries and difficult to compare, a study conducted in Australia analyzed the cost of preventing intraoperative hypothermia versus the estimated costs of the consequences followed by inadvertent intraoperative hypothermia. They concluded that preventing inadvertent perioperative hypothermia using active warming is estimated to lead to significant cost savings across the Australian health system[39].

Managing body temperature

Forced air warming devices

Forced air warming devices have different types of blankets. Depending on the location and type of surgery, an upper body, lower body or underbody type of blanket can be used. The blanket type is a strong predictor of the effectiveness of heating and maintaining the patient's core temperature. The underbody blanket has a greater impact on core temperature than the upper and lower body blanket, this can be explained due to the difference in body area exposed to the warmed air[19].

The Bair HuggerTM is commonly used to prevent perioperative hypothermia in surgical patients to improve patient care, but concerns have arisen about its potential role in surgical site infections (SSIs). The device draws in air from the floor, warms it, and directs it into a warming blanket near the surgical field. Contamination of the device[40] and warmed air is a potential issue, especially if filter maintenance is inadequate. In a study conducted by Watkins et al, only 4 of the 36 devices investigated followed manufacturer's recommendations[41]. However, there is no conclusive evidence to establish a direct link between the use of Bair Hugger devices and increased SSI risk.

Shirozu et al. studied the potential disruption of the downward laminar airflow in the operating room by forced air warming devices. They found that forced air warming causes upward laminar as well as convection flow, but downward laminar air flow was only slightly affected and not considered meaningful[42,43].

Resistive heating system

In patients undergoing elective surgeries, a systematic review and meta-analysis compared the effectiveness of resistive heating with forced air warming for preventing hypothermia. While both methods showed efficacy, the analysis suggests that forced air warming was more effective in preventing hypothermia during elective abdominal surgery[44]. Reports have indicated instances of severe burns associated with the use of forced air warming and resistive heating systems. It is essential to use warming devices in strict accordance with the manufacturer's guidelines and exercise precision in their handling[45].

Management and prevention

Prewarming

According to Lau et al. prewarming patients for 30 minutes with a forced air warming device decreased the overall intraoperative hypothermic exposure[46]. Becerra conducted in 2019 and 2021 two studies to investigate the effect of prewarming surgical patients. The first study, focused on spinal anesthesia, indicates that prewarming for 15 or 30 minutes both significantly reduces the prevalence of hypothermia at the end of surgery and shortens the length of stay in the PACU. The second study, in which patients received general anesthesia, demonstrates that prewarming for 15, 30, or 45 minutes using a forced-air blanket leads to a significant increase in core temperature before induction, contributing to a lower rate of perioperative hypothermia[47,48]. It appears that initiating prewarming in patients has a beneficial effect on their perioperative core temperature, starting as early as 15 minutes into the prewarming process. This could present an elegant solution to assist anesthesiologists in effectively managing perioperative hypothermia.

Warming of fluids

Various fluid heating systems, such as Hotline™, Astotherm, 3M™ Ranger™, and Fluido, are designed for optimal use in the operating room. Hotline™ fluid warmer uses a multi-lumen design to circulate warm water around the intravenous fluid, ensuring a consistent temperature without the risk of cooling as it travels through the tubing. The Astotherm fluid heating system consists of a long linear tubing coiled around a dry flow-heating system. The design quickly and efficiently warms fluids and is very compact, making it ideal for various clinical environments. The 3M™ Ranger™ is a high-efficiency device using dry heat technology to warm fluids quickly with a minimal risk of contamination. It is particularly effective in high-volume fluid administration. The Fluido system uses infrared technology to warm fluids precisely to the desired temperature. A Cochrane review of 2015 found that warming of intravenous fluids administered to patients can help prevent perioperative hypothermia, especially if ambient room temperature is low[49].

Conclusion

In conclusion, perioperative hypothermia is a prevalent and preventable complication with significant implications for patient outcomes, healthcare costs, and overall quality of care. Both general and regional anesthesia pose challenges to the body's thermoregulatory mechanisms, making patients highly susceptible to hypothermia during surgery. Risk factors, including advanced age, lower body weight, and the use of unwarmed fluids, further elevate this risk.

However, it is encouraging to note that effective measures are available to prevent perioperative hypothermia. Active monitoring of core temperature, especially during general anesthesia, is essential. Various measurement techniques exist, each with its advantages and disadvantages, and the choice should align with the specific patient and procedure. Additionally, the use of active warming devices, such as forced air warming systems like the Bair Hugger, is crucial in preventing hypothermia and its associated complications.

Furthermore, while therapeutic hypothermia has its place in specific surgical contexts, recent studies like the POLAR RCT underscore the need for a more nuanced understanding of its benefits. It is essential to compare potential advantages of neuroprotection against possible adverse events in specific patient populations.

In summary, perioperative hypothermia demands careful consideration and proactive management to mitigate its adverse effects. By adopting best practices in temperature monitoring, actively warming patients, and tailoring interventions to individual risk factors and clinical scenarios, healthcare providers can contribute to improved patient comfort, safety, and overall healthcare cost-effectiveness.

Discussion

The discussion surrounding perioperative hypothermia encompasses various critical aspects of patient care and healthcare system efficiency. Firstly, it is vital to recognize the multifactorial nature of this complication. Advanced age and comorbidities elevate the risk, but environmental factors, surgical procedures, and anesthesia choices also contribute significantly. Consequently, a tailored approach to risk assessment and prevention is necessary for optimal patient outcomes.

The choice of temperature monitoring method is a crucial decision during surgery. While some methods, such as pulmonary artery catheters, offer high precision, they are invasive and limit their application to specific patient populations. Tympanic membrane, nasopharyngeal, and esophageal measurements provide accurate results with varying degrees of patient comfort and invasiveness. Understanding the advantages and limitations of these methods is essential for making expert decisions during perioperative care.

Finally, the economic implications of perioperative hypothermia cannot be underestimated. Prolonged hospital stays and increased postoperative care requirements place a considerable burden on healthcare systems. Preventing inadvertent intraoperative hypothermia through active warming measures, such as forced air warming devices like the Bair Hugger, presents a cost-effective solution that not only enhances patient comfort but also contributes to overall healthcare cost savings.

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