Wang and Deng
Anesthesiology and Perioperative Science (2023) 1:24
https://doi.org/10.1007/s44254-023-00022-6

Anesthesiology and Perioperative Science

REVIEW ARTICLE

Inadvertent hypothermia: a prevalent perioperative issue that remains to be improved

Jia-feng Wang[1] and Xiao-ming Deng[1*]

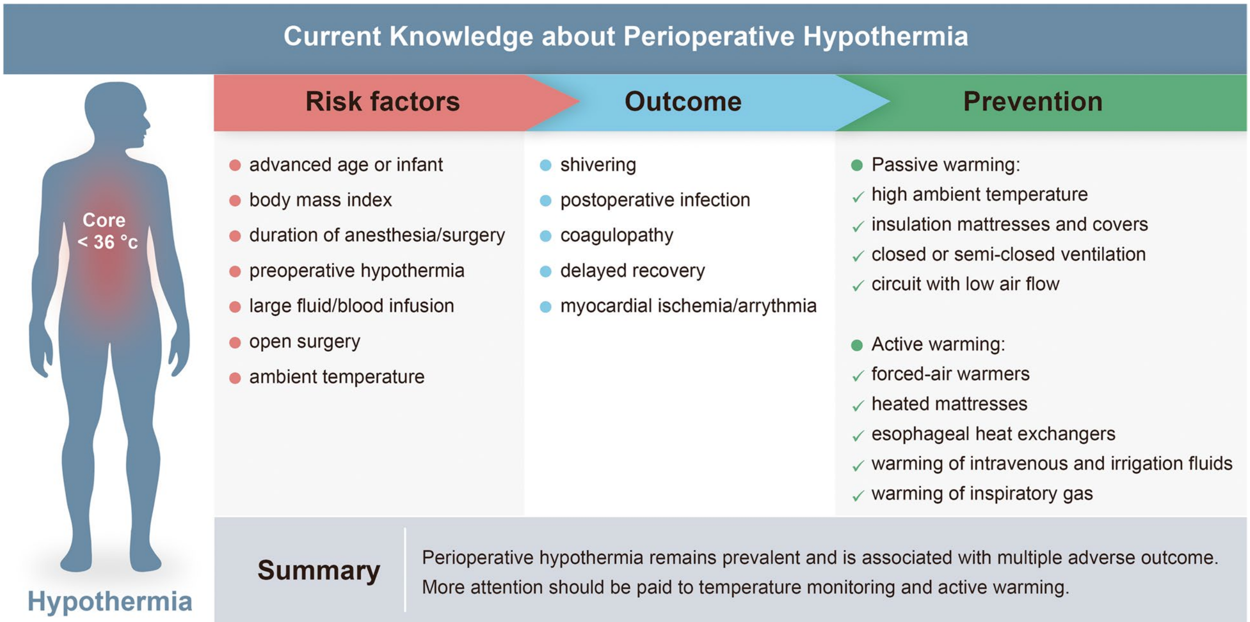
Abstract

Inadvertent hypothermia, defined as a body temperature lower than 36 °C, remains to be a critical issue during the perioperative period. Despite of the development of the active warming devices, the incidence of perioperative hypothermia has been reported to varying between 10%–80%. The top five risk factors of perioperative hypothermia include advanced age, low body mass index, duration of anesthesia or surgery, preoperative hypothermia and large amount of fluid or blood product. A prediction scoring system may be helpful in identifying the population with high risk of perioperative hypothermia. Perioperative hypothermia is associated with shivering, postoperative infection, increased amount of intraoperative blood loss and infusion of fluid or blood products, and delayed recovery after anesthesia. The most accepted warming intervention is forced-air warmers, which has been reported to be associated with elevated intraoperative temperature and reduced intraoperative bleeding and postoperative infection. The present review will focus on the mechanism, incidence, risk factor, adverse outcome, monitoring and warming strategies of perioperative hypothermia.

Keywords Perioperative hypothermia, Perioperative outcome, Risk factor, Active warming

*Correspondence:
Xiao-ming Deng
dengphd@smmu.edu.cn
Full list of author information is available at the end of the article

Graphical Abstract



1 Introduction

Body temperature is one of the most important vital signs, being rigorously regulated to maintain normal cellular and molecular activities in mammals [1]. Homeostasis of temperature is determined by the balance of production and dissipation of heat. However, the temperature homeostasis may be disrupted by anesthetic or surgical conditions during the perioperative period, and inadvertent hypothermia is quite common in patients undergoing surgery and anesthesia [2, 3]. The incidence of inadvertent perioperative hypothermia has been reported to vary from about 10% to 80% in patients undergoing different anesthesia and surgery types [4, 5]. Inadvertent perioperative hypothermia is not simply a phenomenon of reduced body temperature, but has a great impact on postoperative outcome [6]. Although inadvertent hypothermia is usually mild in the perioperative period, it has been well accepted that mild hypothermia will increase the risk of bleeding and infection during perioperative period [7, 8]. Moreover, some other studies even established a correlation of hypothermia with the leakage of gastrointestinal anastomosis and myocardial injury [9–11]. Therefore, inadvertent perioperative hypothermia is far more complicated than transient abnormal body temperature, and it should be treated as important as other vital signs such as blood pressure and breath.

Fortunately, surgeons and anesthesiologists are paying more and more attention on the management of body temperature. The National Institute for Health and Care Excellence (NICE) in the United Kingdom has released a guideline to improve the clinical management of perioperative hypothermia [12]. In the newest standard of medical quality control for anesthesiology in China in 2022, there are four terms regarding temperature management, including incidence of hypothermia when arriving at post-anesthesia care unit (PACU), rate of temperature monitoring during general anesthesia, rate of active warming during surgery and incidence of hypothermia during anesthesia and surgery [13]. These documents showed that temperature management had been emphasized by multiple dimensions, from the health management agencies to academic society. The aim of the present manuscript was to review the recent progresses in the perioperative management of body temperature.

2 Thermoregulation during anesthesia and surgery

Hypothermia is generally defined as a core temperature lower than 35 °C and it can be divided into mild (< 35 °C, ≥ 32 °C), moderate (< 32 °C, ≥ 28 °C), severe (< 28 °C, ≥ 20 °C), profound (< 20 °C, ≥ 14 °C) and deep (< 14 °C) based on the value of core temperature. But the criteria for hypothermia is different for trauma patients to increase the detection rate. Hypothermia in trauma is classified into mild (< 36 °C, ≥ 34 °C), moderate (< 34 °C, ≥ 32 °C), severe (< 32 °C) [14]. In the perioperative settings, hypothermia is generally considered as lower than 36 °C because the core body temperature lower than 36 °C but higher than 35 °C was sufficient to induce undesired adverse effects. Therefore, in most of the perioperative studies, a core body temperature lower than 36 °C was considered as hypothermia requiring warming intervention [15, 16].

It has been concluded that body temperature is controlled by three levels, temperature sensation, activity in the central nervous system and peripheral effector [17, 18]. The thermoreceptor, composed mainly by transient receptor potential (TRP) family proteins [19], can be activated by heat or cold, and the afferent thermal signals can be transduced through the superficial laminae of the spinal dorsal horn, lateral parabrachial nucleus, and finally reach the thermoregulatory center, the preoptic area of the hypothalamus [20], where the core temperature will be centrally controlled. The thermoeffector will be evoked by the thermoregulatory center, in a negative feedback manner, to accommodate the body to the temperature changes in the environment, including volitional and autonomic responses. The volitional responses include posture changes, clothing, movement, and even using the air conditioners, and the autonomic responses include activation of brown fat, sweating, vasodilation, vasoconstriction and shivering [21]. The activation of brown adipocytes may contribute to long-term thermogenesis and it has been seldom discussed in perioperative hypothermia. The autonomic responses are transmitted through the raphe pallidus, rostral ventrolateral medulla, or rostral ventromedial medulla. Then sympathetic regulation of brown adipose tissue, vessels and sweat gland is activated through the interomediolateral column of spinal cord, and the shivering is regulated through the ventral horn of spinal cord [22, 23]. Some other brain region and nucleus may also participate the thermoregulation, but the exact central regulation of hypothermia is beyond the scope of this review.

Several factors may induce hypothermia during the perioperative period. The most apparent factor for hypothermia is the relatively cold environment in the operating room, especially in those with laminar flow [24]. The direct exposure of the skin and incision to the cold air and cold disinfectant is another factor increasing the heat loss. The large amount of cold intravenous fluid, irrigation fluid and even inhalational gas may increase the heat loss by conduction. But other than these physical factors, anesthesia itself is a crucial factor to induce hypothermia. First, different general anesthetics, including both volatile and intravenous, are inhibitory to the thermoregulatory center and can decrease the thermal threshold in a concentration dependent manner. The vasoconstriction threshold can be reduced to 34.5 °C under general anesthesia. Second, shivering can be inhibited or diminished by anesthetics, especially by neuromuscular blockade agents. Third, thermoreceptor can be directly inhibited by volatile anesthetics. Fourth, afferent signals of cold and efferent signals of vasoconstriction and shivering can be blocked by neuraxial blockade [25]. Even the thermoregulatory center has been also be reported to be inhibited by neuraxial blockade, although the mechanism remains unclear [26].

Intraoperative hypothermia can be divided into three stages, including redistribution stage, linear stage and plateau stage [16, 27]. In the redistribution stage, hypothermia occurs rapidly after induction of general anesthesia or neuraxial anesthesia because the responses of vasoconstriction are inhibited by anesthesia. The heat in the core compartment of the body redistributed into the peripheral compartment with the dilation of vessels, where the temperature was normally 2–4 °C lower than in the core compartment. Therefore, the total heat loss may not be significant shortly after anesthesia induction, but the core temperature is diluted and reduced rapidly. In the linear stage, the body temperature is reduced gradually because of the gradient between thermogenesis and heat loss. Heat is produced mainly by energy metabolism, which is reduced by 15%–40% by general anesthetics, while heat loss is increased by radiation, conduction, convection, and evaporation, mainly induced by the increased exposure of skin and incision. The plateau stage usually occurs at 2–4 h after anesthesia and surgery, when the core temperature is maintained at a relatively stable level, at about 34.5 °C. The homeostasis is maintained by a new balance of heat generation and loss. Although the thermoregulatory threshold can be reduced by general anesthesia, the vasoconstriction capacity is not fully diminished and the arterio-venous shunt can be completely shut down when hypothermia happens. Thus, the heat can be well retained in the core compartment to maintain a plateau temperature. But the plateau stage may not be present in neuraxial anesthesia, because after neuraxial blockade, the vasoconstriction and shivering cannot be induced in the lower limbs, which play a more important role in maintaining body temperature than the upper limbs. Therefore, hypothermia will be more severe when general anesthesia is combined with neuraxial blockade [28]. The Fig. 1 shows a summarizing diagram how anesthesia affects the occurrence of intraoperative hypothermia.

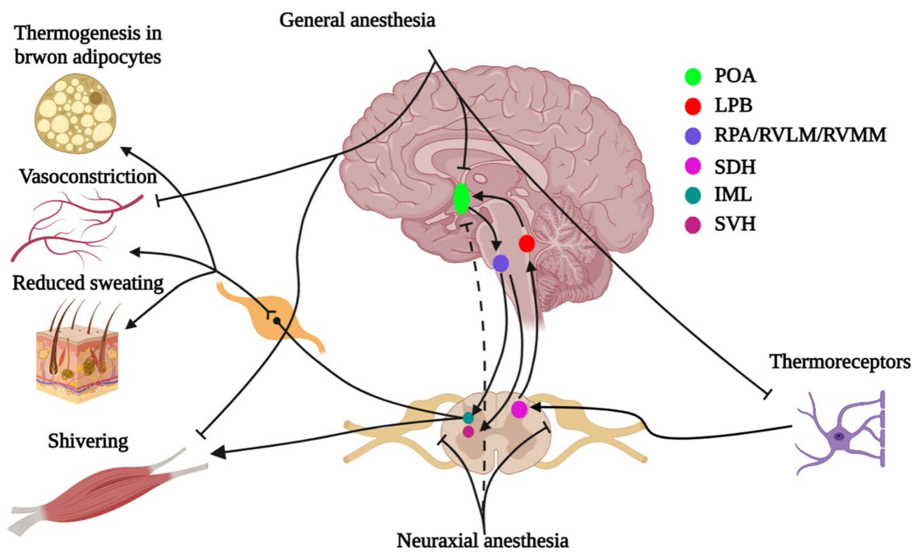


Fig. 1 The thermoregulatory mechanism and the mechanism of intraoperative hypothermia facilitated by anesthesia. Hypothermia sensed by thermoreceptors can be transmitted to the thermoregulatory center (POA of hypothalamus) by afferent signaling through SDH and LPB. Efferent signaling can be transmitted to the thermoeffector through RPA, RVLM or RVMM. Thermogenesis by brown adipocytes, vasoconstriction and reduced sweating are regulated by sympathetic nerve, innervated by the IML in spinal cord. The involuntary contraction of skeletal muscle (shivering) was regulated by SVH in the spinal cord. General anesthetics may act on the thermoregulatory center to reduce the threshold temperature of vasoconstriction and shivering. Thermoreceptor can also be directly inhibited by volatile anesthetics. Shivering can be completely inhibited by neuromuscular blockade agents. Neuraxial anesthesia can inhibit the afferent and efferent pathways of thermoregulation. Thermoregulatory may also be directly inhibited by neuraxial anesthesia. POA, preoptic area; LPB, lateral parabrachial nucleus; RPA, raphe pallidus; RVLM, rostral ventrolateral medulla; RVMM, rostral ventromedial medulla; SDH, spinal dorsal horn; IML, interomediolateral column; SVH, spinal ventral horn

3 Incidence and risk factors for perioperative hypothermia

The issue of inadvertent perioperative hypothermia has been proposed for more than 30 years and the incidence varied greatly in different surgeries and different population, with disparity in the degree of emphasis on this issue. In order to review the incidence and risk factors for perioperative hypothermia, we retrieved the Pubmed database with "(risk factor or prediction) and perioperative hypothermia" and finally identified 22 publications with potential reports on the risk factors [4, 5, 29–48], one of which was a meta-analysis of cohort and case–control studies [48] (Table 1). The incidence of inadvertent hypothermia ranged from 12% to 81%. The lowest incidence of hypothermia occurred in a retrospective study including patients undergoing total knee or hip arthroplasty, in which routine forced air warming was applied [4]. But in another retrospective study performed in total knee or hip arthroplasty without routinely-used active warming strategy showed an incidence of 37% [33]. The highest incidence of 81% happened in a neonate study [5]. The highest incidence of hypothermia in the adults appeared in a study including patients undergoing mixed types of surgeries under general anesthesia, with an incidence of 79% [43]. It was discouraging to notice that the incidence of hypothermia remained higher than 50% despite of the routine use of active warming devices in 6 studies [5, 35–38, 42], among which 1 was performed in neonates [5].

The risk factors for hypothermia identified by different studies also varied remarkably because of the great discrepancies in the population involved. But among the risk factors identified in the publications with original data, advanced age was considered as a risk factor in 12 studies. The second most frequent risk factor is body mass index (BMI), which was reported in 9 studies, and weight was reported in 2 studies. Duration of anesthesia or surgery was identified as a risk for hypothermia in 10 studies. Preoperative core temperature was reported in 8 studies, and pre-existing hypothermia before anesthesia was considered as a risk factor. Large amount of fluid or blood product administered was reported in 7 studies. Active warming measures was reported to be associated with lower incidence of intraoperative hypothermia in 6 studies. Surgery type or grade was reported in 6 studies, and compared with endoscopy surgery, open surgery was a risk factor for hypothermia according to 3 studies. Ambient temperature in the operating room was reported in 4 studies and another study showed that laminar airflow operating room was associated with

Table 1 Incidence and risk factors of inadvertent intraoperative hypothermia reported in the references

References	Surgery	Study design	Sample size	Subjects	Incidence	Warming intervention	Risk factor	Analysis method
Alfonsi 2019 [29]	Mixed	prospective	893	adult	58%	not routinely	age, duration of anesthesia (> 60 min and ≤ 120 min), pre & intraoperative -warming, Tc before induction of anesthesia, core temperature difference between surgical incision and anesthesia induction	multivariate analysis
Chalari 2019 [30]	TURP or TURis	prospective	168	adult	TURis 64%, TURP 60%	not mentioned	age, BMI, sugery duration, blood pressure (time point not defined)	univariate analysis
Emmert 2018 [31]	thoracic surgery	retrospective	339	adult	64%	not routinely	BMI, induction time, intraoperative fluid substitution, lung impairment, epidural anesthesia, open thoracotomy	multivariate analysis
Frisch 2016 [32]	surgical fixation of hip fractures	retrospective	1525	adult	17%	not routinely	lower body mass index, increasing age, CAD and Arrhythmia	univariate analysis
Frisch 2017 [33]	total hip and knee arthroplasty	retrospective	2397	adult	37%	not routinely	OR time, surgery time, rewarmer use, transfusion	univariate analysis
Kasai 2002 [34]	open abdominal surgery	retrospective	400	adult	not mentioned	a circulating-water mattress warmed at 38 °C, heat-moisture exchanger for ventilation and warmed IV fluids	age, weight, preoperative low SBP, Preoperative low HR	multivariate analysis
Kim 2014 [35]	abdominal surgery	prospective	147	adult	54%	airway heating exchanger and a circulating water mattress set to 38 °C	age, preoperative heart rate, weight, preoperative baseline core temperature	multivariate analysis
Li 2020 [36]	video-assisted thoracoscopic surgery	retrospective	1467	adult	73%	a circulating-water mattress warmed at 38 °C	age, BMI, the duration of preparation, the duration of surgery, timing of surgery, ambient temperature in the operating room and general anesthesia combined with paravertebral block after induction of anesthesia	multivariate analysis
Long 2013 [37]	ovarian cytoreductive surgery	retrospective	297	adult	72%	both warmed intravenous fluids and a forced-air warming device	estimated blood loss, intraoperative vasopressors, transfusion of fresh frozen plasma, and epidural anesthesia	univariate analysis

Table 1 (continued)

References	Surgery	Study design	Sample size	Subjects	Incidence	Warming intervention	Risk factor	Analysis method
Mehta 2013 [38]	major colorectal surgery	retrospective	255	adult	74%	warming blankets	age > 70, elective presentation, preoperative hypothermia	multivariate analysis
Mekete 2022 [39]	mixed	prospective	339	pediatric	40%	not routinely	neonate or infant, operation room temperature < 26, warmed fluid administered, the volume of fluid administer > 500 ml, duration of surgery, duration of anesthesia	multivariate analysis
Mendonca 2021 [40]	mixed	prospective	312	adult	57%	not routinely	surgical specialty, diabetes, fentanyl usage, surgery time, and patients' temperature on arrival in the operating room	multivariate analysis
Miyazaki 2019 [41]	abdominal surgery	retrospective	2574	adult	not mentioned	a forced-air warming device was routinely used	age, BMI, sex, laparoscopic surgery, and the blanket type of the forced-air warmer	multivariate analysis
Moslemi-Kebria 2012 [42]	open abdominal surgery for ovarian cancer	retrospective	146	adult	55%	an upper body forced-air warmer	age	univariate analysis
Sari 2021 [43]	mixed	prospective	2015	adult	79%	not routinely	age, BMI, ASA score and chronic disease status, surgical grade, endoscopic surgery use, anaesthesia and surgery length, irrigation application, amount of irrigation and infusion, preoperative body temperature	univariate analysis
Scholtena 2018 [4]	total knee or hip arthroplasty	retrospective	2600	adult	12%	use forced air warming (Bair hugger) placed over the patient's chest and arms as long as the operation took, irrespective of core temperature. The Bair hugger was set on maximum temperature (42 °C)	gender, type of anesthesia, BMI, date of surgery	multivariate analysis
Wetz 2016 [44]	Non-cardiac	prospective	493	adult	21%	not routinely	age and male sex	multivariate analysis

Table 1 (continued)

References	Surgery	Study design	Sample size	Subjects	Incidence	Warming intervention	Risk factor	Analysis method
Yang 2015 [45]	mixed	prospective	1840	adult	26%	not routinely	advanced age, laminar airflow operating rooms and general surgeries	multivariate analysis
Yi 2015 [46]	mixed	prospective	830	adult	40%	not routinely	major plus surgery, IV fluid replacement (> 1000 ml), duration of Anesthesia > 1 h, active warming, baseline core temperature before anesthesia, BMI < 25, OR ambient temperature	multivariate analysis
Yi 2017 [47]	mixed	prospective	3132	adult	44%	not routinely	active warming, BMI, higher baseline core temperature, higher ambient temperature, major-plus surgery, longer duration of anesthesia (> 2 h), non-endoscopic surgery, IV fluid > 1000 ml, and intraoperative irrigation fluid > 500 ml	multivariate analysis
Zhang 2022 [5]	mixed	retrospective	401	pediatric	81%	all patients were warmed passively by preheated disinfectant, covering sheets, surgical draping, or warm blankets and were warmed actively by air heaters, infusion warming instruments, or radiant beds	gestational week, preoperative temperature, duration of anaesthesia, and type of surgery	multivariate analysis
Pu 2022 [48]	mixed	meta-analysis	15,010	adult	not mentioned	not mentioned	age, body mass index, ambient temperature, preoperative systolic blood pressure, preoperative heart rate, duration of anesthesia, and intravenous fluid administration > 1,000 mL	Meta-analysis

TURis transurethral resection in saline, *TURP* transurethral resection of the prostate, *CAD* coronary artery disease, *OR* operating room, *SBP* systolic blood pressure, *HR* heart rate, *IV* intravenous, *BMI* body mass index, *ASA* American Society of Anesthesiologists hypothermia, which might be also due to the low ambient temperature or increased convection induced by laminar airflow. Preoperative blood pressure and heart rate were reported in 3 studies, and comorbidities including coronary heart disease, arrhythmia, lung impairment, diabetes, other chronic disease status or a high grade of American Society of Anesthesiologists (ASA) physical status were reported as risk factors in 4 other studies. Male gender was correlated with hypothermia in 3 studies. Combination of general anesthesia and epidural anesthesia or paravertebral anesthesia was reported to be associated with hypothermia in 2 studies, but hypothermia was more common in general anesthesia when compared with neuraxial anesthesia alone in 1 study. For pediatric patients, neonates or infants were associated with hypothermia, and the gestational week of neonates were a determinant for intraoperative hypothermia. The meta-analysis of risk factors further demonstrated the association of intraoperative hypothermia with age, BMI, ambient temperature, preoperative systolic blood pressure, preoperative heart rate, duration of anesthesia, and intravenous fluid administration > 1,000 mL, but the significant heterogeneity might hinder our interpretation of the results [48].

Understanding these risk factors for intraoperative hypothermia might be useful in screening patients with high risk of hypothermia during surgery and with high demand of active warming treatment. Yi et al. [23] established a risk prediction scoring system for intraoperative hypothermia, involving the risk factors in two of their independent studies including magnitude of surgery, BMI, amount of intravenous fluid administered, duration of anesthesia, mode of warming intervention, baseline core temperature, and ambient temperature in the operating room. In a validation cohort, they got an area under the receiver operating characteristic curve of 0.771. But other important risk factors were not included, such as age, surgery type, comorbidities. The clinical efficacy of the prediction model remained to be evaluated and modified by more large-scale multicenter studies.

4 Adverse outcome associated with intraoperative hypothermia

Normal temperature is a principal element of cellular activity, and hypothermia may inhibit cell metabolism, and reduce the consumption of glucose and oxygen. Therefore, therapeutic hypothermia has been widely used in treating cardiac arrest and cerebral ischemia diseases, although several studies failed to observe any benefits on survival after cardiac arrest [49, 50]. However, the clinical situation of perioperative patients is totally different from those with cardiovascular ischemia, and mild inadvertent perioperative hypothermia is associated with more adverse events than benefits on reduced cellular metabolism. The most definite event induced by perioperative hypothermia should be the shivering in awake patients or anesthetized patients at recovery period. Shivering is an unpleasant involuntary oscillatory muscular activity, which is also an important determinant for the satisfaction of patients [51]. Moreover, shivering will increase the oxygen demand and work of breath. Perioperative imbalance between oxygen supply and consumption in myocardium may be induced, and finally lead to cardiovascular complications [52]. Immune system is also affected by hypothermia, which has been demonstrated to inhibit HLA-DR expression in monocytes. The capacity of migration and phagocytosis in leukocyte can be compromised in hypothermic conditions [53, 54]. The poor perfusion of surgical site may also delay the recovery of anastomosis and incision, which may increase the risk of contamination. Thus, the risk of postoperative infection may increase in patients with perioperative hypothermia. Hypothermia can induce coagulopathy, with dysfunctional platelets and reduced activity of coagulation factors. It has been reported that even a reduction of 1 °C in body temperature will increase the bleeding amount by about 20% [7, 55]. The activity of multiple enzymes will be inhibited by hypothermia, including those in charge of drug metabolism, so that the clearance of anesthetics may be delayed and the recovery from anesthesia may be prolonged [56]. Hypothermia will also induce vasoconstriction, which is important in reducing heat loss and maintaining the body temperature. Vasoconstriction during hypothermia may be harmful to cardiovascular system, increasing the risks of myocardial ischemia and arrhythmia [57]. Other potential effects of perioperative hypothermia include the disturbance of electrolytes and delayed recovery of gastrointestinal function [58, 59].

The adverse effects of perioperative hypothermia have been confirmed by many clinical trials comparing the clinical outcome when using active warming intervention or not. A meta-analysis of randomized controlled trials (RCTs) including 54 papers and 6557 patients undergoing noncardiac surgery compared the postoperative pain, opioid use, surgery duration, intraoperative bleeding, total fluids administered, patient satisfaction score, postoperative shivering, perioperative blood transfusion, postoperative would infection, 24 h major adverse cardiovascular events and 3-month mortality [60]. It was demonstrated that active warming intervention increased body temperature by 0.28 (0.2–0.35), 0.38 (0.27–0.49), 0.8 (0.59–1.01), 1.07 (0.86–1.28), 0.87 (0.62–1.11), and 0.34 (0.19–0.49) °C at 30 min, 60 min, 2 h after anesthesia induction, the end of surgery, 60 min and 4 h after surgery, respectively. The elevation of perioperative temperature was associated with a reduction by 80%, 36%, 66% and 79% in the incidences of postoperative shivering, blood transfusion, wound infection and 24 h major adverse cardiovascular events. The patient satisfaction was also enhanced by active warming interventions. Another Cochrane meta-analysis found similar results that active body surface warming reduced the incidence of postoperative surgical site infection, shivering and improve the patient satisfaction [61]. But in this study, the estimated blood loss and intravenous fluid administered was reduced by warming treatment, but not the amount of transfusion.

There are also some observational studies suggesting that intraoperative hypothermia is associated with prolonged length of hospitalization, arrhythmia, increased amount of estimated blood loss, intravenous fluid administered, and 30-day readmission [62]. Some retrospective studies even suggested that unintended perioperative hypothermia was correlated with postoperative delirium [63]. However, a recent large-scale, multicenter, international RCT, enrolling 5056 patients and comparing an aggressive intraoperative warming intervention and routine management strategy, failed to find any difference of outcome when maintaining a body temperature of 37 °C or 35.5 °C, including cardiovascular events such as myocardial injury after noncardiac surgery, non-fatal cardiac arrest, mortality, and surgical site infection, transfusion requirement and hospital readmission [64]. Therefore, the clinical impact of intraoperative hypothermia might be determined by the severity degree of hypothermia.

5 Intraoperative monitoring of body temperature

The NICE guideline recommends that the body temperature should be monitored before anesthesia, every 30 min during surgery, at the end of surgery and arrival at the recovery room, and every 15 min in the recovery room. The patients who should be monitored for temperature include those with general anesthesia longer than 30 min and those undergoing major surgery under neuraxial anesthesia [12]. The site of temperature monitoring is more important than the devices. Core temperature has been considered to be the target temperature that we aimed to maintain during surgery, and multiple sites have been used for temperature monitoring during surgery, including pulmonary artery, distal esophagus, nasopharynx with the probe inserted 10–20 cm, and tympanic membrane. Other sites include sublingual area, axilla, bladder, rectum and lateral forehead. Noninvasive forehead temperature monitoring (such as 3 M™ Bair Hugger™ device) has been demonstrated to be comparable to other core temperature monitoring approach, such as tympanic membrane [65], blood, bladder [66], esophagus, or rectum [67], and may be clinically convenient because this monitoring method is noninvasive and continuous. Trachea temperature monitoring, using a probe embedded into the cuff of the trachea intubation, has been also evaluated, but the result remains to be controversial. Matsukawa et al. found that the accuracy of trachea temperature was insufficient when compared to distal esophageal temperature [68, 69]. But some others showed that trachea temperature correlated well with blood temperature and might be suitable for intubated patients [70–72].

6 Active warming against perioperative hypothermia

A variety of warming interventions have been applied to prevent or treat perioperative hypothermia. The warming interventions can be divided into passive warming and active warming. The former includes maintaining relatively high ambient temperature, insulation mattresses and covers, closed or semi-closed ventilation circuit with low air flow, and the latter includes forced-air warmers, heated mattresses with electric device or warm circulating water, esophageal heat exchangers, warming of intravenous and irrigation fluids and inspiratory gas [73]. In some studies, fluid or gas warmers were considered as passive warming measures. Most of the RCTs have demonstrated that active body surface warming device was capable of increasing the core temperature during surgery. Aggressive active warming has been shown to be able to maintain a body temperature above 37 °C, although in this study it has been demonstrated to be unable to induce any improvement regarding the main cardiovascular, infectious and bleeding complications when compared to maintenance of a body temperature at 35.5 °C [64]. But it should be noticed that this RCT by Sessler et al. [64] did not deny the use of active warming device to prevent intraoperative hypothermia. What they concerned was the right target temperature that we should achieved.

The most widely accepted active warming device is the forced-air warming device, which has been demonstrated to be with the highest efficacy of maintaining a proper core temperature during surgery in most of the clinical studies. Several RCTs comparing forced-air warming and heating mattresses showed that forced-air warming increased intraoperative core temperature and reduced the incidence of intraoperative hypothermia [74, 75]. But the effects of different active warming strategies were shown not significantly different according to a meta-analysis of RCTs, including forced-air warming device, electric heating device, resisting heating device, warm-water circulation device, and radiant heating [61]. The active warming interventions can be chosen based on the medical cost and the devices available in the institutions.

The site of warming was also a determinant of warming efficacy, and it was interesting to find that lower body warming was more effective in maintaining body temperature than upper body warming in patients in lateral decubitus position [76]. Fluid warming was also widely used in patients receiving large amount of intravenous fluid. It was shown that large amount of unwarmed intravenous fluid (1L/h) was a risk factor for intraoperative hypothermia. But the NICE guideline suggested that intravenous administration of fluid more than 500 ml should be warmed to 37 °C [12]. A Cochrane meta-analysis demonstrated that warming of intravenous fluid was associated with a temperature increase of about 0.5 °C and there was still not sufficient evidence to support that in-line fluid warming could improve the outcome except shivering, including bleeding, infection and other adverse events [77].

What makes a difference in the clinical effects of active warming intervention may be the timing of the initiation of warming therapy. Because of the heat redistribution of anesthesia induction, many studies showed that active warming intervention should be started before anesthesia induction. In the NICE guideline for perioperative hypothermia, it was recommended that each patient should be evaluated for the risk of perioperative hypothermia and the baseline temperature should be measured. Active warming intervention should be started to maintain a preoperative temperature above 36 °C except for emergent surgeries. Wetz et al. [44] found that preoperative hypothermia was present in 21% patients undergoing noncardiac surgery, and Alfonsi et al. [29] showed that pre-anesthesia use of warming intervention was associated with a lower incidence of hypothermia in the recovery room. An RCT performed by Horn et al. showed that even a short time of prewarming treatment for 10 or 20 min would significantly reduce the incidence of hypothermia (from 69% without prewarming to 13% with prewarming for 10 min, 7% for 20 min and 6% for 30 min) [78]. The prewarming was also suggested in the NICE guideline, but cost-benefit of forced-air warming should be taken into consideration if the patients were anesthetized in the preoperative induction room.

It should be aware that prevention of perioperative hypothermia was a systemic project which required an interprofessional collaboration between anesthesiologists, surgeons, nurses and staffs in the ward. The working conditions of the surgeons are always influenced by the ambient temperature and the NICE guideline recommend a unique equipment to cool the surgical team [12]. The temperature of the irrigation fluids should be closely concerned by the surgeons and nurses. Therefore, the anesthesiologists should work on the consensus of teamwork in maintaining a normal perioperative temperature.

The cost of active warming may be a problem for some institutes because of the disposable use of blankets for forced-air warming. A cost–benefit analysis showed that the cost of intraoperative hypothermia was $363.8 and the use of active warming device might save $152.8 [79]. The cost issue of active warming varies among different countries or regions, and for instances, the disposable blanket for forced-air warming cannot be charged due to policy of health committee in Shanghai. The cost-benefit analysis should be further evaluated for the use of active warming interventions.

When using the body surface warming techniques, it should be cautious that the temperature of warming device should be not higher than 41 °C. A high temperature may lead to thermal injury to the skin, and peripheral hypoperfusion, induced by hypothermia, may further worsen the condition. Therefore, there are still some case reports of ulcer occurring with the use of body surface warming devices [80].

7 Conclusions

Inadvertent perioperative hypothermia is not only a phenomenon of reduced body temperature, but also an undesirable adverse event which may lead to compromised perioperative outcome, including uncomfortable shivering, infection, bleeding, delayed recovery and even adverse cardiovascular events. The patients undergoing general anesthesia longer than 30 min or undergoing major surgery under neuraxial anesthesia should be monitored for core temperature, and active warming intervention should be applied from pre-induction to recovery period to maintain a proper target, which remains to be investigated by future studies. One recent large-scale multicenter RCT showed that 35.5 °C might be sufficient to prevent hypothermia-associated complications. A variety of active warming interventions are available, and the most effective one appears to be the forced-air warming device according to the current evidence-based studies. Despite the use of active warming measures, incidence of hypothermia remains unexpected high in some studies. Several factors may influence the warming efficacy of active warming device, including the timing of warming, target temperature, warming site. Future studies are warranted to establish a standard warming strategy against perioperative hypothermia. Nevertheless, the current evidences have told us that perioperative hypothermia is quite common and we should pay more attention and effort to prevent this perioperative issue.

Abbreviations

ASA	American Society of Anesthesiologists
BMI	Body mass index
CAD	Coronary artery disease
HR	Heart rate
IML	Interomediolateral column
IV	Intravenous
LPB	Lateral parabrachial nucleus
NICE	National Institute for Health and Care Excellence in the United Kingdom
OR	Operating room
PACU	Post-anesthesia care unit
POA	Preoptic area
RCT	Randomized controlled trial
RPA	Raphe pallidus
RVLM	Rostral ventrolateral medulla
RVMM	Rostral ventromedial medulla
SBP	Systolic blood pressure
SDH	Spinal dorsal horn
SVH	Spinal ventral horn
TRP	Transient receptor potential
TURis	Transurethral resection in saline
TURP	Transurethral resection of the prostate

Acknowledgements
We would like to thank BioRender (http://app.biorender.com) for figure drawing.

Authors' contributions
JFW and XMD designed the review structure. JFW retrieved the references and analyzed the data. JFW and XMD wrote the manuscript. All authors read and approved the final manuscript.

Funding
This work was supported by the Sci-Tech Innovation 2030 Brain Science and Brain-Like Intelligence Technology Project (2022ZD0208100), Shanghai Rising-Star Program (21QA1411800) and Shanghai "Medical New Star" Training Program of Youth Medical Staff ([2020]87).

Availability of data and material
Not applicable.

Declarations

Competing interests
The authors have no competing interests.

Author details
[1]Faculty of Anesthesiology, Changhai Hospital, Naval Medical University, Shanghai 200433, China.

Received: 3 January 2023 Revised: 7 May 2023 Accepted: 22 May 2023
Published online: 12 September 2023

References

1. Avila J, Diaz-Nido J. Tangling with hypothermia. Nat Med. 2004;10(5):460–1.
2. Harper CM, McNicholas T, Gowrie-Mohan S. Maintaining perioperative normothermia. BMJ. 2003;326(7392):721–2.
3. Hearn CM, Chandradeva K. Maintaining perioperative normothermia: hyperthermia must be avoided. BMJ. 2003;326(7404):1457.
4. Scholten R, Leijtens B, Kremers K, Snoeck M, Koeter S. The incidence of mild hypothermia after total knee or hip arthroplasty: a study of 2600 patients. J Orthop. 2018;15(2):408–11.
5. Zhang MQ, Ying PD, Wang YJ, Zhao JL, Huang JJ, Gong FQ. Intraoperative hypothermia in the neonate population: risk factors, outcomes, and typical patterns. J Clin Monit Comput. 2022;37(1):93–102.
6. Enwright A, Plowes D. Inadvertent hypothermia: is it just a perioperative problem? Nurs Stand. 1999;14(4):46–7.
7. Rajagopalan S, Mascha E, Na J, Sessler DI. The effects of mild perioperative hypothermia on blood loss and transfusion requirement. Anesthesiology. 2008;108(1):71–7.
8. Buhre W, Rossaint R. Perioperative management and monitoring in anaesthesia. Lancet. 2003;362(9398):1839–46.
9. Frank SM, Fleisher LA, Breslow MJ, Higgins MS, Olson KF, Kelly S, et al. Perioperative maintenance of normothermia reduces the incidence of morbid cardiac events. a randomized clinical trial. JAMA. 1997;277(14):1127–34.
10. Ju JW, Park SJ, Yoon S, Lee HJ, Kim H, Lee HC, et al. Detrimental effect of intraoperative hypothermia on pancreatic fistula after pancreaticoduodenectomy: a single-centre retrospective study. J Hepatobiliary Pancreat Sci. 2021;28(11):983–92.
11. van Rooijen SJ, Huisman D, Stuijvenberg M, Stens J, Roumen RMH, Daams F, et al. Intraoperative modifiable risk factors of colorectal anastomotic leakage: why surgeons and anesthesiologists should act together. Int J Surg. 2016;36(Pt A):183–200.
12. Hypothermia: prevention and management in adults having surgery. NICE Clinical Guidelines, No. 65[Internet]. 2016 Dec [cited 2022 Jun14]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK554181/.
13. China NHCotPsRo. [Standard of medical quality control in anesthesia practice (2022 edition)]. 2022 Jun 1[cited 2022 Jun 14]. Chinese. Available from: http://www.nhc.gov.cn/cms-search/downFiles/aeba2f780ff546b1abc17dd7b9c5fdac.pdf.
14. Peng RY, Bongard FS. Hypothermia in trauma patients. J Am Coll Surg. 1999;188(6):685–96.
15. Link T. Guidelines in practice: hypothermia prevention. AORN J. 2020;111(6):653–66.
16. Sessler DI. Perioperative thermoregulation and heat balance. Lancet. 2016;387(10038):2655–64.
17. Tan CL, Knight ZA. Regulation of body temperature by the nervous system. Neuron. 2018;98(1):31–48.
18. Morrison SF, Nakamura K. Central mechanisms for thermoregulation. Annu Rev Physiol. 2019;81:285–308.
19. Yarmolinsky DA, Peng Y, Pogorzala LA, Rutlin M, Hoon MA, Zuker CS. Coding and plasticity in the mammalian thermosensory system. Neuron. 2016;92(5):1079–92.
20. Yahiro T, Kataoka N, Nakamura Y, Nakamura K. The lateral parabrachial nucleus, but not the thalamus, mediates thermosensory pathways for behavioural thermoregulation. Sci Rep. 2017;7(1):5031.
21. Tansey EA, Johnson CD. Recent advances in thermoregulation. Adv Physiol Educ. 2015;39(3):139–48.
22. Tan CL, Cooke EK, Leib DE, Lin YC, Daly GE, Zimmerman CA, et al. Warm-Sensitive neurons that control body temperature. Cell. 2016;167(1):47–59 e15.
23. Yu S, Qualls-Creekmore E, Rezai-Zadeh K, Jiang Y, Berthoud HR, Morrison CD, et al. Glutamatergic preoptic area neurons that express leptin receptors drive temperature-dependent body weight homeostasis. J Neurosci. 2016;36(18):5034–46.
24. Dasari KB, Albrecht M, Harper M. Effect of forced-air warming on the performance of operating theatre laminar flow ventilation. Anaesthesia. 2012;67(3):244–9.
25. Bindu B, Bindra A, Rath G. Temperature management under general anesthesia: compulsion or option. J Anaesthesiol Clin Pharmacol. 2017;33(3):306–16.
26. Doufas AG, Morioka N, Maghoub AN, Mascha E, Sessler DI. Lower-body warming mimics the normal epidural-induced reduction in the shivering threshold. Anesth Analg. 2008;106(1):252–6.
27. Sessler DI. Perioperative heat balance. Anesthesiology. 2000;92(2):578–96.
28. Insler SR, Sessler DI. Perioperative thermoregulation and temperature monitoring. Anesthesiol Clin. 2006;24(4):823–37.
29. Alfonsi P, Bekka S, Aegerter P. investigators SRN. Prevalence of hypothermia on admission to recovery room remains high despite a large use of forced-air warming devices: findings of a non-randomized observational multicenter and pragmatic study on perioperative hypothermia prevalence in France. PLoS One. 2019;14(12):e0226038.
30. Chalari E, Intas G, Zyga S, Fildissis G, Tolia M, Toutziaris C, et al. Perioperative inadvertent hypothermia among urology patients who underwent transurethral resection with either TURis or transurethral resection of the prostate method. Urologia. 2019;86(2):69–73.
31. Emmert A, Gries G, Wand S, Buentzel J, Bräuer A, Quintel M, et al. Association between perioperative hypothermia and patient outcomes after thoracic surgery: a single center retrospective analysis. Medicine (Baltimore). 2018;97(17): e0528.

32. Frisch NB, Pepper AM, Jildeh TR, Shaw J, Guthrie T, Silverton C. Intraoperative hypothermia during surgical fixation of hip fractures. Orthopedics. 2016;39(6):e1170–7.
33. Frisch NB, Pepper AM, Rooney E, Silverton C. Intraoperative hypothermia in total hip and knee arthroplasty. Orthopedics. 2017;40(1):56–63.
34. Kasai T, Hirose M, Yaegashi K, Matsukawa T, Takamata A, Tanaka Y. Preoperative risk factors of intraoperative hypothermia in major surgery under general anesthesia. Anesth Analg. 2002;95(5):1381–3.
35. Kim EJ, Yoon H. Preoperative factors affecting the intraoperative core body temperature in abdominal surgery under general anesthesia: an observational cohort. Clin Nurse Spec. 2014;28(5):268–76.
36. Li Y, Liang H, Feng Y. Prevalence and multivariable factors associated with inadvertent intraoperative hypothermia in video-assisted thoracoscopic surgery: a single-center retrospective study. BMC Anesthesiol. 2020;20(1):25.
37. Long KC, Tanner EJ, Frey M, Leitao MM Jr, Levine DA, Gardner GJ, et al. Intraoperative hypothermia during primary surgical cytoreduction for advanced ovarian cancer: risk factors and associations with postoperative morbidity. Gynecol Oncol. 2013;131(3):525–30.
38. Mehta OH, Barclay KL. Perioperative hypothermia in patients undergoing major colorectal surgery. ANZ J Surg. 2014;84(7–8):550–5.
39. Mekete G, Gebeyehu G, Jemal S, Fentie Y. Magnitude and associated factors of intra-operative hypothermia among pediatric patients undergoing elective surgery: a multi-center cross-sectional study. Ann Med Surg (Lond). 2022;75:103338.
40. Mendonca FT, Ferreira JDS, Guilardi VHF, Guimaraes GMN. Prevalence of Inadvertent perioperative hypothermia and associated factors: a cross-sectional study. Ther Hypothermia Temp Manag. 2021;11(4):208–15.
41. Miyazaki R, Hoka S. What is the predictor of the intraoperative body temperature in abdominal surgery? J Anesth. 2019;33(1):67–73.
42. Moslemi-Kebria M, El-Nashar SA, Aletti GD, Cliby WA. Intraoperative hypothermia during cytoreductive surgery for ovarian cancer and perioperative morbidity. Obstet Gynecol. 2012;119(3):590–6.
43. Sari S, Aksoy SM, But A. The incidence of inadvertent perioperative hypothermia in patients undergoing general anesthesia and an examination of risk factors. Int J Clin Pract. 2021;75(6): e14103.
44. Wetz AJ, Perl T, Brandes IF, Harden M, Bauer M, Brauer A. Unexpectedly high incidence of hypothermia before induction of anesthesia in elective surgical patients. J Clin Anesth. 2016;34:282–9.
45. Yang L, Huang CY, Zhou ZB, Wen ZS, Zhang GR, Liu KX, et al. Risk factors for hypothermia in patients under general anesthesia: Is there a drawback of laminar airflow operating rooms? a prospective cohort study. Int J Surg. 2015;21:14–7.
46. Yi J, Xiang Z, Deng X, Fan T, Fu R, Geng W, et al. Incidence of inadvertent intraoperative hypothermia and its risk factors in patients undergoing general anesthesia in Beijing: a prospective regional survey. PLoS ONE. 2015;10(9): e0136136.
47. Yi J, Lei Y, Xu S, Si Y, Li S, Xia Z, et al. Intraoperative hypothermia and its clinical outcomes in patients undergoing general anesthesia: National study in China. PLoS ONE. 2017;12(6): e0177221.
48. Pu J, Zhao WJ, Xie XF, Huang HP. A Systematic review and meta-analysis of risk factors for unplanned intraoperative hypothermia among adult surgical patients. J Perianesth Nurs. 2022;37(3):333–8.
49. Dankiewicz J, Cronberg T, Lilja G, Jakobsen JC, Levin H, Ullén S, et al. Hypothermia versus normothermia after out-of-hospital cardiac arrest. N Engl J Med. 2021;384(24):2283–94.
50. Le May M, Osborne C, Russo J, So D, Chong AY, Dick A, et al. Effect of moderate vs mild therapeutic hypothermia on mortality and neurologic outcomes in comatose survivors of out-of-hospital cardiac arrest: The CAPITAL CHILL randomized clinical trial. JAMA. 2021;326(15):1494–503.
51. Cobb B, Cho Y, Hilton G, Ting V, Carvalho B. Active warming utilizing combined iv fluid and forced-air warming decreases hypothermia and improves maternal comfort during cesarean delivery: a randomized control trial. Anesth Analg. 2016;122(5):1490–7.
52. Polderman KH. Mechanisms of action, physiological effects, and complications of hypothermia. Crit Care Med. 2009;37(7 Suppl):S186-202.
53. Qadan M, Gardner SA, Vitale DS, Lominadze D, Joshua IG, Polk HC Jr. Hypothermia and surgery: immunologic mechanisms for current practice. Ann Surg. 2009;250(1):134–40.
54. Evans SS, Repasky EA, Fisher DT. Fever and the thermal regulation of immunity: the immune system feels the heat. Nat Rev Immunol. 2015;15(6):335–49.
55. Cau MF, Ali-Mohamad N, Yeh H, Baylis JR, Peng H, Gao HZ, et al. Percutaneous delivery of self-propelling thrombin-containing powder increases survival from non-compressible truncal hemorrhage in a swine model of coagulopathy and hypothermia. J Trauma Acute Care Surg. 2022;93(2S Suppl 1):S86–93.
56. Caldwell JE, Heier T, Wright PM, Lin S, McCarthy G, Szenohradszky J, et al. Temperature-dependent pharmacokinetics and pharmacodynamics of vecuronium. Anesthesiology. 2000;92(1):84–93.
57. Zhang Z, Xu M, Wu D, Zhang X, Wu J. Postoperative myocardial injury in middle-aged and elderly patients following curative resection of esophageal cancer with aggressive or standard body temperature management: a randomized controlled trial. Anesth Analg. 2019;129(2):352–9.
58. Polderman KH, Peerdeman SM, Girbes AR. Hypophosphatemia and hypomagnesemia induced by cooling in patients with severe head injury. J Neurosurg. 2001;94(5):697–705.
59. Polderman KH, Herold I. Therapeutic hypothermia and controlled normothermia in the intensive care unit: practical considerations, side effects, and cooling methods. Crit Care Med. 2009;37(3):1101–20.
60. Balki I, Khan JS, Staibano P, Duceppe E, Bessissow A, Sloan EN, et al. Effect of perioperative active body surface warming systems on analgesic and clinical outcomes: a systematic review and meta-analysis of randomized controlled trials. Anesth Analg. 2020;131(5):1430–43.
61. Madrid E, Urrutia G, Roque i Figuls M, Pardo-Hernandez H, Campos JM, Paniagua P, et al. Active body surface warming systems for preventing complications caused by inadvertent perioperative hypothermia in adults. Cochrane Database Syst Rev. 2016;4:CD009016.
62. Cajigas I, Mahavadi AK, Shah AH, Borowy V, Abitbol N, Ivan ME, et al. Analysis of intra-operative variables as predictors of 30-day readmission in patients undergoing glioma surgery at a single center. J Neurooncol. 2019;145(3):509–18.
63. Wagner D, Hooper V, Bankieris K, Johnson A. The relationship of postoperative delirium and unplanned perioperative hypothermia in surgical patients. J Perianesth Nurs. 2021;36(1):41–6.
64. Sessler DI, Pei L, Li K, Cui S, Chan MTV, Huang Y, et al. Aggressive intraoperative warming versus routine thermal management during non-cardiac surgery (PROTECT): a multicentre, parallel group, superiority trial. Lancet. 2022;399(10337):1799–808.
65. Aykanat VM, Broadbent E, Peyton PJ. Reliability of alternative devices for postoperative patient temperature measurement: two prospective, observational studies. Anaesthesia. 2021;76(4):514–9.
66. Brauer A, Fazliu A, Perl T, Heise D, Meissner K, Brandes IF. Accuracy of zero-heat-flux thermometry and bladder temperature measurement in critically ill patients. Sci Rep. 2020;10(1):21746.
67. Wagner M, Lim-Hing K, Bautista MA, Blaber B, Ryder T, Haymore J, et al. Comparison of a continuous noninvasive temperature to monitor core temperature measures during targeted temperature management. Neurocrit Care. 2021;34(2):449–55.
68. Matsukawa T, Ozaki M, Sessler DI, Nishiyama T, Imamura M, Kumazawa T. Accuracy and precision of "deep sternal" and tracheal temperatures at high- and low-fresh-gas flows. Br J Anaesth. 1998;81(2):171–5.
69. Matsukawa T, Sessler DI, Ozaki M, Hanagata K, Iwashita H, Kumazawa T. Comparison of distal oesophageal temperature with "deep" and tracheal temperatures. Can J Anaesth. 1997;44(4):433–8.
70. Hayes JK, Collette DJ, Peters JL, Smith KW. Monitoring body-core temperature from the trachea: comparison between pulmonary artery, tympanic, esophageal, and rectal temperatures. J Clin Monit. 1996;12(3):261–9.
71. Krizanac D, Haugk M, Sterz F, Weihs W, Holzer M, Bayegan K, et al. Tracheal temperature for monitoring body temperature during mild hypothermia in pigs. Resuscitation. 2010;81(1):87–92.
72. Yamakage M, Kawana S, Watanabe H, Namiki A. The utility of tracheal temperature monitoring. Anesth Analg. 1993;76(4):795–9.
73. Van Duren A. Perioperative prewarming: heat transfer and physiology. AORN J. 2022;115(5):407–22.
74. Leung KK, Lai A, Wu A. A randomised controlled trial of the electric heating pad vs forced-air warming for preventing hypothermia during laparotomy. Anaesthesia. 2007;62(6):605–8.
75. John M, Crook D, Dasari K, Eljelani F, El-Haboby A, Harper CM. Comparison of resistive heating and forced-air warming to prevent inadvertent perioperative hypothermia. Br J Anaesth. 2016;116(2):249–54.

76. Min SH, Yoon S, Yoon SH, Bahk JH, Seo JH. Randomised trial comparing forced-air warming to the upper or lower body to prevent hypothermia during thoracoscopic surgery in the lateral decubitus position. Br J Anaesth. 2018;120(3):555–62.
77. Campbell G, Alderson P, Smith AF, Warttig S. Warming of intravenous and irrigation fluids for preventing inadvertent perioperative hypothermia. Cochrane Database Syst Rev. 2015;2015(4):CD009891.
78. Horn EP, Bein B, Bohm R, Steinfath M, Sahili N, Hocker J. The effect of short time periods of pre-operative warming in the prevention of peri-operative hypothermia. Anaesthesia. 2012;67(6):612–7.
79. Xu H, Wang Z, Lu Y, Guan X, Ma Y, Malone DC, et al. Value of active warming devices for intraoperative hypothermia prevention-a meta-analysis and cost-benefit analysis. Int J Environ Res Public Health. 2021;18(21):11360.
80. Brauer A, Perl T, Heise D, Quintel M, Seipelt R. Intraoperative full-thickness pressure ulcer in a patient after transapical aortic valve replacement using a novel underbody forced-air warming blanket. J Clin Anesth. 2010;22(7):573–4.

Publisher's Note