Perioperative thermal-management in children

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Summary

Children are particularly vulnerable to develop perioperative hypothermia. In general, the smaller the child, the greater the sensitivity to heat loss. In newborns, hypothermia can lead to the life-threatening triad of hypoxemia, metabolic acidosis and hypoglycemia, and is associated with increased morbidity such as apnea, the need for mechanical ventilation, arrhythmia, infection, intraventricular cerebral haemorrhage, prolonged hospital stays and poor neurological outcome. Retrospective studies showed that perioperative hypothermia leads to increased surgical site infections, higher blood loss, and the need for transfusion, longer stay in the recovery room, in the intensive care unit, and overall longer hospital stay. To avoid perioperative hypothermia, it should be critically examined whether the planned procedure can be performed in the intensive care unit in premature or newborn infants, since transportation in these children is associated with an increased risk of hypothermia. The operating room temperature should be increased for pediatric surgical procedures. Heat loss before induction of anesthesia should be prevented by active prewarming. During anesthesia, active warming therapy should be applied to the body surface. If larger amounts of fluids are given, infusion warming should be used in addition. In order to recognize and treat changes in core temperature, accurate measurement of the core temperature of children is mandatory.

Introduction

Historical aspects

In the 1950s and 1960s, perioperative hypothermia was associated with undesirable side effects for the first time. In paediatric anaesthesia in particular, it was observed that **hypothermic infants** were lethargic postoperatively and exhibited **respiratory depression** [1]. In case series from this period, severe hypothermia in infants was even associated with increased perioperative mortality [2]. For this reason, the use of an electric warming blanket was first described in 1953 [3], followed by the first use of a heated water mattres in infants [4] and convective air warming systems in 1973 [5].

Definitions

The normal core body temperature (CBT) is between 36.0 °C and 37.5 °C and between 36.5 °C and 38.0 °C in children <5 years [6]. If the temperature falls below these values in the perioperative setting, this is referred to as perioperative hypothermia. A CBT <35.0 °C can be described as severe perioperative hypothermia in children.

A CBT >38 °C is defined as perioperative hyperthermia.

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Conflict of Interests

AB has served on the advisory boards of 37 Company and 3M over the past two years. He has also received fees for lectures and/or expert opinions from 3M, 37 Company and Moeck & Moeck. All other authors have no conflict of interest.

Keywords

Perioperative Hypothermia – Children – Prewarming – Forced-air Warming – Measurement of Core Temperature

Frequency of perioperative hypothermia in children

Although paediatric anaesthetists were the first to take effective measures against perioperative hypothermia, infants and children are still frequently hypothermic today. Physiological characteristics of this patient group on the one hand and inadequate perioperative thermal management on the other could be the reasons for this.

In two large retrospective studies with 6737 children [7] and 530 children [8], the occurrence of postoperative hypothermia was observed in 45 % and 52 % respectively; while other studies in premature infants, neonates and babies reported prevalence rates of > 80 % [9–12]. In contrast, it has been shown that with **appropriate perioperative thermal management,** the hypothermia rate can be less than 10 % [13–16], even in preterm infants [17]. The large discrepancy suggests that the prevalence of perioperative hypothermia depends more on the warming strategy used and less on patient factors such as age or surgical procedure. To better understand this, it is worth taking a closer look at the development of perioperative hypothermia.

Development of perioperative hypothermia

Children are particularly vulnerable to the development of perioperative hypothermia. As a general rule: the smaller the child, the greater the sensitivity to heat loss.

This is mainly due to **four physiological causes:**

- larger ratio of body surface area to weight,
- larger head in relation to the rest of the body,
- not yet fully developed thermoregulatory abilities and
- lower thermal insulation due to less developed subcutaneous fatty tissue, especially in premature and newborn infants [18,19].

Thermoregulation

As a large number of physiological processes depend on the CBT, it must be kept constant via autonomous thermoregulation mechanisms. Within a **thermoneutral environment,** the human body does not need to activate any additional mechanisms for temperature homeostasis. The range at which a thermoneutral ambient temperature is considered depends on age and accompanying factors: A newborn baby that is not yet dried and has just been born, for example, requires an ambient temperature of 32 °C; a newborn baby that is dried out, covered and lying on its mother’s stomach only needs 25 – 28 °C [20].

However, In a non-thermoneutral environment, counter-regulation measures must be taken. The primary mechanisms are sweating and peripheral vasodilation in the event of overheating, while shivering and vasoconstriction are intended to counteract cooling. As heat production through shivering is only possible to a limited extent in newborns, they are dependent on **non-shivering thermogenesis** [21].

It is important to realise that an unclothed newborn at an ambient temperature of 23 ° Celsius has about the same heat loss as an unclothed adult at 0 °C [20].

Risk factors for the development of perioperative hypothermia

Low room temperature

At room temperatures below the thermoneutral range, children quickly lose heat and develop hypothermia [18]

Age of children

The larger ratio of body surface area to weight in small children contributes to the fact that they cool down much more quickly in a cold environment, as is often the case in the operating theatre [22]. Heat loss is particularly high via the large head.

General anaesthesia

General anaesthesia considerably disturbs autonomic thermoregulation. However, with the exception of immature premature and newborn babies, there is no relevant difference to adults. In children, too, there are no signs that non-shivering thermogenesis occurs during intraoperative hypothermia [23]. The redistribution of heat from the body core to the body periphery after induction of general anaesthesia leads to a drop in the CBT, especially directly after induction of anaesthesia [24].

Caudal anaesthesia in addition to general anaesthesia appears to have little effect on thermoregulatory vasoconstriction [25].

Additional risk factors

In addition to the anatomical-physiological causes, there are other risk factors:

- Interventions in the operating theatre instead of in the neonatal intensive care unit [26]
- Interventions in the cardiac catheterisation laboratory [27] or e. g. during magnetic resonance imaging
- Failure to perform adequate CBT-monitoring
- Low initial temperature [8,28]
- Type and duration of a procedure[8,28]
- High blood loss and need for transfusion [8,28]

A further risk factor could be that due to a lack of routine in the performance of paediatric anaesthesia, attention is not focused on the child’s body temperature, so that CBT measurement and timely thermal management take a back seat.

Complications due to hypothermia in newborns

Important findings on hypothermia-related complications originate from neonatology. Cold stress can trigger several physiological processes, such as catecholaminergic response, reduced surfactant synthesis, vasoconstriction and increased metabolism.

Hypothermia can lead to the life-threatening triad of hypoxaemia, metabolic acidosis and hypoglycaemia in neonates (Fig. 1) [29] and is associated with increased morbidity such as apnoea, ventilator dependency, arrhythmia, infection, intraventricular cerebral haemorrhage, prolonged hospitalisation and poorer neurological outcome [30,31].

There are only a few studies on the influence of perioperative hypothermia in premature and newborn infants. Morehouse et al. observed significantly more respiratory complications [26]. Hypothermic premature and newborn infants also received six times more measures to stabilise the heat balance, required cardio-circulatory support five times more frequently and were three times more likely to require ventilation.

Complications due to perioperative hypothermia in infants and children

There is also little data on hypothermia-related side effects in infants and older children. It is known from studies in **adults** that perioperative hypothermia is associated with disorders such as

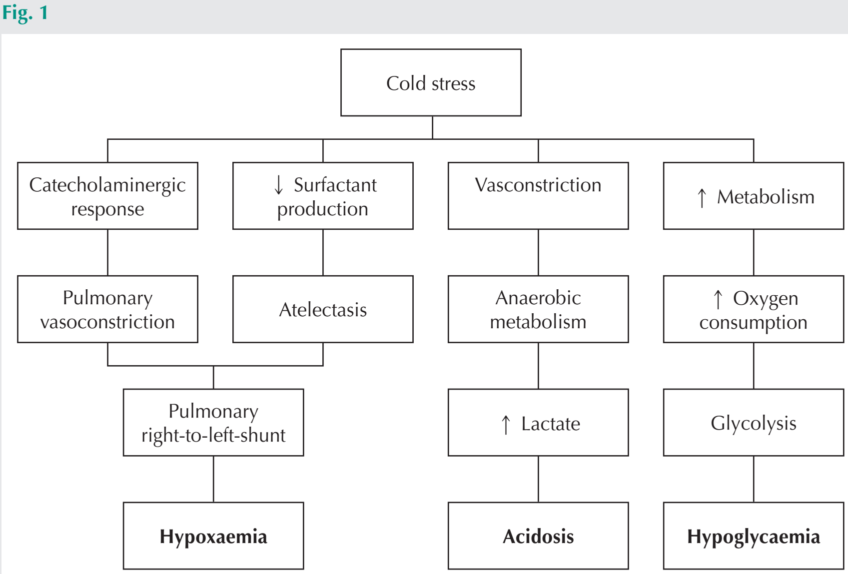
- coagulopathy,
- increased need for transfusion
- cardiac complications,
- increased wound infections and
- prolonged duration of action of drugs (especially muscle relaxants).

In addition, hypothermia postoperatively results in reduced thermal comfort, prolonged postoperative recovery time and longer hospitalisation [32].

Even if it is assumed that many hypothermia-associated complications also occur in a similar way in **children**, there are only a few, mostly retrospective studies for these age groups. These show:

- increased wound dehiscence [7]
- more wound infections [11]
- higher blood loss and transfusion requirements [11,33]
- prolonged stay in the recovery room [11]
- more frequent admission to the intensive care unit [11]
- longer post-operative ventilation in the intensive care unit [11]
- longer stay in the intensive care unit [11]
- longer hospitalisation [11]

Fig. 1



Pathophysiological mechanisms and resulting side effects caused by cold stress in premature- and newborn (according to [29]).

Prevention of hypothermia

Attention must be paid to the special challenges of children from an **organisational point of view.** As it is not possible to set **an elevated operating theatre temperature** in every operating theatre, these procedures must take place in specially selected and equipped operating theatres. It should be borne in mind that warming up an operating theatre can take up to 60 minutes, depending on the technical equipment [34]. Short-term rescheduling can therefore lead to inadequately low operating theatre temperatures. In addition, a timely announced, delay-free transport of the child from the ward or intensive care unit to the operating theatre must be organised. Furthermore, these operating theatres must be equipped with warming devices or warming blankets specially designed for paediatric patients.

Thermal management before anaesthesia induction

Thermal management during transport

Transports to the operating theatre are one of the causes of the development and worsening of hypothermia in premature and newborn infants [35,36].

Particularly in this sensitive patient group, the indication for transport to the operating theatre should be assessed individually, as many surgical and interventional procedures can also be performed in the intensive care unit (Fig. 2) [26]. If these transports cannot be avoided, they must be carefully planned and prepared. As external environmental factors such as draughty corridors, the setting of the central air conditioning system or longer distances can hardly be influenced by the transport team providing care, a **combination of heat supply and heat maintenance** should be provided for the transport.

A transport in an incubator or heated bed is ideal for the smallest chil-

Fig. 2

Surgical intervention in the intensive care unit.

dren. The integrated temperature control and radiant heat ensure temperature stability (Fig. 3).

Premature babies, newborns and small children in particular should be dressed and given a head covering before transport. Plastic or synthetic caps have proven to be more effective than cotton caps in terms of heat retention [37].

Prolonged positioning or repositioning can quickly lead to cooling and should be avoided. Care should be taken to ensure that exposed parts of the body are consistently covered.

Continuous CBT measurement is also required during transport. In this way, a dangerous loss of heat can be recognised at an early stage and intervened in good time. The creation of an interdisciplinary checklist or procedural instructions for the transport of premature and newborn babies and critically ill children can reduce the occurrence of complications such as hypothermia [36].

Room temperature

The operating theatre room temperature should be raised for paediatric anaesthesia. High operating room temperatures have been shown to be effective in reducing the initial drop in core temperature after induction of anaesthesia [34,38] and help to prevent hypothermia [18]. An increase in room temperature to 32 °C is considered appropriate for neonates, while room temperatures above 24 °C are recommended for infants [6].

In addition to the increased room temperature, it is extremely important to start **active warming therapy** before anaesthesia is induced. The easiest way to do this is to place the child on a preheated convective blanket. Only then is the child undressed as far as necessary and unnecessarily exposed body surfaces covered again. In this way, heat loss can be minimised as far as possible (Fig. 4).

Prewarming

In adults, **active prewarming** of at least 10 minutes is recommended [6] in order to reduce the redistribution of heat from the warm body core to the colder periphery [39]. In children, the mass of the body core (head and trunk) is significantly greater in relation to the body periphery (arms and legs) than in adults. Therefore, less heat is redistributed to the periphery after induction of anaesthesia in children than in adults. On the other hand, smaller children cool down much faster due to convective heat loss, which can be minimised by prewarming and insulation. From a physiological point of view, it is therefore more a case of active heat therapy to prevent cooling before induction of anaesthesia than active prewarming to reduce heat distribution. From a practical point of view, however, it is the same measure.

Intraoperative thermal management

Active warming therapy via the body surface

Intraoperatively, it is essential to continue active warming therapy. Although the low ratio of weight to body surface area means that children cool down more quickly in a cold environment, they can also be (re)warmed more quickly than adults if convective air warmers are used [22,40,41]. It is therefore generally easier to protect children from perioperative hypothermia [40–42]. **Conductive warming devices,** e. g. in the form of electrically heated mattres, are rarely used in children [43,44]. This is because it is difficult to establish good contact between the surface of the warming system and the skin over a large area in children. However, this is absolutely necessary for a conductive warming system to be efficient [45]. **Modern radiant warmers** can also be used for premature or newborn babies.

When using active warming therapy, it is important that it is carried out as continuously as possible. Interrupt-

Fig. 3

Transport of an infant in a heated bed.

Fig. 4

Induction of anesthesia in a newborn.

ing convective air warming unnecessarily increases the risk of intraoperative hypothermia.

This risk increases the longer the warming therapy is interrupted [46]. The question of whether convective air warming should be continued during positioning and disinfection of the surgical site repeatedly leads to discussions within the treatment team. To date, there is no evidence that active warming therapy during positioning and draping increases the risk of infection [47].

Insulation, heating of irrigation solutions and breathing gas conditioning

The parts of the body surface that cannot be actively warmed should be insulated to reduce heat loss. Irrigation solutions used intraoperatively should be warmed to body temperature. For example, irrigation solutions used in urogenital laser surgery or intraventricular lavage in paediatric neurosurgery can be warmed well with **infusion warmers.** Active or passive **airway humidification** reduces heat loss from the airways. This appears to be somewhat more important in small children than in adults, as small children have a higher respiratory minute volume per kilogram of body weight [48].

Infusion warmers

An intraoperative basic infusion of 10 ml/kg/h is considered the standard in paediatric anaesthesia [49]. This would correspond to an infusion rate of around 700 to 1000 ml/h in adults. At such high infusion rates, the guidelines for adults recommend the consistent use of infusion warming [6]. Nevertheless, low hypothermia rates are achieved in children even without the use of infusion warming for the basic infusion [15,16,42]. The continuous heat loss through the basic infusion can usually be compensated for by warming the body surface using convective air warming.

If large infusion volumes and blood products have to be used, infusion

solutions and blood products should also be warmed with a blood and fluid warmer in children [50].

In contrast to adults, the absolute infusion rates (in ml/h) are relatively low in children. Therefore, from the heat exchanger of the infusion warmer the system should be as short as possible in order to prevent relevant heat losses of the infusion on the way from the heat exchanger to the vein.

Infusion warmers that can release aluminium into the infusion solution should no longer be used under any circumstances, as aluminium is toxic [51]. These devices have now been withdrawn from the market.

Measuring core body temperature

In order for temperature changes to be recognised and treated, an accurate measurement of the body's core temperature is required [52].

An **ideal temperature monitoring**

- measures accurately,
- is practicable,
- non-invasive,
- allows continuous measurement over the entire perioperative period and
- is tolerable for all age groups and procedures such as monitored-care anaesthesia, procedural sedation or regional anaesthesia alone [29].

Recently investigated sensors based on (zero) heat flux technology, which potentially fulfil all these requirements, still reveal weaknesses that need to be considered [15,16,53]. Therefore – and due to the high costs of these methods – proven (semi-) invasive measurement methods are usually used. In children, this is most frequently done by **oro- and nasopharyngeal as well as rectal measurements** [54]. In general, these measurement procedures rarely cause relevant problems [29]. However, there are individual case reports of critical mispositioning and entrapment of probes [55]. The nasopharynx in particular is a reliable localisation for measuring CBT [56]. However, standardised recommendations for the insertion depth of nasopharyngeal temperature probes in children based on age [57] or height [58] have only recently become available. Both recommendations aim to place the end of the temperature probe at the point in the upper nasopharynx closest to the internal carotid artery.

Oesophageal measurements also accurately reflect the CBT [59] if the end of the temperature probe is placed in the lower third of the oesophagus between the left atrium of the heart and the descending aorta [60]. There is then no risk of influence from potentially cooling airways [61]. The S3 guideline also recommends rectal measurement in children up to the age of two [6], which, however, lags significantly behind more rapid changes in the CBT.

Although **infrared measurement of body temperature** via the ear canal is very widespread and popular, it is often inaccurate due to the anatomy of the ear canal, as usually only the cutaneous surface temperature of the ear canal is recorded instead of that of the tympanic membrane [52]. **Axillary and enoral measurements** are not accurate enough. Vesical measurement (after insertion of a bladder catheter with integrated thermistor), only reflects the CBT with a time delay, particularly in the case of rapid temperature changes. Peripheral body sites are unsuitable for perioperative monitoring of the CBT [52].

Thermal management in the recovery room

As with adults, extubation should not be performed if children are significantly hypothermic. In this case, they should be rewarmed while still under anaesthesia. Safe temperature limits at which anaesthesia can be terminated are not known [6]. After the anaesthetic has been withdrawn, each child should return to a **pre-warmed bed.**

On admission to the recovery room, the CBT should be measured in order to detect hypothermia that has developed after the end of continuous measurement in the operating theatre during transport to the recovery room. If possible, a non-invasive method should be used for this purpose. If the child is hypothermic, active **rewarming** using convective air warming should be performed before the child leaves the recovery room.

Apart from neonates, children who are clearly hypothermic postoperatively also exhibit thermoregulatory **shivering** just like adults [62]. In addition to postoperative warming therapy, this sometimes also requires drug therapy with **clonidine.** Alternatively, the anti-shivering effect of nalbuphine can be utilised [63]. Although such drug therapy is an "off-label use" of these substances, but studies have described it as effective and with few side effects [64].

Risks of active warming therapy

General considerations

Perioperative heat therapy is generally very safe, and the benefits greatly outweigh the few adverse events that can occur with active warming therapy.

Risks of convective air warming

Burns

Burns are the most feared complication. Convective air warming is an extremely safe procedure with approximately 15 to 25 million applications per year and only about one reported case of burns per year [65]. The most common cause is the unauthorised use of a convective air warmer without an associated warming blanket [66].

However, cases of burns have also been published where a suitable warming blanket was properly connected to the device. In this case, burns can occur if the blower's nozzle is in direct contact with the skin [67], as the nozzle is one of the hottest parts of the appliance. Critically reduced tissue perfusion can also predispose to this [68].

Kinking of endotracheal tubes

When using convective air warming, endotracheal tubes can soften and kink, leading to ventilation problems if this is not recognised in time [69].

Noise

Convective air warmers can generate noise of up to 84 dB [70], which can disturb the concentration of operating theatre staff. However, this is usually not a real problem.

Risks of conductive warming therapy

There is also a **low risk of burns** with conductive warming. The first reports of fatal burns with conductive warmers date back to the 1960s [71], in which children suffered extensive third-degree burns [72]. In principle, there is also a risk of burns with today's systems.

Especially the combination of pressure and heat in particular can increase the risk of burns.

Risks of infusion warmers

Risks of burns

If the heated fluids are considerably too hot, infusion warming can also lead to burns and thrombosis [73]. In addition, contact of the infusion warmer line with the skin can also lead to burns [74].

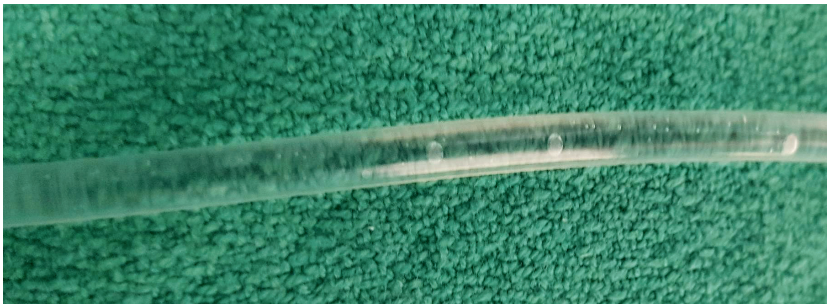
Risks of infection and haemolysis

Infusion warmers that use water as a heat exchange medium can harbour a risk of infectious complications. In some cases, more than 100,000 colonies of gram-negative bacteria have been detected in the water of these infusion warmers. If leaks occur in such infusion warmers, the sterile infusion fluid may mix with the bacterially contaminated warming fluid. This can lead to bacteraemia, electrolyte disturbances and haemolysis [75].

Air embolism

A fundamental problem with warming infusion solutions is that the solubility of gases in liquids or blood decreases as the temperature rises, which leads to the formation of nitrogenous bubbles. These gas bubbles can practically always be seen when infusion warmers are used (Fig. 5). These bubbles are normally trapped in the pulmonary circulation and are not associated with clinical problems, even in children. However, there is also the possibility that air emboli may occur in the brain or other organs in children with **congenital heart defects** who have a right-to-left shunt under certain haemodynamic constellations (e. g. patent foramen ovale, atrial or ventricular septal defects, transposition of the great arteries, tetralogy of Fallot).

Fig. 5



Gas bubbles in an infusion system after warming of fluid solutions.

It must be emphasised that outgassing during the heating of cold liquids is a process that always occurs when these liquids are heated and is not a problem with infusion warmers per se. If no infusion warmer is used, this process takes place in the blood.

Development of perioperative hyperthermia

Perioperative temperature increases have various causes. Pathophysiologically, a distinction can be made between **fever and hyperthermia:** Whilst fever is a regulated increase in CBT, hyperthermia is caused by an imbalance between heat production and loss. Infections and sepsis are the main causes of fever and frequently occurring reasons for perioperative temperature rises, but other causes should also be considered, especially if the cause is unclear. These include, among others

- Poisoning and toxins,
- Blood in the ventricular system,
- Withdrawal of medication,
- Serotonin syndrome or malignant neuroleptic syndrome,
- Thyrotoxic crisis or
- Transfusion reactions.

Malignant hyperthermia can also manifest itself in an increase in temperature [76]. Another common cause is iatrogenic perioperative hyperthermia due to **excessive or prolonged application of heat** [41,77]. This can result from an overly aggressive warming strategy with the aim of avoiding intraoperative hypothermia at all costs or from a too late reduction in the temperature setting of the convective air warming system [40]. According to a recent survey, iatrogenic perioperative hyperthermia is even more common than perioperative hypothermia [54].

Hyperthermia can lead to thermal discomfort and **increased metabolism, including increased oxygen demand,** and is associated with **increased wound infections** [78]. Younger children are particularly at risk [41,77]. The peak appears to be between the 2nd and 3rd year of life, which is presumably due to the imbalance between heat production and loss in relation to the ratio of body surface area to weight [41]. Infants, on the other hand, probably cool down too quickly to become hyperthermic with the same thermal regime. Higher initial body temperatures and more prolonged interventions have been identified as further risk factors. Perioperative hyperthermia can easily occur, especially in procedures with extensive coverage and relatively small surgical areas, such as oral and maxillofacial surgery [77] or hypospadias correction [41].

Avoiding hyperthermia

Iatrogenic perioperative hyperthermia due to excessive heat supply does not occur suddenly, but develops gradually [41]. In order to recognise this development, **continuous monitoring of the CBT** is required. This allows timely anticipation of changes in CBT towards hyperthermia, which can usually be prevented by early adaptation of the temperature settings. **Clearly defined alarm limits** for the CBT on the monitor are helpful for this [77]. Due to the gradual development of iatrogenic perioperative hyperthermia and the lingering effect of the counter-reaction, these may well be set more narrowly than 36 and 38 °C. Dynamically adjusted alarm limits could prove favourable. There are currently no evidence-based recommendations as to which settings the active heat supply should be adapted to when the temperature trend increases. Presumably, lower temperature settings could be applied at a higher initial temperature than is often practised. However, increased vigilance is probably sufficient to prevent the development of intraoperative hyperthermia.

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