# Perioperative Hypothermia:
## Mechanism, Risk Factors and New Protocols in Prevention and Treatment

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Abstract

**Aim:** Perioperative hypothermia (POH) is defined as a core temperature drop below 36°C during anaesthesia and surgery and leads to coagulation disorders, increased transfusion requirements, delayed wound healing and an elevated infection risk, prolonged hospitalisation and increased costs. It is therefore vital to maintain normal body temperature both before and after surgery in order to ensure optimal surgical outcomes, as well as patient safety and satisfaction.

**Methods:** In order to ensure optimal outcomes, it is imperative that prevention and management of POH should include preoperative risk assessments, monitoring of perioperative body temperature, control of environmental temperature, and the development of comprehensive warming protocols and checklists.

**Conclusions:** The present review examines recent studies and technological advancements regarding risk factors and prevention strategies for POH, with the aim of providing a practical guide for clinicians.

***Keywords**: Perioperative hypothermia; general anaesthesia; neuroaxial blocks; normothermia*

## 1. Introduction

Human core body temperature is generally maintained at 37 °C by mechanisms regulated by the thermoregulatory system, thereby ensuring the proper functioning of both physiological and immunological processes[1].

A normal thermoregulatory system consists of afferent thermal sensing, central regulation, and efferent responses[2]. Afferent signals originate from various tissues, including the skin, deep tissues, and the spinal cord. These thermal signals ascend via the spinothalamic tract of the anterior spinal cord to reach the hypothalamus, the central integrator of thermoregulatory control[3,4]. The regulation of body temperature is achieved through three primary mechanisms: The sympathetic nervous system plays a pivotal role in the regulation of heat distribution. This is achieved through the activation of skin vasoconstriction or vasodilation, as well as the stimulation of sweat gland activity. Additionally, the system modulates the metabolism of brown adipose tissue, thereby facilitating heat production. Secondly, behavioural thermoregulation is adjusted through the activation of the somatic nervous system, which involves changes in skeletal muscle activity and tone. Thirdly, modulation of metabolic activity for heat production is provided via the release of thyroid hormones, adrenaline, noradrenaline, and growth hormone[4,5]. Efferent responses encompass behavioural and autonomic regulation. It is evident that behavioural responses are predominantly governed by thermal inputs from the skin surface, while approximately 80% of autonomic responses are under the control of thermal inputs from core structures. Behavioural regulation represents the most powerful mechanism and requires conscious perception of body temperature; approximately 50% of this is provided by skin temperature[6,7]. The primary autonomic responses to cold exposure include vasoconstriction of the small arteries in the extremities, which reduces skin blood flow to minimise heat loss, and shivering. Vasoconstriction significantly reduces blood flow through arteriovenous shunts on the skin surface, thereby minimising convective and radiative heat loss and effectively conserving metabolic heat. This response is primarily regulated by local α-adrenergic sympathetic nerve activity[8]. In infants, non-shivering thermogenesis in brown adipose tissue serves as the primary mechanism of heat production[9].

Perioperative hypothermia (POH) is defined as a core temperature drop below 36°C during anaesthesia and surgery. This is due to the redistribution of heat from the core to the periphery, impaired thermoregulation associated with anaesthesia, and exposure to a cold environment. POH is classified as mild (34°C–36°C), moderate (32°C–34°C), and severe (<32°C)[6]. The prevalence of the condition during the perioperative period has been documented to range from approximately 25.7% to 90%[10-12].

Hypothermia causes histotoxic hypoxia, cardiovascular events, slowed drug metabolism, delayed reversal of neuromuscular blockade and delayed recovery, delayed wound healing and increased infection, postoperative shivering, disseminated intravascular coagulation, increased blood transfusion, and patient dissatisfaction[13]. Billeter et al.[14] found that patients subjected to perioperative hypothermia during surgery for gastrointestinal,

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pancreatic and hepatobiliary disorders, joint replacement and spine, vascular, neurosurgical, thoracic, gynaecological and urological pathologies had a fourfold increase in mortality and a twofold increase in the risk of stroke and sepsis. A meta-analysis of studies conducted on patients undergoing hip surgery reported that low perioperative body temperature was associated with an increased risk of 30-day mortality. This increase in mortality risk was found to be significantly higher than the increase associated with delayed surgery[15]. It has been demonstrated that even mild hypothermia can increase the incidence of wound infection[16,17]. A meta-analysis encompassing 25 studies and 28,761 patients revealed a substantial augmentation in the likelihood of surgical site infection (SSI) when the body temperature declined to 35°C or below during surgical procedures[18]. Consequently, this results in an economic crisis for the patient and the community as a whole. It is therefore vital to maintain normal body temperature both before and after surgery in order to ensure optimal surgical outcomes, as well as patient safety and satisfaction.

In recent years, with the frequent implementation of Enhanced Recovery After Surgery (ERAS) protocols, the prevention and treatment of POH has become one of the most important components of ERAS protocols. Despite the increased awareness among anaesthetists and surgeons regarding the risks associated with POH and the increasingly frequent use of various physical warming methods, the incidence of POH remains high[13]. In order to address this issue, a range of heating devices have been developed in tandem with technological advances. Each of these devices possesses its own set of advantages and limitations, necessitating a specific selection based on the particular clinical conditions of the patient. The present review aims to evaluate the protocols that can be applied in the risk assessment, prevention, and treatment of POH, as well as the effectiveness of the developed devices.

## Perioperative Hypothermia Risk Assessment

Numerous factors have been demonstrated to influence perioperative core temperature, including patient health status and illnesses, the nature of the surgical procedure, and the anaesthetic agent used. The aforementioned variables have been demonstrated to contribute to the development of hypothermia, albeit to differing extents. Risk factors for POH can be identified through effective preoperative assessment, which has been shown to significantly reduce the incidence of POH and related complications (Table 1). A preoperative risk prediction model was developed using risk factors such as body mass index, preoperative basal body temperature, and duration of surgery and anaesthesia. Furthermore, the necessity of preventing POH and the effectiveness of the tools used were investigated. Although the efficacy of this prediction model was confirmed through pre-validation, its clinical application remains restricted. The necessity for further research is emphasised by the requirement for prospective, large-sample, multicentre clinical studies[19].

**Table 1**
Risk factors associated with perioperative hypothermia

| | **Risk Factors** | **Clinical Significance** |
|---|---|---|
| **Patient-related** | Ageing | Poor thermoregulatory response<br>Delayed vasoconstriction |
| | Low body mass index | Low subcutaneous fat → increased heat loss |
| | Female | Lower muscle mass and basal metabolic rate |
| | Newborns and infants | Higher surface area/body weight ratio |
| | Hypothyroidism | Reduced heat production |
| | Diabetes (Autonomic neuropathy) | Impaired vasomotor response |
| | Sepsis / serious illness | Impaired thermoregulation |
| | ASA III–IV | Low general physiological reserves |
| **Anaesthesia-related** | General anaesthesia | Vasodilatation → heat redistribution |
| | Regional anaesthesia (spinal/epidural) | Sympathetic block → peripheral heat loss |
| | Combined GA + regional | The risk of hypothermia increases further |
| | Long anaesthesia duration | Cumulative heat loss |
| | Volatile agents | Lower the thermoregulatory threshold |
| | Opioids | Suppressed the tremor response |
| **Surgery-related** | Long surgery duration | Heat loss by convection and radiation |
| | Major surgical procedures | Increased exposed body surface area |
| | Thoracic / abdominal surgery | Major heat loss areas |
| | Open surgery (laparotomy) | Greater heat loss compared to laparoscopy |
| | Major blood loss | Cold blood and fluid replacement |
| **Environmental factors** | Low OR temperature | Heat loss through radiation and convection |
| | Cold antiseptics | Local and systemic heat loss |
| | Unheated irrigation fluids | Long surgeries |
| **Fluids and transfusions** | Unheated IV fluids | Each 1 L of fluid at room temperature → ≈0.25 °C drop |
| | Massive transfusion | Severe hypothermia with cold blood products |
| **Perioperative management** | Preoperative hypothermia | The strongest predictor |
| | No active warming | Lack of mandatory preventive measures |
| | Long holding time | Heat loss begins before surgery |

## Intraoperative Period

During transfer to the operating theatre, exposure to low temperatures may cause heat loss, and cutaneous vasoconstriction may occur as a thermoregulatory mechanism to maintain normal body temperature. Cooling of peripheral body regions and a temperature gradient between the core and periphery may occur. It has been established that warming the skin surface for a period of 30 minutes prior to the induction of anaesthesia does not result in a significant increase in core temperature. However, this procedure does result in an increase in peripheral tissue temperature and total body heat content, and it prevents the occurrence of redistribution hypothermia[7,20]. A meta-analysis encompassing 27 studies has demonstrated that the implementation of a pre-warming system has the potential to attenuate the severity of perioperative hypothermia, thereby facilitating the achievement and maintenance of normothermia during the intraoperative and postoperative periods[21].

The most significant factor in determining intraoperative heat loss is the ambient temperature of the operating theatre[22]. Researchs have indicated that when the operating theatre temperature is below 21°C, patients are more prone to developing hypothermia[23]. The maintenance of an appropriate operating theatre temperature (21–25°C) has been demonstrated to reduce the temperature difference between the patient's skin and the environment, thereby minimising heat loss through radiation. However, an increase in temperature above 26°C has been observed to reduce the incidence of POH, although it has also been demonstrated to increase the risk of infection and cause discomfort for the surgical team[24]. Therefore, intraoperative room temperature should be adjusted dynamically according to the patient's needs and surgical procedures.

## Anaesthesia induced hypothermia

The development of hypothermia during the intra-anaesthetic period is characterised by a distinct pattern that can be subdivided into three phases: redistribution, linear, and plateau **(Figure 1)**.

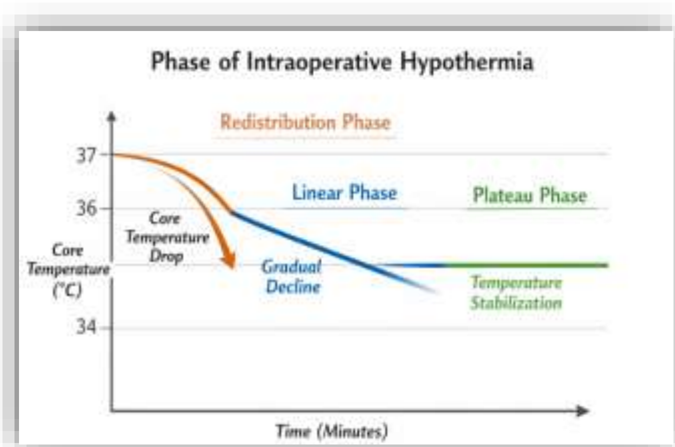


***Figure 1*** *Phases of Intraoperative Hypothermia*

### *Redistribution Phase*

Approximately 40% of perioperative heat loss occurs through radiation, 30% through convection due to air movement, 25% through evaporation, and a small portion through conduction to the operating table[25,26]. However, the precipitous initial decline in core temperature of approximately 1.0–1.5 °C during the initial hour of anaesthesia cannot be explained by heat loss alone[27]. Following the administration of anaesthesia, hypothermia arises not so much from the dissipation of body heat into the environment, but rather as a result of heat distribution from the internal core to the periphery. In the majority of cases, the core generates the majority of metabolic heat. A thermal gradient is established from the core to the peripheral tissues, the skin, and finally the environment. This prevents the accumulation of heat in the core. The thermal core, defined as the highly vascularised tissue of the trunk and head, exhibits a comparable dimensionality to the peripheral thermal compartment, which is predominantly composed of the arms and legs. Indeed general anaesthesia exerts minimal influence on the regulation of body temperature. However, it has been demonstrated that any dose of general anaesthesia significantly disrupts thermoregulatory arteriovenous shunt vasoconstriction[27-31]. The initial rapid decrease in core temperature after anaesthesia induction is due to the dilation of thermoregulatory arteriovenous shunts, allowing heat to redistrubion from the core to the periphery; thus, the core temperature decreases much more significantly than the small decrease in overall body heat content[25].

Subsequent to the induction of general anaesthesia, the temperature decline that occurs during the process of heat redistribution is related to the patient's body composition and haemodynamics. The increase in cardiac output or peripheral vasodilation results in accelerated redistribution. The most significant factor is the peripheral temperature prior to the induction of anaesthesia. The lower the temperature gradient between the core and periphery, the less heat redistribution occurs and the smaller the decrease in core temperature. Weaker, smaller patients with greater blood loss cool more strongly and rapidly[32].

Neuraxial anaesthesia techniques disrupt thermoregulation by reducing vasoconstriction and shivering thresholds[33]. Furthermore, central responses to afferent thermal inputs in the blocked segments are altered[34]. Moreover, vasodilation in blocked dermatomes increase skin temperature and further blunt behavioural responses to cooling, thereby exacerbating hypothermia[35]. In contrast to the general anaesthesia, neuraxial anaesthesia induced by hypothermia occurs rapidly through redistribution, followed by a gradual cooling without a plateau phase, as the ongoing heat loss exceeds metabolic heat production[34,35]. It has been demonstrated that temperature drops are more pronounced when general and regional anaesthesia are administered in combination[36]. Conversely, peripheral nerve blocks do not result in clinically significant impairment of thermoregulation, even in elderly patients[37,38].

### *Linear Phase*

In unheated patients during prolonged surgeries, redistribution hypothermia, which is mainly completed within an hour, is followed by a linear core temperature decrease lasting 2–3 hours. Although redistribution is less significant during this phase, heat loss through radiation and convection is predominant. The linear phase results from heat loss exceeding heat production[39]. During general anaesthesia, metabolic heat production decreases by approximately 30%[27]. Peripheral blocks do not reduce metabolic heat production, and neuroaxial anaesthesia methods have very little effect[40]. The second mechanism is heat loss through the skin. In this phase, heat loss occurs through the skin and depends on surface insulation and ambient temperature. This phase of linear decrease in core temperature lasts about two hours and ends when the body reaches its autonomic thermoregulatory threshold of about 34.5 °C. During anaesthesia, modern heaters largely prevent heat loss through the skin and even rewarm hypothermic patients[41].

### Plateu Phase

Following a decline in core body temperature to approximately 34.5 °C, this level remains constant irrespective of the large and duration of the operation. This phenomenon can be attributed to the reactivation of vasoconstriction caused by hypothermia, resulting in the body entering a plateau phase in its thermal state[25]. The threshold for vasoconstriction, which is triggered by core temperature, is dependent on the drug and its dosage. However, in typical anaesthetic drug combinations, vasoconstriction reappears at approximately 34.5 °C. Conversely, the combination of general and neuroaxial anaesthesia results in a sustained decline in core temperature. This is attributable to the fact that neuroaxial blocks centrally reduce vasoconstriction and the shivering threshold, and prevent arteriovenous shunt vasoconstriction[31,34,36,42].

## Intraoperative Temperature Monitoring

Accurate monitoring of core body temperature and appropriate measurement techniques are crucial for clinical interpretation. The mean body temperature is reflective of the total heat content and is calculated using the following equation: mean body temperature = 0.87 × core temperature + 0.13 × skin temperature[43]. In the event of anaesthesia lasting over 30 minutes, whether general or neuroaxial, or of a surgical intervention lasting over one hour, core body temperature should be measured at regular intervals (at least every 15 minutes). If the temperature falls below 36 °C, timely warming interventions should be provided[44]. Temperature in the pulmonary artery is widely regarded as the gold standard for core temperature, yet its practical application is challenging. The most suitable areas for core temperature measurement are the distal third of the oesophagus adjacent to the left atrium, the tympanic membrane, and the nasal pharynx. The rectal or bladder temperature is a measure of the core temperature, but with a significant delay. In light of the rapid fluctuations in temperature that are characteristic of the perioperative environment, the efficacy of bladder and rectal temperatures as measurement sites may be compromised. It is therefore imperative to exercise caution and take measurement delays into consideration[45,46]. In theory, the temperature of the subcutaneous tissue may be representative of core temperature. However, it should be noted that deviations may occur due to the effects of convective blood flow. Zero heat flux thermometers offer a non-invasive method for estimating tissue temperatures. The application of these devices to the skin has been demonstrated to provide excellent thermal insulation. The temperature of the insulated skin area is representative of the core temperature following a period of equilibration. The forehead is considered a suitable site for zero-heat-flow thermometer use[47].

## Perioperative Hypothermia Management

The purpose of maintaining the patient's body temperature during perioperative period is to keep heat loss to a minimum by reducing radiation and convection from the skin, evaporation from open surgical sites, and cooling caused by the administration of cold intravenous fluids[48].

### Passive Warming Systems

Passive warming measures are aimed at maintaining body temperature and reducing heat loss, and are generally more effective in mild hypothermia[49,50]. The methods employed in this regard include the augmentation of the ambient temperature, the insulation of the body surface with fabric covers, the utilisation of artificial noses, reflective and thermal blankets, and a low-flow semi-closed anaesthesia circuit[51-53]. AORN guidelines recommend the use of at least one passive warming technique during the perioperative period[54]. Single-layer passive warming has the capacity to reduce heat loss by 30%[13].

### Active Warming Systems

Active heating methods function by augmenting heat supply and transfer. Active heating systems transfer heat directly to the patient using methods such as infrared light, electric and hot water circulation blankets and mattresses, forced-air heating or convective air heating units, heating intravenous and irrigation fluids, and humidifying anaesthetic air and carbon dioxide[55-57].

Forced air warming (FAW) devices are composed of a power unit and a blanket that transfers heated air directly to the patient's body surface via convective and conductive processes. It has been demonstrated that these substances reduce heat loss and maintain body temperature[58]. A meta-analysis conducted by Wang et al., involving 19 studies and 861 patients, found that FAW devices significantly increased core and overall body temperature in patients undergoing laparoscopic surgery and significantly reduced the incidence of hypothermia and shivering[59]. The combined preoperative and intraoperative use of FAW has been demonstrated to be the most efficacious approach; the benefits of preoperative use alone are limited[52,53]. Furthermore, factors such as the location, duration, and temperature of heating have been demonstrated to affect the efficacy of FAW[60]. In recent years, lower body blankets have been developed for use in upper body surgeries, including thoracic and cardiac surgery. A meta-analysis was conducted to ascertain the optimal application area of FAW devices in preventing POH in patients undergoing abdominal surgery. The results of the meta-analysis reported that FAW devices are effective in preventing preoperative hypothermia in both open abdominal surgery and laparoscopic surgery. The meta-analysis also found that FAW devices are used more in the upper body compared to the lower body and whole body[60]. In a study evaluating body temperature at 60 and 120 minutes following anaesthetic induction in patients undergoing abdominal surgery, the use of lower body blankets was found to be more effective than the use of upper body blankets and passive insulation. Furthermore, the study demonstrated that lower body blankets were more effective than passive insulation in preventing postoperative shivering. It was also reported that lower body blankets regulate core temperature and prevent shivering within the first two hours following anaesthesia induction[61]. Nevertheless, the meta-analyses strongly emphasise that current studies have significant limitations in terms of sample size and that more comprehensive studies are required[59,60].

The self-regulated heated air garment is a disposable garment connected to a portable heating unit that produces 1000 BTU per hour. Patients can manage this device in accordance with their individual heat requirements, thereby enabling utilisation during the intraoperative period, as well as the preoperative and postoperative periods. The implementation of measures aimed at preventing hypothermia in patients may enhance their level of comfort during the perioperative period, thereby reducing anxiety levels[62]. The utilisation of the self-regulated heated air garment, when employed in a patient-controlled manner throughout the entirety of the perioperative process, may alleviate preoperative anxiety and postoperative pain[63].

### Heated Infusion Fluids

For patients undergoing general anaesthesia, the administration of 1000 ml of room temperature fluid or a single unit of blood transfusion stored at 0.5 °C has been demonstrated to result in a reduction of body temperature by 0.25–0.5 °C[64]. Fluids, colloids, or blood administered at a rate exceeding 500 ml/hour should be warmed to 37°C[65]. The administration of intravenous fluids at a temperature of 37–41 °C results in an increase in body temperature and a reduction in shivering compared to fluids at room temperature[66]. However, the difference between warmed and room temperature irrigation fluids is less significant.

A body of research has been conducted on the impact of warmed intravenous fluids on POH during the intraoperative period. The findings from these studies have produced a range of outcomes. A study by De Mattia et al. found that the use of warmed intravenous fluids had no impact on the incidence of hypothermia[67]. In contrast, a study by Campbell et al. found that the use of warmed intravenous fluids during the intraoperative period reduced POH and the risk of postoperative shivering compared to room temperature fluids[66]. A meta-analysis was conducted to evaluate the efficacy of a combination of FAW and warmed intravenous fluids in preventing POH in caesarean section. The findings of this meta-analysis demonstrated that this combination effectively maintains maternal body temperature above the 36°C hypothermia threshold during caesarean section and in the postoperative period. Additionally, the analysis revealed that this combination reduces shivering[68].

In laparoscopic surgery, the utilisation of cold and dry $CO_2$ gas for abdominal distension has been demonstrated to contribute to POH by lowering body temperature. While the use of heated and humidified $CO_2$ has been demonstrated to assist in the maintenance of body temperature, its clinical benefits are considered to be limited[69,70]. The combination of this method with FAW has been shown to result in a substantial reduction in the incidence of POH[71,72]. In obese patients, visceral fat insulation has been demonstrated to reduce organ temperature loss[73]. These findings suggest that the selection of appropriate warming methods should be based on the type of surgery and patient characteristics.

### Postoperative warming and monitoring

Maintaining normothermia is imperative during the postoperative period, with the utilisation of convective or conductive heat therapy. It is crucial to avert the occurrence of hypothermia[7]. It is imperative that temperature is meticulously monitored in the postoperative care unit. In the event of a decline in temperature, timely intervention is to be administered. Complications related to POH, such as shivering and arrhythmias, should be monitored. The combination of postoperative warming with pain management and fluid therapy has been demonstrated to enhance patient comfort and facilitate recovery[74].

## 2. Conclusion

POH is a frequent complication in the perioperative period, leading to coagulation disorders, increased transfusion requirements, delayed wound healing and an elevated infection risk, prolonged hospitalisation and increased costs. It is therefore crucial to be aware of POH and to ensure that normothermic conditions are maintained in the perioperative period. In order to ensure optimal outcomes, it is imperative that prevention and management of POH should include preoperative risk assessments, monitoring of perioperative body temperature, control of environmental temperature, and the development of comprehensive warming protocols and checklists.

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## Conflict of interest statement

The authors declare that they have no conflict of interest.

## genAI

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## References

1. Nakamura K. Central circuitries for body temperature regulation and fever. Am J Physiol Regul Integr Comp Physiol. 2011;301(5):R1207-R1228. Crossref
2. Romanovsky AA. Thermoregulation: some concepts have changed. Functional architecture of the thermoregulatory system. Am J Physiol Regul Integr Comp Physiol. 2007;292(1):R37-R46. Crossref
3. Charkoudian N. Skin blood flow in adult human thermoregulation: how it works, when it does not, and why. Mayo Clin Proc. 2003;78(5):603-612. Crossref
4. De Witte J, Sessler DI. Perioperative shivering: physiology and pharmacology. Anesthesiology. 2002;96(2):467-484. Crossref
5. Hales JR, Jessen C, Fawcett AA, King RB. Skin AVA and capillary dilatation and constriction induced by local skin heating. Pflugers Arch. 1985;404(3):203-207. Crossref
6. Díaz M, Becker DE. Thermoregulation: physiological and clinical considerations during sedation and general anesthesia. Anesth Prog. 2010;57(1):25-32. Crossref
7. Bindu B, Bindra A, Rath G. Temperature management under general anesthesia: compulsion or option. J Anaesthesiol Clin Pharmacol. 2017;33(3):306-316. Crossref
8. Buggy DJ, Crossley AW. Thermoregulation, mild perioperative hypothermia and postanaesthetic shivering. Br J Anaesth. 2000;84(5):615-628. Crossref
9. Tews D, Wabitsch M. Brown adipose tissue in children and its metabolic function. Horm Res Paediatr. 2022;95(2):104-111. Crossref
10. Akhtar Z, Hesler B, Fiffick A, Mascha E, Sessler D, Kurz A, et al. A randomized trial of prewarming on patient satisfaction and thermal comfort in outpatient surgery. J Clin Anesth. 2016;33:376-385. Crossref
11. Diamond A, Prasad D, Abbott D. One size does not fit all: assuming the same normal body temperature for everyone is not justified. PLoS One. 2021;16(2):e0245257. Crossref
12. Lee Y, Kim K. Optimal application of forced air warming to prevent peri-operative hypothermia during abdominal surgery: a systematic review and meta-analysis. Int J Environ Res Public Health. 2021;18(5):2517. Crossref
13. Zhang B, Zhou H, Wang X, Zheng Y, Hu L. Advances in the multimodal management of perioperative hypothermia: approaches from traditional Chinese and Western medicine. Perioper Med (Lond). 2024;13(1):107. Crossref
14. Billeter AT, Hohmann SF, Druen D, Cannon R, Polk Jr H. Unintentional perioperative hypothermia is associated with severe complications and high mortality in elective operations. Surgery. 2014;156(5):1245-1252. Crossref
15. Mroczek TJ, Prodromidis AD, Pearce A, Malik RA, Charalambous CP. Perioperative Hypothermia Is Associated With Increased 30-Day Mortality in Hip Fracture Patients in the United Kingdom: A Systematic Review and Meta-analysis. J Orthop Trauma. 2022;36(7):343-348. Crossref
16. Xu H, Wang Z, Guan X, Lu Y, Malone DC, Salmon JW, et al. Safety of intraoperative hypothermia for patients: meta-analyses of randomized controlled trials and observational studies. BMC Anesthesiol. 2020;20(1):202. Crossref
17. Bu N, Zhao E, Gao Y, Zhao S, Bo W, Kong Z, et al. Association between perioperative hypothermia and surgical site infection: A meta-analysis. Medicine (Baltimore). 2019;98(6):e14392. Crossref
18. Chen R, Du Y, Chen L, Bai Y, Zhang Y, Yu T, et al. The impact of perioperative hypothermia on surgical site infection risk: a meta-analysis. BMC Anesthesiol. 2025;25(1):443. Crossref
19. Yi J, Zhan L, Lei Y, Xu S, Si Y, Li S, et al. Establishment and validation of a prediction equation to estimate risk of intraoperative hypothermia in patients receiving general anesthesia. Sci Rep. 2017;7(1):13927. Crossref
20. Torossian A, Bräuer A, Höcker J, Bein B, Wulf H, Horn EP. Preventing inadvertent perioperative hypothermia. Dtsch Arztebl Int. 2015;112(10):166-172. Crossref

21. Uçak A, Çatal AT, Karadağ E, Cebeci F. The effect of prewarming on perioperative hypothermia: A systematic review and meta-analysis of randomized controlled studies. J Perianesth Nurs. 2024;39(4):611-623. **Crossref**
22. de Bernardis RCG, Siaulys MM, Vieira JE, Mathias LAST. Perioperative warming with a thermal gown prevents maternal temperature loss during elective cesarean section. A randomized clinical trial. Braz J Anesthesiol. 2016;66(5):451-455. **Crossref**
23. Giuliano KK, Hendricks J. Inadvertent Perioperative Hypothermia: current nursing knowledge. AORN J. 2017;105(5):453-463. **Crossref**
24. Yang L, Huang C, Zhou Z, Wen Z, Zhang G, Liu K, 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;21:14-17. **Crossref**
25. Sessler DI. How three linked clinical observations led to an understanding of perioperative heat balance: a personal reflection on the scientific process. J Clin Anesth. 2024;96:111496. **Crossref**
26. Riley C, Andrzejowski J. Inadvertent perioperative hypothermia. BJA Educ. 2018;18(8):227-233. **Crossref**
27. Matsukawa T, Sessler DI, Sessler AM, Schroeder M, Ozaki M, Kurz A, et al. Heat flow and distribution during induction of general anesthesia. Anesthesiology. 1995;82(3):662-673. **Crossref**
28. Xiong J, Kurz A, Sessler DI, Plattner O, Christensen R, Dechert M, et al. Isoflurane produces marked and non-linear decreases in the vasoconstriction and shivering thresholds. Anesthesiology. 1996;85(2):240-245. **Crossref**
29. Matsukawa T, Kurz A, Sessler DI, Bjorksten AR, Merrifield B, Cheng C. Propofol linearly reduces the vasoconstriction and shivering thresholds. Anesthesiology. 1995;82(5):1169-1180. **Crossref**
30. Annadata RS, Sessler DI, Tayefeh F, Kurz A, Dechert M. Desflurane slightly increases the sweating threshold, but produces marked, non-linear decreases in the vasoconstriction and shivering thresholds. Anesthesiology. 1995;83(6):1205-1211. **Crossref**
31. Kurz A, Go JC, Sessler DI, Kaer K, Larson M, Bjorksten AR. Alfentanil slightly increases the sweating threshold and markedly reduces the vasoconstriction and shivering thresholds. Anesthesiology. 1995;83(2):293-299. **Crossref**
32. Lai LL, See MH, Rampal S, Ng KS, Chan L. Significant factors influencing inadvertent hypothermia in pediatric anesthesia. J Clin Monit Comput. 2019;33(6):1105-1112. **Crossref**
33. Kurz A, Sessler DI, Schroeder M, Kurz M. Thermoregulatory response thresholds during spinal anesthesia. Anesth Analg. 1993;77(4):721-726. **Crossref**
34. Leslie K, Sessler DI. Reduction in the shivering threshold is proportional to spinal block height. Anesthesiology. 1996;84(6):1327-1331. **Crossref**
35. Kim JS, Ikeda T, Sessler DI, Turakhia M, Jeffrey R. Epidural anesthesia reduces the gain and maximum intensity of shivering. Anesthesiology. 1998;88(4):851-857. **Crossref**
36. Joris J, Ozaki M, Sessler DI, Hardy AF, Lamy M, McGuire J, et al. Epidural anesthesia impairs both central and peripheral thermoregulatory control during general anesthesia. Anesthesiology. 1994;80(2):268-277. **Crossref**
37. Sessler DI. Perioperative thermoregulation and heat balance. Lancet. 2016;387(10038):2655-2664. **Crossref**
38. Cho SA, Chang M, Lee SJ, Sung TY, Cho CK. Prewarming for prevention of hypothermia in older patients undergoing hand surgery under brachial plexus block. Ann Geriatr Med Res. 2022;26(2):175-182. **Crossref**
39. Hynson J, Sessler DI. Intraoperative warming therapies: a comparison of three devices. J Clin Anesth. 1992;4(3):194-199. **Crossref**
40. Bickler P, Sessler DI. Efficiency of airway heat and moisture exchangers in anesthetized humans. Anesth Analg. 1990;71(4):415-418. **Crossref**
41. Giesbrecht GG, Ducharme MB, McGuire JP. Comparison of forced-air patient warming systems for perioperative use. Anesthesiology. 1994;80(3):671-679. **Crossref**
42. Ozaki M, Kurz A, Sessler DI, Lenhardt R, Schroeder M, Moayeri A, et al. Thermoregulatory thresholds during spinal and epidural anesthesia. Anesthesiology. 1994;81(2):282-288. **Crossref**
43. Brück K, Zeisberger E. Adaptive changes in thermoregulation and their neuropharmacological basis. Pharmacol Ther. 1987;35(1-2):163-215. **Crossref**
44. Recio-Pérez J, Miró Murillo M, Martin Mesa M, García JS, Santonocito C, Sanfilippo F, et al. Effect of prewarming on perioperative hypothermia in patients undergoing loco-Regional or general anesthesia: a randomized clinical trial. Medicina (Kaunas). 2023;59(12):2082. **Crossref**
45. Sessler DI. Perioperative Temperature Monitoring. Anesthesiology. 2021;134(1):111-118. **Crossref**
46. Bock M, Hohlfeld U, Von Engeln K, Meier PA, Motsch J, Tasman AJ. The accuracy of a new infrared ear thermometer in patients undergoing cardiac surgery. Can J Anaesth. 2005;52(10):1083-1087. **Crossref**
47. Boisson M, Alaux A, Kerforne T, Mimoz O, Debaene B, Dahyot-Fizelier C, et al. Intra-operative cutaneous temperature monitoring with zero-heat-flux technique (3M SpotOn) in comparison with oesophageal and arterial temperature: a prospective observational study. Eur J Anaesthesiol. 2018;35(11):825-830. **Crossref**
48. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. **Crossref**
49. Horosz B, Malec-Milewska M. Methods to prevent intraoperative hypothermia. Anaesthesiol Intensive Ther. 2014;46(2):96-100. **Crossref**
50. Perlman R, Callum J, Laflamme C, Tien H, Nascimento B, Beckett A, et al. A recommended early goal-directed management guideline for the prevention of hypothermia-related transfusion, morbidity, and mortality in severely injured trauma patients. Crit Care. 2016;20(1):107. **Crossref**
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):1490-1497. **Crossref**
52. Min S, Yoon S, Yoon S, Bahk J, Seo J. 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):555-562. **Crossref**
53. Thiel B, Mooijer B, Kolff-Gart A, Kerklaan B, Poolman R, de Haan P, et al. Is preoperative forced-air warming effective in the prevention of hypothermia in orthopedic surgical patients? A randomized controlled trial. J Clin Anesth. 2020;61:109633. **Crossref**
54. Van Duren A. Perioperative prewarming: heat transfer and physiology. AORN J. 2022;115(5):407-422. **Crossref**
55. Madrid E, Urrútia G, Figuls MR, 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(4):CD009016. **Crossref**
56. Horn EP, Bein B, Böhm R, Steinfath M, Sahili N, Höcker J. The effect of short time periods of pre-operative warming in the prevention of peri-operative hypothermia. Anaesthesia. 2012;67(6):612-617. **Crossref**
57. Sultan P, Habib A, Cho Y, Carvalho B. The Effect of patient warming during Caesarean delivery on maternal and neonatal outcomes: a meta-analysis. Br J Anaesth. 2015;115(4):500-510. **Crossref**
58. Alparslan V, Kus A, Hosten T, Ertargin M, Ozdamar D, Toker K, Solak M. Comparison of forced-air warming systems in prevention of intraoperative hypothermia. J Clin Monit Comput. 2018;32(2):343-349. **Crossref**
59. Wang X, Su W, Yuqing M, Ge H, Chang W, Ma G, et al. Effectiveness of Forced-air Warming in Preventing Hypothermia During Laparoscopic Surgery: A RCT Meta-analysis. J Perianesth Nurs. 2025:S1089-9472(25)00172-8. **Crossref**
60. Lee Y, Kim K. Optimal application of forced air warming to prevent peri-operative hypothermia during abdominal surgery: a systematic review and meta-analysis. Int J Environ Res Public Health. 2021;18(5):2517. **Crossref**
61. Chen YC, Cherng YG, Romadlon DS, Chang KM, Huang CJ, Tsai PS, et al. Comparative effects of warming systems applied to different parts of the body on hypothermia in adults undergoing abdominal surgery: A systematic review and network meta-analysis of randomized controlled trials. J Clin Anesth. 2023;89:111190. **Crossref**
62. Fossum S, Hays J, Henson MM. A comparison study on the effects of prewarming patients in the outpatient surgery setting. J Perianesth Nurs. 2001;16(3):187-194. **Crossref**
63. Ji N, Wang J, Li X, Shang Y. Strategies for perioperative hypothermia management: advances in warming techniques and clinical implications: a narrative review. BMC Surg. 2024;24(1):425. **Crossref**
64. Roxby D, Sobieraj-Teague M, von Wielligh J, Sinha R, Kuss B, Smith AL, et al. Warming blood prior to transfusion using latent heat. Emerg Med Australas. 2020;32(4):604-610. **Crossref**
65. Munday J, Hines S, Wallace K, Chang AM, Gibbons K, Yates P. A systematic review of the effectiveness of warming interventions for women undergoing cesarean section. Worldviews Evid Based Nurs. 2014;11(6):383-393. **Crossref**
66. 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. **Crossref**
67. De Mattia AL, Barbosa MH, de Freitas Filho JP, Rocha Ade M, Pereira NH. Warmed intravenous infusion for controlling intraoperative hypothermia. Rev Lat Am Enfermagem. 2013;21(3):803-810. **Crossref**

68. Tubog TD, Kane TD, Ericksen AM. Combined Forced Air Warming and Warm Intravenous Fluid Strategy for Perioperative Hypothermia in Cesarean Delivery: A Systematic Review and Meta-Analysis. J Perianesth Nurs. 2023;38(1):21-32. **Crossref**
69. Balayssac D, Pereira B, Bazin JE, Le Roy B, Pezet D, Gagniere J. Warmed and humidified carbon dioxide for abdominal laparoscopic surgery: metaanalysis of the current literature. Surg Endosc. 2017;31(1):1-12. **Crossref**
70. Birch DW, Dang JT, Switzer NJ, Manouchehri N, Shi X, Hadi G, et al. Heated insufflation with or without humidification for laparoscopic abdominal surgery. Cochrane Database Syst Rev. 2016;10(10):CD007821. **Crossref**
71. Noll E, Diemunsch S, Pottecher J, Rameaux JP, Diana M, Sauleau E, et al. Prevention of laparoscopic surgery induced hypothermia with warmed humidified insufflation: is the experimental combination of a warming blanket synergistic? PLoS One. 2018;13(7):e0199369. **Crossref**
72. Wittenborn J, Mathei D, van Waesberghe J, Zeppernick F, Zeppernick M, Tchaikovski S, et al. The effect of warm and humidified gas insufflation in gynecological laparoscopy on maintenance of body temperature: a prospective randomized controlled multi-arm trial. Arch Gynecol Obstet. 2022;306(3):753-767. **Crossref**
73. Miyazaki R, Hoka S, Yamaura K. Visceral fat, but not subcutaneous fat, is associated with lower core temperature during laparoscopic surgery. PLoS One. 2019;14(6):e0218281. **Crossref**
74. Chen Y, Wang Y, Zhang YL, Zhang JJ, Hua Z, Li ZJ, et al. A prediction model for estimating risk of intraoperative hypothermia in patients undergoing general anesthesia: a prospective multicenter study. Zhongguo Yi Xue Ke Xue Yuan Xue Bao. 2022;44(6):1028-1032. **Crossref**