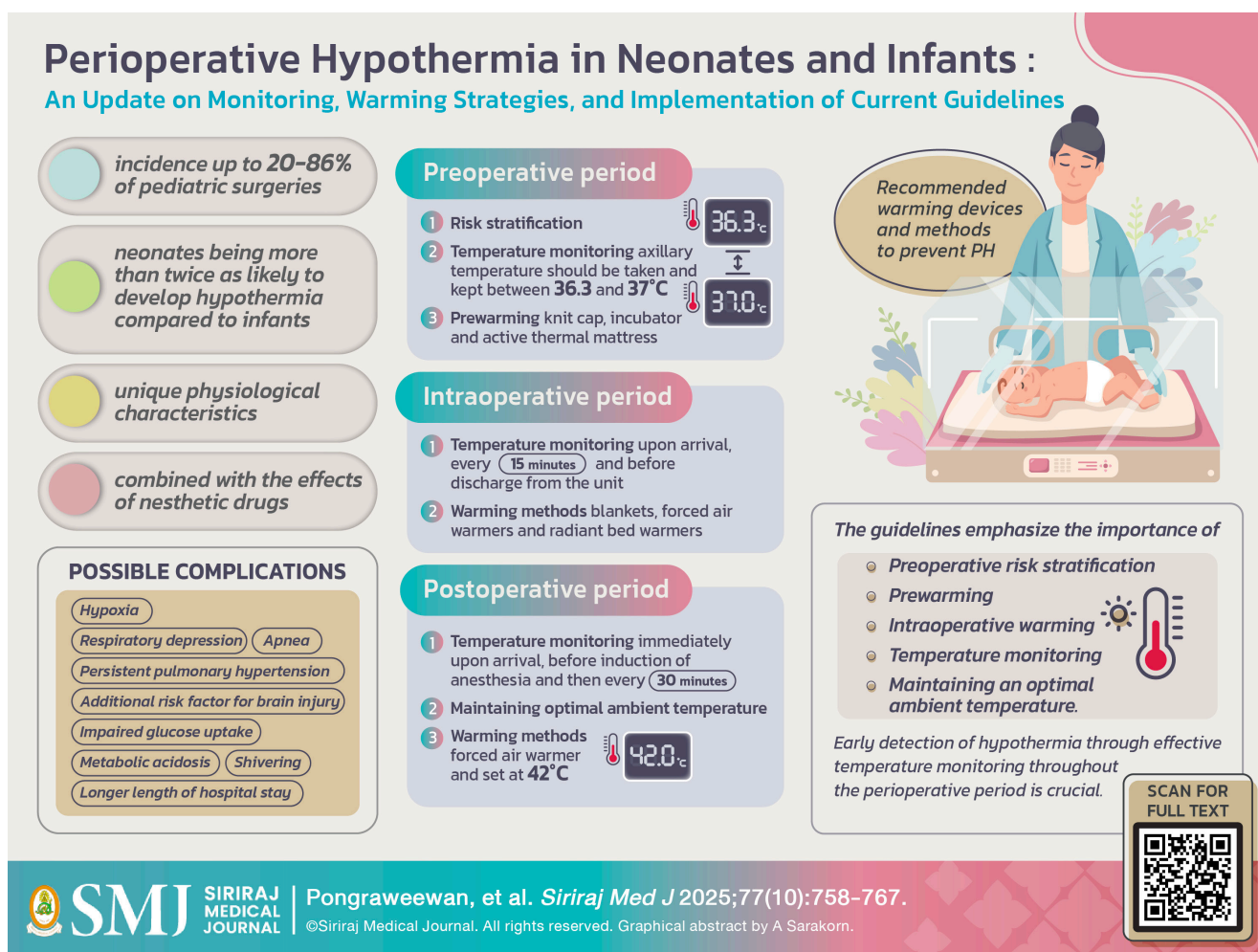


Perioperative Hypothermia in Neonates and Infants: An Update on Monitoring, Warming Strategies, and Implementation of Current Guidelines

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ABSTRACT

Perioperative hypothermia (PH) is a common concern in neonates and infants, and neonates are more than twice as likely to develop hypothermia due to their unique physiological characteristics. Combined with the effects of anesthetic drugs, these factors make them particularly susceptible to heat loss. Despite the implementation of effective warming methods, maintaining normothermia in this vulnerable population remains challenging.

Several guidelines tailored to specific hospitals and institutions aimed to emphasize the importance of preoperative risk stratification, prewarming, intraoperative warming, temperature monitoring, and maintaining an optimal ambient temperature. Early detection of hypothermia through effective temperature monitoring throughout the perioperative period is crucial. Combining the use of warming devices with specific techniques is more effective in reducing perioperative hypothermia.

This article highlights recent updates in monitoring and warming strategies, comparing the advantages and disadvantages of different approaches, and reviews the guidelines designed to prevent perioperative hypothermia in neonates and infants in order to optimize surgical outcomes.

Keywords: Perioperative hypothermia; pediatric; anesthesia; guideline; warming methods (Siriraj Med J 2025; 77: 758-767)

INTRODUCTION

Perioperative hypothermia, defined as a core body temperature below 36.5°C in children up to five years of age and below 36°C for children older than five years during the perioperative period¹, is a common concern among neonates and infants, as these age groups are particularly susceptible due to their unique physiological and anatomical features. Compared to older children and adults, they are at a significantly higher risk of developing perioperative hypothermia.

The incidence of perioperative hypothermia was reported in 82.83% of neonates and 38.31% of infants², while intraoperative hypothermia occurred in 54%³ of patients. Despite efforts to monitor, detect, and implement interventions, the incidence of neonates and young children developing perioperative hypothermia remains high. This article highlights recent updates on monitoring, warming strategies, and the implementation of guidelines to prevent perioperative hypothermia in neonates and infants in order to optimize surgical outcomes.

Complications of perioperative hypothermia

Perioperative hypothermia in neonates and infants can ultimately lead to serious complications across multiple systems, as reported in [Table 1](#).

Pathophysiology

Pediatric patients are particularly prone to developing perioperative hypothermia due to their unique physiological characteristics. Compared to adults, they have a larger body surface area-to-weight ratio, immature thermoregulation,

and lower thermal insulation due to reduced subcutaneous fat. As a result, they lose heat primarily through conduction and radiation. In infants, **non-shivering thermogenesis** plays a dominant role in heat production, defined as an increase in metabolic heat production regardless of associated muscle activity. Brown fat, commonly located at the nape of the neck, interscapular region, axillae, and groin and around the kidneys and adrenals, results in double heat production in children up to 2 years of age.

Heat is produced from the aerobic metabolism of body cells, with skeletal muscles and the heart being the primary sources during physical activity. At rest, heat production comes mainly from the kidneys, brain, and liver. In response to exposure to cold, the body typically increases heat production through physical activity and shivering.

Effects of anesthesia on thermoregulation**General anesthesia**

General anesthesia commonly causes hypothermia by increasing heat loss and suppressing heat production, resulting in significantly impaired thermoregulation which leads to an imbalance between heat gain and heat loss. Radiation is the most significant source of heat loss in pediatric patients (40%), followed by convection (30%), evaporation (25%), and conduction (5%).⁴ The overall physiological changes during general anesthesia include: (1) **Abolition of behavioral responses**, leaving only autonomic defenses. (2) **Expansion of the interthreshold range**, the temperature difference between the onset of vasoconstriction and the initiation of shivering, from 0.4°C

TABLE 1. Complications of perioperative hypothermia.

Systems	Complications
Respiratory system	Hypoxia, respiratory depression and apnea, decreased surfactant synthesis
Cardiovascular system	Persistent pulmonary hypertension, right-to-left shunting
Central nervous system	Additional risk factor for brain injury
Endocrine system	Impaired glucose uptake, hypoglycemia, increased noradrenaline release, and metabolic acidosis
Other	Thermal discomfort, shivering, decreased tissue perfusion leading to increased risk of surgical site infection, increased transfusion requirement, and longer length of hospital stay

to 4°C, combined with an immature thermoregulatory center in neonates and infants, increases their susceptibility to develop hypothermia during anesthesia.⁴ **(3) Reduction in vasoconstriction and shivering thresholds**, consequently, these thermoregulatory responses are triggered at higher core temperatures than usual, and may disrupt normal temperature regulation. **(4) Alteration of the sweating threshold**, most anesthetics increase the sweating threshold in a concentration-dependent manner. Conversely, midazolam tends to decrease the sweating threshold and reduces the vasoconstriction threshold.⁵ **(5) Systemic vasodilation and (6) Catecholamine reduction.** However, sufficient stress levels can still activate autonomic defenses.

Neuraxial anesthesia effects on thermoregulation

Regional anesthesia affects thermoregulation by inhibiting peripheral vasoconstriction and shivering in blocked areas below the level of the blockade³, which prevents patients from achieving a steady thermal state. Compared to general anesthesia, patients undergoing general or regional anesthesia face an equally significant risk of developing hypothermia⁶ and the combination of both anesthetic techniques results in the most heat loss.⁴

Risk factors for developing PH

(1) Age Neonates experience hypothermia significantly more often than older infants as they have an increased body surface-to-weight ratio. **(2) Lower body weight** **(3) Prematurity** **(4) Longer duration of surgery** Temperature decrease during the redistribution phase to linear phase, taking up to 3 hours before continuing steadily in the plateau phase in the next hours after induction.⁴ **(5) Lower baseline temperature** Temperature before induction of anesthesia lower than 36.5°C is known to have greater risk of perioperative hypothermia.⁴

(6) Greater blood loss⁷ and transfusion rate⁷ **(7) More fluid administered** Infusion of a volume of fluid greater than half a liter contributes to intraoperative hypothermia **(8) Lack of prewarming measures** **(9) Major surgery** Invasive procedures, i.e. major surgery, were at greater risk compared to non-invasive procedures. Some specific types of surgery are also associated with a greater risk of developing hypothermia, including bronchoscopy, burn surgery, cystoscopy, hypospadias, mastoidectomy, neurosurgery, thoracic, squint surgery, esophagoduodenoscopy, and colonoscopy.⁸ **(10) Choice of anesthesia** Patients are at an equal risk of developing hypothermia in both general anesthesia and regional anesthesia, with combined techniques accounting for the greatest heat loss. **(11) Lower operating room temperature**

Updates in monitoring sites and devices

The optimal period for perioperative temperature monitoring, together with the appropriate sites and devices, plays a key role in determining whether patients develop hypothermia or hyperthermia, which could possibly lead to serious events.

Sites

- Core temperature monitoring sites include the nasopharynx, distal esophagus, tympanic membrane, pulmonary artery, and rectum.
- The esophageal temperature has limitations, as it has been shown to increase significantly during ventilation with warmed and /or humidified respiratory gases.⁹
- For all patients 2 years and under and those at high risk for hypothermia, temperature should only be monitored via **rectal probe**, to a maximum depth of 2 cm, or by **esophageal probe or nasopharyngeal probe**.¹⁰
- Skin temperature is **not** an acceptable means of measuring temperature and should only be used in specific cases determined by the anesthesiologist.^{9,10}

TABLE 2. Active warming devices.

Active warming devices	Details
Forced air warmer	Advantages Rapid distribution of heat Easy to use Does not require direct skin contact Disposable blanket More effective than a water-circulating mattress Reduces the incidence of post-anesthetic shivering Disadvantages Loud noise Bacteria could potentially be introduced into the surgical field Still a limited supply in some specific countries Could be unsuitable for young, awake children Suggestion Should be considered only for pediatric patients with a baseline temperature below 36°C with the presence of a caregiver in the induction room
Water-circulating mattress	Requires significantly less time to warm hypothermic patients, compared with forced air warmer Inferior to both resistive heating blanket and forced air warmer
Intravenous blood-fluid warming	As effective as forced air warmers in adults Combined with the warming blankets, showed the shortest rewarming time
Overhead radiant heater	Inexpensive and effective Significantly increase insensible water loss
Resistive heating blanket	As effective as the forced air warmer Non-inferior to radiant warmer in short-term use

TABLE 3. Passive warming devices.

Passive warming devices	Details
Head caps and thermal hats	Plastic caps are more effective than cotton caps Combined with overhead warmers, can effectively reduce hypothermia in neonates
Warm blankets	Reduce conductive heat loss to the operating table Patients should be covered during sterile prep and exposed for the minimum time as necessary
Heat-moisture exchangers	Lightweight Easy-to-use Cost-effective Provide sufficient humidity to prevent tracheal damage Increase dead space Increase airway resistance results in greater inspiratory workload Increase intrinsic PEEP Limited in patients with secretions, variable minute ventilation, have large air leaks, and increased airway resistance
Warm irrigation fluids	Prevent conductive heat loss Should be warmed to 37° - 38°C, or 38°C-40°C and no more than 50°C

Abbreviation: PEEP; Positive end-expiratory pressure

- Axillary temperature is close to core temperature and appears to be an acceptable alternative to rectal/oral temperature measurements in children¹¹ possibly minimizing discomfort, potential risk of perforation¹² and can reasonably be used for most patients recovering from anesthesia. However, some studies revealed that it does not accurately represent the oral/rectal temperatures and should therefore be interpreted with caution.¹³

Timing

- Generally, if the operative time is expected to last 30 minutes or longer, the patient's temperature should be documented, and her temperature should be monitored preoperatively before induction as a baseline temperature^{8,10}, specifically, 1 hour before surgery and then every 30 minutes until the end of the surgery.^{14,15} Patients 2 years and younger and those at risk for hypothermia should have the core temperature documented every 15 minutes.¹⁰

- If the preoperative baseline temperature is below 36°C, the temperature should be checked every 15 minutes until the temperature reaches 36°C or greater.¹⁰

- *Continuous intraoperative monitoring* should be considered, especially in surgeries that exceed 60 minutes. In children at risk, they should also receive intraoperative active warming in conjunction with continuous temperature monitoring.⁸

Devices

Thermistors and Thermocouples

Both thermistors and thermocouples are temperature-sensing devices. However, thermistors are more sensitive and capable of detecting smaller temperature changes, whereas thermocouples have a wider temperature range. Both devices produce a continuous, rapid response, are sufficiently accurate for clinical use, and are inexpensive enough to be disposable. However, thermistors require calibration and may not be reproducible, and thermocouples could be too complicated.¹⁶

Infrared

Infrared thermometers offer rapid and noninvasive usage, application of the device to temporal and mid-forehead sites causes only minimal disturbance in neonates. They are most commonly used to measure temperature through the tympanic membrane or forehead, but they can be used on any part of the body surface.¹⁶ However, infrared thermometers are subject to variable accuracy as environmental factors can interfere with measurement¹, require calibration during thermometer use, and could also be expensive.¹⁶ Whether infrared

signals obtained from the tympanic membrane truly reflect core temperature remains debatable. Earphone-type infrared tympanic thermometers have been proposed for reliable, continuous intraoperative core temperature monitoring.¹⁷ However, "tympanic membrane" systems essentially measure aural canal skin temperature and often provide poor estimates of core temperature, as none of the tested devices has demonstrated sufficient accuracy or precision for perioperative use.¹⁸ This limitation may stem from the anatomical challenge of reaching the tympanic membrane.¹ In practice, probes are frequently not inserted deeply enough, resulting in measurement of the canal's skin temperature rather than the membrane's.¹⁹ Notably, current data in pediatric populations remain scarce.

Zero-Heat-Flux

Zero-heat-flux thermometers provide continuous, noninvasive, and reliable core temperature monitoring under hypothermic and normothermic conditions.²⁰ Sang et al. reported that the 3M™ SpotOn™ sensor was closely correlated with esophageal temperatures in pediatric patients and could serve as a noninvasive alternative to pulmonary catheter monitoring.²¹

Recommended warming devices and methods to prevent PH in each perioperative

Period-- based on guidelines

The physiological characteristics of children make them particularly vulnerable to heat loss and more susceptible to hypothermia. Therefore, the implementation of effective hypothermia prevention methods is crucial from preoperative care to postoperative recovery on the wards. In this section, we review and summarize guidelines from multiple studies that focused on patient temperature during the perioperative period.

Preoperative period

Before and during transport to the operating theater

During transportation, heat supply and maintenance should be provided. Premature infants should be nursed in an incubator (4) and infants less than 6 months of age should wear a hat, preferably a plastic cap. Furthermore, combining an incubator or overhead warmer with a thermal hat provides greater effectiveness.²² All patients should be kept warm with blankets and older children should be encouraged to walk to the operating theater if possible.^{4,10,15}

1. Risk stratification should be applied to all patients undergoing surgery and anesthesia in order to identify

patients at increased risk of developing hypothermia using the following criteria:

- Expected duration of the procedure of more than 1 hour
- Age of 1 year or younger

Several types of surgery in pediatric patients were found to be associated with the occurrence of PH, including angiography, arthroscopic knee repair, anterior cruciate ligament (ACL) reconstruction, bronchoscopy, burn surgery, cystoscopy, hypospadias, mastoidectomy, neurosurgery, thoracic, squint surgery, esophagoduodenoscopy, and colonoscopy.⁸

According to the National Institute for Health and Care Excellence (NICE) prevention of hypothermia in adults guideline¹⁵, these criteria could possibly be adapted in the pediatric age group and in adults. Two or more of the following should be considered high risk of developing PH;

- American Society of Anesthesiologists (ASA) grades 2 to 5
- Preoperative temperature below 36.0°C with inadequate warming (could be due to clinical urgency or emergency)
- Undergoing combined general and regional anesthesia
- Undergoing major or intermediate surgery
- At risk of cardiovascular complications

Following risk stratification, pediatric patients at risk should receive intraoperative active warming and continuous temperature monitoring.^{8,14}

2. Prewarming

Passive warming should be considered in all patients undergoing anesthesia for more than 30 minutes.¹⁴ Place a knit cap on the patient's head and place the patient in the OR warmer.

An incubator should be applied, but an active thermal mattress should only be applied if the patient's temperature is below 37°C.²³

3. Temperature monitoring

- Before transport from the ward, the axillary temperature should be taken and kept between 36.3 and 37°C.²³

• Baseline temperatures should be taken in all patients preoperatively, specifically 1 hour before surgery^{14,15}, and if the temperature is found to be below 36°C, it should be checked every 15 minutes until the patient reaches 36 degrees Celsius or greater¹⁰ then active warming measures should be initiated in the ward and continued throughout the surgical procedure.^{8,14}

Intraoperative period

Intraoperative hypothermia, primarily occurring after the induction period³, accounts for more than half of perioperative hypothermia cases. The patient's baseline temperature should be maintained above 36°C before the induction of anesthesia. If not, an active warming should be applied for at least 30 minutes before induction of anesthesia until achieving the desired temperature at above 36°C, unless there is a need to expedite surgery because of clinical urgency.^{14,15} Proper use of warming devices is also crucial, and clinicians should be trained to use the monitoring device properly and be aware of any possible chance of developing complications. Optimal operating room temperature should be maintained above 26°C, as an increase in operating room temperature by 1°C results in up to 10% reduction in heat loss.²³

Temperature monitoring

The axillary temperature should be taken immediately upon arrival, before induction of anesthesia and then every 30 minutes¹⁵, at the end of the operation, and before transport back to the NICU.²³ Additionally, *Continuous intraoperative monitoring* should only be considered in surgeries that exceed 60 minutes or in high-risk surgeries.⁸

Maintaining optimal ambient temperature

The maintenance of the ambient temperature plays a crucial role in keeping patients in an optimal temperature range. The ambient temperature in the operating room should be maintained above 23°C⁸ when the patient is not draped. Specifically, for patients aged 1 year or younger, the ambient temperature should be set at higher levels: 25°C for infants, 27°C for full-term newborns, and 29°C for premature newborns.^{8,10}

Operating room temperature should not be adjusted unless instructed by the anesthesiologist or surgeon.¹⁰ However, if the ambient temperature cannot be determined or falls below 21°C, active warming should be considered.⁸

Warming methods

- Upon arrival in the OR, the patient should be placed in the **forced air warmer** (3M™ Bair Hugger™) and set at 42 degrees Celsius.¹⁰

• A thermal mattress or warming blanket should be placed on the operating table. All irrigation fluids should be warmed and plans to minimize fluid pooling should be discussed before the start of the procedure.¹⁰

• After surgery, before removing the drapes, room temperature should be readjusted to 85°F (29.44 °C) and the patient should be placed on OR warmer or Giraffe

Omni-bed with shuttle, with a knit cap placed on the patient's head in conjunction with active warming.¹⁰

- Sultana et al. at KK Women's and Children's Hospital in Singapore demonstrated the following guidelines:

- For temperatures below 36.0°C, forced air warming will be applied.

- For temperatures between 36.0°C and 36.2°C, warm blankets will be used for children, and radiant warmers will be used for neonates and infants.

- For temperatures above 36.2°C, the patient can proceed to surgery.⁸

Postoperative period

Warming methods

- Before transfer to PACU, patients should be warmed with blankets, forced air warmers, and, if needed, radiant bed warmers for patients 8 kg or less.¹⁰

- The incubator or warmer should be plugged in immediately and then switched to baby control mode. The thermal mattress should be removed immediately, unless axillary temperature is below 36.3°C.¹⁰

- Passive warming using blankets and cotton sheets or a duvet should be provided to keep the patient comfortably warm.^{10,14,15}

- Moreover, if the patient's temperature is below 36°C, active warming using a forced-air warmer should be applied until discharging from the recovery room or until they are comfortably warm along with temperature documented at least every 30 minutes during warming.^{10,14,15}

- Ambient room temperature in the PACU should be maintained at 24°C or higher at all times.¹⁰

Temperature monitoring

- In the PACU, the patient's temperature should be recorded upon arrival, every 15 minutes, and before discharge from the unit.^{10,14,15}

- Axillary temperature should be documented immediately upon arrival at the ward or NICU, and kept between 36.3-37°C²³, if it falls below 36.3°C, or above 37°C, rectal temperature should be monitored every 30 minutes until normothermic, and incubator temperature should also be recorded.²³

- Only discharge the patient from the PACU if the patient's temperature is above 36°C.^{14,15}

Pros, Cons, Comparison and Recommendations on Warming Devices

Active warming devices

Forced air warmer (3M™ Bair Hugger™)

Forced air warmer offers various advantages. It distributes heat quickly, has disposable blankets, and does

not require direct skin contact. Compared to a **water-circulating mattress**, a **forced air warmer** was found to be more effective in preventing neonatal hypothermia during intraabdominal operations²⁴ and in reducing postanesthetic shivering.²⁵

However, the use of a forced air warmer may introduce bacteria into the surgical field, potentially increasing the risk of surgical wound infection.²⁶ However, another study reported that using a forced air warmer does not cause nosocomial infections.²⁷ Moreover, this method could be inappropriate for young, awake children; thus, it should only be considered for pediatric patients with a baseline temperature below 36°C with the presence of a caregiver in the induction room.⁸

Water-circulating mattress

A Water-filled mattress warms the patient through conduction with thermostatic control. Water-circulating systems required significantly less time to warm hypothermic patients compared to **forced-air systems**.²⁸

Intravenous blood-fluid warming

Rapid infusion of cold intravenous (I.V.) fluids could induce hypothermia; therefore, it is recommended to **apply** intravenous blood-fluid warming if not contraindicated.¹⁰ In adults, intravenous fluids (500 ml or more) and blood products should be warmed to 37°C¹⁵, but the optimal temperature is still unclear in small children. Compared to **forced air warmers**, no statistically significant differences were reported in terms of body temperature.²⁹ Furthermore, the combination of warming blankets and pre-warmed intravenous infusion showed the shortest rewarming time.³⁰

Incubators

Incubators offer effective temperature control and reduce metabolic demand as much as **heated water-filled mattresses**.³¹

Overhead radiant heaters

A radiant heater uses infrared radiation to warm the patient. Although this method appeared to be inexpensive and effective, a significant increase in insensible water loss in neonates has been reported.²³ The patient should be closely monitored for signs of overheating and burns.

Resistive heating blanket

The resistive heating blanket consists of a polymer fiber sheet that produces heat through and warms the patient through conduction. It is as effective as the **forced-air warming system** to maintain the core temperature of the patient, and both are reported to be superior to the circulating water mattress.³² The short-term use of conductive thermal mattresses is not inferior to radiant warmers to maintain body temperature.³

Passive warming devices

Head caps and thermal hats

Especially in premature and newborn infants, **plastic caps** should be considered as they are proven to be more effective to prevent heat loss, compared to **cotton caps**.³³ The combined use of **thermal hats** and **overhead warmers** was also proven to be effective in reducing perioperative hypothermia in neonatal patients.²²

Warm blankets

Simple, affordable, and effective warming blankets reduce conductive heat loss to the operating table. Patients should also be covered with warm blankets. During the sterile preparation, the patient should be exposed for the minimum necessary time.¹⁰ For infants undergoing open abdominal surgery, **waterproof draping** is also recommended.

Heat-moisture exchangers filters

Heat-moisture exchanger filters (HMEFs) are used during general anesthesia to humidify and warm inspired gases and to filtrate bacteria. These devices are lightweight, easy to use, and cost-effective. Passive humidification helps minimize body temperature loss, while active humidification can increase the core temperature.³⁴

However, HMEFs, also known as artificial noses, can increase dead space, airway resistance, and intrinsic positive end-expiratory pressure (PEEP), leading to increased breathing work, particularly in infants.³⁵

Warm irrigation fluids

Large amounts of irrigation fluids could potentially cause conductive heat loss.²³ Therefore, all intraoperative irrigation fluids should be warmed in a thermostatically controlled cabinet to 37° - 38°C²³, or 38°C to 40°C^{14,15} but should not exceed 50°C.¹⁰

After the implementation

Following their own guidelines, Sultana et al reported that the incidence of PH decreased to 213 cases out of 1,766 patients analyzed (12.1%).⁸ This rate was significantly lower compared to the findings of Pearce et al. study in 2010, which illustrated that out of 530 patients, 278 developed PH (52%).⁵

This suggests that tailored guidelines may effectively reduce the occurrence of perioperative hypothermia in neonates and infants. However, further analysis of the results and effectiveness of other guidelines is needed.

CONCLUSIONS

Perioperative hypothermia occurs in 20 to 86% of pediatric surgeries, with neonates being more than twice as likely to develop hypothermia compared to infants. Despite the availability of effective warming methods,

their unique physiological characteristics, combined with the effects of anesthetic drugs, make them particularly susceptible to temperature loss.

The guidelines emphasize the importance of preoperative risk stratification, prewarming, intraoperative warming, temperature monitoring, and maintaining an optimal ambient temperature. Early detection of hypothermia through effective temperature monitoring throughout the perioperative period is crucial. Combining warming devices and techniques is more effective than using a single method to reduce PH.

Finally, the development of local guidelines tailored to the available resources and cost effectiveness in different countries and hospitals can help prevent perioperative hypothermia and its complications, thus optimizing postoperative outcomes.

Reflective questions

1. In the context of your hospital or institution, what tailored guidelines can be implemented to effectively reduce the incidence of perioperative hypothermia in neonates and infants?
2. What is the optimal combination of anesthetic agents to minimize the risk of intraoperative hypothermia?
3. How can monitoring techniques be enhanced to detect early signs of perioperative hypothermia in neonates and infants during surgery?

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The authors declare that they have no conflicts of interest.

Author Contributions

Conceptualization and methodology : P.P., S.M. and O.C.; Visualization and writing – original draft: P.P., S.M.; Writing – review and editing : S.M. and O.C.; Supervision : S.M. and O.C. All authors have read and agreed to the final version of the manuscript.

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