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Hypothermia during Surgery-How to Prevent It

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

I. INTRODUCTION

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

THERMOREGULATION DURING ANESTHESIA AND SURGERY

Hypothermia is generally defined as a core temperature lower than 35 °C and it can be divided into mild (< 35 °C, ≥ 32 °C), moderate (< 32 °C, ≥ 28 °C), severe (< 28 °C, ≥ 20 °C), profound (< 20 °C, ≥ 14 °C) and deep (< 14 °C) based on the value of core temperature. But the criteria for hypothermia is different for trauma patients to increase the detection rate. Hypothermia in trauma is classified into mild (< 36 °C, ≥ 34 °C), moderate (< 34 °C, ≥ 32 °C), severe (< 32 °C) [12]. In the perioperative settings, hypothermia is generally considered as lower than 36 °C because the core body temperature lower than 36 °C but higher than 35 °C was sufficient to induce undesired adverse effects. Therefore, in most of the perioperative studies, a core body temperature lower than 36 °C was considered as hypothermia requiring warming intervention [13, 14].

It has been concluded that body temperature is controlled by three levels, temperature sensation, activity in the central nervous system and peripheral effector [15, 16]. The thermoreceptor, composed mainly by transient receptor potential (TRP) family proteins [17], can be activated by heat or cold, and the afferent thermal signals can be transduced through the superficial laminae of the spinal dorsal horn, lateral parabrachial nucleus, and finally reach the thermoregulatory center, the preoptic area of the hypothalamus [18], where the core temperature will be centrally controlled. The thermoeffector will be evoked by the thermoregulatory center, in a negative feedback manner, to accommodate the body to the temperature changes in the environment, including volitional and autonomic responses. The volitional responses include posture changes, clothing, movement, and even using the air conditioners, and the autonomic responses include activation of brown fat, sweating, vasodilation, vasoconstriction and shivering [19]. The activation of brown adipocytes may contribute to long-term thermogenesis and it has been seldom discussed in perioperative hypothermia. The autonomic responses are transmitted through the raphe pallidus, rostral ventrolateral medulla, or rostral ventromedial medulla. Then sympathetic regulation of brown adipose tissue, vessels and sweat gland is activated through the interomediolateral column of spinal cord, and the shivering is regulated through the ventral horn of spinal cord [20, 21].

Several factors may induce hypothermia during the perioperative period. The most apparent factor for hypothermia is the relatively cold environment in the operating room, especially in those with laminar flow [22]. The direct exposure of the skin and incision to the cold air and cold disinfectant is another factor increasing the heat loss. The large amount of cold intravenous fluid, irrigation fluid and even inhalational gas may increase the heat loss by conduction. But other than these physical factors, anesthesia itself is a crucial factor to induce hypothermia. First, different general anesthetics, including both volatile and intravenous, are inhibitory to the thermoregulatory center and can decrease the thermal threshold in a concentration dependent manner. The vasoconstriction threshold can be reduced to 34.5 °C under general anesthesia. Second, shivering can be inhibited or diminished by anesthetics, especially by neuromuscular blockade agents. Third, thermoreceptor can be directly inhibited by volatile anesthetics. Fourth, afferent signals of cold and efferent signals of vasoconstriction and shivering can be blocked by neuraxial blockade [23]. Even the thermoregulatory center has been also be reported to be inhibited by neuraxial blockade, although the mechanism remains unclear [24].

Intraoperative hypothermia can be divided into three stages, including redistribution stage, linear stage and plateau stage [14, 25]. In the redistribution stage, hypothermia occurs rapidly after induction of general anesthesia or neuraxial anesthesia because the responses of vasoconstriction are inhibited by anesthesia. The heat in the core compartment of the body redistributed into the peripheral compartment with the dilation of vessels, where the temperature was normally 2–4 °C lower than in the core compartment. Therefore, the total heat loss may not be significant shortly after anesthesia induction, but the core temperature is diluted and reduced rapidly. In the linear stage, the body temperature is reduced gradually because of the gradient between thermogenesis and heat loss. Heat is produced mainly by energy metabolism, which is reduced by 15%–40% by general anesthetics, while heat loss is increased by radiation, conduction, convection, and evaporation, mainly induced by the increased exposure of skin and incision. The plateau stage usually occurs at 2–4 h after anesthesia and surgery, when the core temperature is maintained at a relatively stable level, at about 34.5 °C. The homeostasis is maintained by a new balance of heat generation and loss. Although the thermoregulatory threshold can be reduced by general anesthesia, the vasoconstriction capacity is not fully diminished and the arterio-venous shunt can be completely shut down when hypothermia happens. Thus, the heat can be well retained in the core compartment to maintain a plateau temperature. But the plateau stage may not be present in neuraxial anesthesia, because after neuraxial blockade, the vasoconstriction and shivering cannot be induced in the lower limbs, which play a more important role in maintaining body temperature than the upper limbs. Therefore, hypothermia will be more severe when general anesthesia is combined with neuraxial blockade [26]. The Fig. 1 shows a summarizing diagram how anesthesia affects the occurrence of intraoperative hypothermia.

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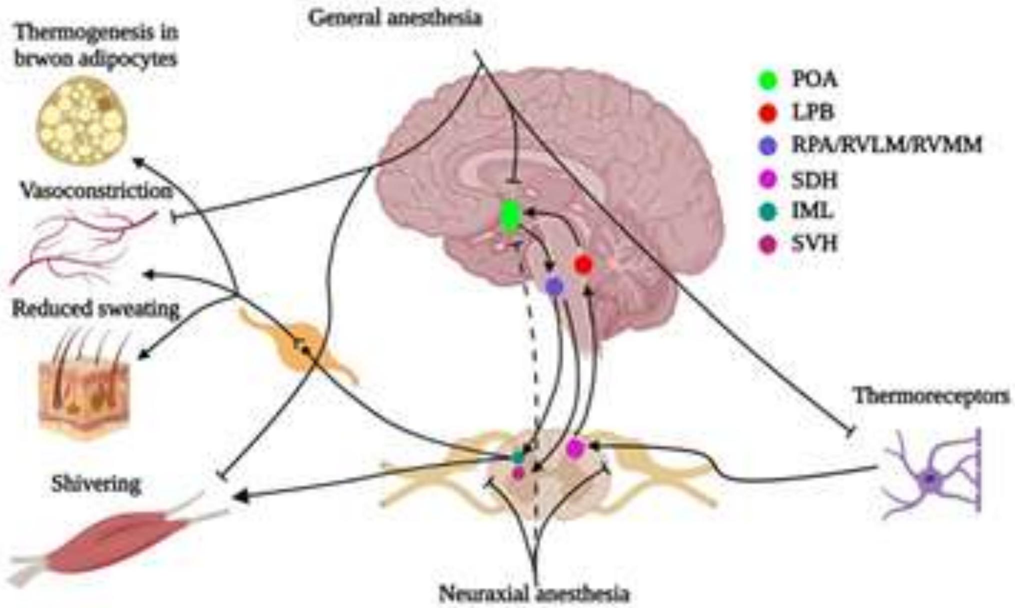

Fig. 1 The thermoregulatory mechanism and the mechanism of intraoperative hypothermia facilitated by anesthesia. Hypothermia sensed by thermoreceptors can be transmitted to the thermoregulatory center (POA of hypothalamus) by afferent signaling through SDH and LPB. Efferent signaling can be transmitted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

INCIDENCE AND RISK FACTORS FOR PERIOPERATIVE HYPOTHERMIA :

The issue of inadvertent perioperative hypothermia has been proposed for more than 30 years and the incidence varied greatly in different surgeries and different population, with disparity in the degree of emphasis on this issue. The incidence of inadvertent hypothermia ranged from 12% to 81%. The lowest incidence of hypothermia occurred in a patients undergoing total knee or hip arthroplasty, in which routine forced air warming was applied [4]. But in another retrospective study performed in total knee or hip arthroplasty without routinely-used active warming strategy showed an incidence of 37% [27]. The highest incidence of 81% happened in a neonate study [5]. The highest incidence of hypothermia in the adults appeared in a study including patients undergoing mixed types of surgeries under general anesthesia, with an incidence of 79% [28]. It was discouraging to notice that the incidence of hypothermia remained higher than 50% despite of the routine use of active warming devices in 6 studies [5, 29–32, 33], among which 1 was performed in neonates [5].

The risk factors for hypothermia identified by different studies also varied remarkably because of the great discrepancies in the population involved. But among the risk factors identified in the publications with original data, advanced age was considered as a risk factor in 12 studies. The second most frequent risk factor is body mass index (BMI), which was reported in 9 studies, and weight was reported in 2 studies. Duration of anesthesia or surgery was identified as a risk for hypothermia in 10 studies. Preoperative core temperature was reported in 8 studies, and pre-existing hypothermia before anesthesia was considered as a risk factor. Large amount of fluid or blood product administered was reported in 7 studies. Active warming measures was reported to be associated with lower incidence of intraoperative hypothermia in 6 studies. Surgery type or grade was reported in 6 studies, and compared with endoscopy surgery, open surgery was a risk factor for hypothermia according to 3 studies. Ambient temperature in the operating room was reported in 4 studies and another study showed that laminar airflow operating room was associated with hypothermia, which might be also due to the low ambient temperature or increased convection induced by laminar airflow. Preoperative blood pressure and heart rate were reported in 3 studies, and comorbidities including coronary heart disease, arrhythmia, lung impairment, diabetes, other chronic disease status or a high grade of American Society of Anesthesiologists (ASA) physical status were reported as risk factors in 4 other studies. Male gender was correlated with hypothermia in 3 studies. Combination of general anesthesia and epidural anesthesia or paravertebral anesthesia was reported to be associated with hypothermia in 2 studies, but hypo-thermia was more common in general anesthesia when compared with neuraxial anesthesia alone in 1 study. For pediatric patients, neonates or infants were associated with hypothermia, and the gestational week of neonates were a determinant for intraoperative hypothermia. The meta-analysis of risk factors further demonstrated the association of intraoperative hypothermia with age, BMI, ambient temperature, preoperative systolic blood pressure, preoperative heart rate, duration of anesthesia, and intravenous fluid administration > 1,000 mL, but the significant heterogeneity might hinder our interpretation of the results [34].

Understanding these risk factors for intraoperative hypothermia might be useful in screening patients with high risk of hypothermia during surgery and with high demand of active warming treatment. Yi et al. [21] established a risk prediction scoring system for intraoperative hypothermia, involving the risk factors in two of their independent studies including magnitude of surgery, BMI, amount of intravenous fluid administered, duration of anesthesia, mode of warming intervention, baseline core temperature, and ambient temperature in the operating room.

CHANGES INDUCED BY ANAESTHESIA AND SURGERY

All three periods of the perioperative setting (pre-, intra-, and post-anaesthetic period) influence the core temperature. Thus, proper temperature management starts with the patient still on the ward.

Pre-Anaesthetic Period:

Patients with a pre-existing low core temperature before arriving in the operating room are at higher risk for remaining hypothermic intraand postoperatively [35]. Risk factors for a pre-existing low core temperature include older age [36], low body mass index [37], and diseases, such as diabetic neuropathy [38], paraplegia, or severe hypothyroidism [39]. Emergency patients, e.g., with multiple trauma, are often accidentally hypothermic (<35 ˚C) on hospital admission [40,41].

Several medications can influence core temperature. For instance, antipsychotic drugs (both first and second generation) can reduce temperature [42], while antidepressants (in particular, tricyclic antidepressants) increase core temperature [43]. In particular, drugs used for preoperative anxiolysis can influence core temperature. Benzodiazepines can decrease core temperature in a concentration-dependent matter [44,45] similar to clonidine [46] and opioids [47]. Anticholinergics oppose the drop in core temperature associated with benzodiazepines [48].

During transport from the ward to the operating room, patients usually wear hospital gowns and are often covered with only a thin blanket. During this transport, heat loss can be considerable. Patients may activate thermoregulatory cutaneous vasoconstriction to maintain normal core temperature. This exposure to cold may lead to clinically relevant cooling of peripheral body regions and a temperature gradient between the core and the periphery. Induction of anaesthesia reduces the threshold for autonomic thermoregulatory responses and induces vasodilatation, which will result in the redistribution of heat from the core to the periphery of the body, thereby causing perioperative hypothermia.

Intra-Anaesthetic Period:

Hypothermia during the intra-anaesthetic period develops with a characteristic pattern and can be subdivided into three phases: redistribution, linear, and plateau [49].

Redistribution of heat is the main cause of perioperative hypothermia after induction of anaesthesia, but the reduced heat generation contributes to a further decrease in core temperature. Independently of the type of anaesthesia, anaesthetics impair the autonomic thermoregulatory control because they reduce vasoconstriction and shivering thresholds.

Hypnotic drugs for general anaesthesia inhibit the thermoregulatory system. The hypothalamus and the spinal cord are affected by volatile anaesthetics primarily in a nonlinear, concentration-dependent manner [50]. Propofol reduces core temperature in a linear, concentration-dependent way [51]. Opioids attenuate thermoregulation concentrationdependently, too, but differ in the incidence of postoperative shivering [52]. Ketamine seems to have the least influence on thermoregulation because it maintains the peripheral vascular tone and therefore limits the magnitude of blood redistribution [53]. Muscle relaxants do not pass the blood–brain barrier and therefore have no effect on thermoregulation. Drugs used for anaesthesia decrease the thermoregulatory vasoconstriction threshold in a concentration-dependent manner to around 34.5 ˚C [54].

The extent of temperature drop during heat redistribution from the core to the periphery after induction of general anaesthesia depends on several factors. Body morphology and the haemodynamic status of the patient play a role. For instance, redistribution is faster with higher cardiac output or peripheral vasodilatation. The most important factor is the temperature of the periphery before anaesthesia induction. The lower the temperature gradient between the core and the periphery, the lower the redistribution of heat and the lower the drop in core temperature. Leaner, smaller patients with higher blood loss cool more strongly and more quickly [55].

About an hour after induction of anaesthesia, the temperature decrease slows down and becomes more linear. While redistribution is less important in this phase, heat loss by radiation and convection prevail. Metabolic rate is reduced by about one-third that of baseline [49].

This linear phase of core temperature drop lasts about two hours and ends when the threshold of autonomous thermoregulation is reached at around 34.5 ˚C. The degree of the shift in the threshold for thermoregulatory defence mechanisms depends on the concentration of the anaesthetic agents administered. Vasoconstriction can subsequently be (re-)activated and transforms the thermal state of the body into a plateau phase. If the patient is actively warmed, core temperature may rise again [56]. However, further phases of redistribution can occur, e.g., after opening an arterial cross-clamp or a tourniquet.

In contrast to general anaesthesia, neuraxial anaesthesia does not impair heat production but likewise causes heat redistribution by vasodilatation in the caudad part of the body and impairs thermoregulation at the level of the spinal cord [57]. On the one hand, a patient is exposed to the cold when bare skinned for the administration of neuraxial anaesthesia. This lowers the body temperature before surgery and therefore activates the physiologic thermoregulatory vasoconstriction. On the other hand, the administered drugs prevent most of the neural activity of the caudad body and lead to a redistribution of blood similar to that in general anaesthesia. Due to its more rapid onset, hypothermia occurs more quickly in spinal than in epidural anaesthesia [58]. Furthermore, the extent of hypothermia is directly dependent on the height of the blockade [59]. A combination of neuraxial and general anaesthesia potentiates the risk of perioperative hypothermia by overlapping the effects of redistribution and vasodilatation [60]. It is assumed that extended peripheral nerve blocks, for example, of both lower limbs, will have a similar sized effect on the redistribution of heat.

Drugs commonly used for sedation have the same effect as those used in general anaesthesia. However, the concentration dependency explains the lesser effect on thermoregulation and body temperature with lower doses of sedatives. The effect of dexmedetomidine on the thermoregulatory thresholds is comparable to that of propofol [61].

In addition to the anaesthetic procedures, surgery itself has its own effects on the risk for perioperative hypothermia. First, as the temperature of the environment is key for mammals to maintain their body temperature, the temperature of the operating room should not fall below 21 ˚C [62]. The relationship between cutaneous heat loss and room temperature is linear [39]. Second, preparation with disinfection of large areas may lower the skin temperature. Third, large, exposed operating sites contribute to heat loss. Fourth, the insufflation of cold gases, e.g., for laparoscopy or the administration of cold irrigation fluids, e.g., for transurethral prostatic resection, can significantly lower the body temperature [63]. Fifth, deflation of tourniquets leads to a second redistribution [64]. In summary, a team approach between surgery and anaesthesia to minimise pauses in active warming therapy and to minimize loss of heat through the explained mechanisms is absolutely imperative. This applies not only for the direct effects as described but also for the indirect effects of surgery, such as the administration of intravenous fluids for substitution of fluid losses if they are inadequately warmed [65].

Post-Anaesthetic Period:

Thermal discomfort and shivering are common complaints of patients in the postanaesthetic phase. This underlines the importance of continuing optimal thermal management also after surgery.

ADVERSE OUTCOME ASSOCIATED WITH INTRAOPERATIVE HYPOTHERMIA:

Normal temperature is a principal element of cellular activity, and hypothermia may inhibit cell metabolism, and reduce the consumption of glucose and oxygen. Therefore, therapeutic hypothermia has been widely used in treating cardiac arrest and cerebral ischemia diseases, although several studies failed to observe any benefits on survival after cardiac arrest [66, 67]. However, the clinical situation of perioperative patients is totally different from those with cardiovascular ischemia, and mild inadvertent perioperative hypothermia is associated with more adverse events than benefits on reduced cellular metabolism. The most definite event induced by perioperative hypothermia should be the shivering in awake patients or anesthetized patients at recovery period. Shivering is an unpleasant involuntary oscillatory muscular activity, which is also an important determinant for the satisfaction of patients [68]. Moreover, shivering will increase the oxygen demand and work of breath. Perioperative imbalance between oxygen supply and consumption in myocardium may be induced, and finally lead to cardiovascular complications [69]. Immune system is also affected by hypothermia, which has been demonstrated to inhibit HLA-DR expression in monocytes. The capacity of migration and phagocytosis in leukocyte can be compromised in hypothermic conditions [70, 71]. The poor perfusion of surgical site may also delay the recovery of anastomosis and incision, which may increase the risk of contamination. Thus, the risk of postoperative infection may increase in patients with perioperative hypothermia. Hypothermia can induce coagulopathy, with dysfunctional platelets and reduced activity of coagulation factors. It has been reported that even a reduction of 1 °C in body temperature will increase the bleeding amount by about 20% [7, 72]. The activity of multiple enzymes will be inhibited by hypothermia, including those in charge of drug metabolism, so that the clearance of anesthetics may be delayed and the recovery from anesthesia may be prolonged [73]. Hypothermia will also induce vasoconstriction, which is important in reducing heat loss and maintaining the body temperature. Vasoconstriction during hypothermia may be harmful to cardiovascular system, increasing the risks of myocardial ischemia and arrhythmia [74]. Other potential effects of perioperative hypothermia include the disturbance of electrolytes and delayed recovery of gastrointestinal function [75, 76].

The adverse effects of perioperative hypothermia have been confirmed by many clinical trials comparing the clinical outcome when using active warming intervention or not. A meta-analysis of randomized controlled trials (RCTs) undergoing noncardiac surgery compared the postoperative pain, opioid use, surgery duration, intraoperative bleeding, total fluids administered, patient satisfaction score, postoperative shivering, perioperative blood transfusion, postoperative would infection, 24 h major adverse cardiovascular events and 3-month mortality [77]. It was demonstrated that active warming intervention increased body temperature by 0.28 (0.2–0.35), 0.38 (0.27–0.49), 0.8 (0.59–1.01), 1.07 (0.86–1.28), 0.87 (0.62–1.11), and 0.34 (0.19–0.49) °C at 30 min, 60 min, 2 h after anesthesia induction, the end of surgery, 60 min and 4 h after surgery, respectively. The elevation of perioperative temperature was associated with a reduction by 80%, 36%, 66% and 79% in the incidences of postoperative shivering, blood transfusion, wound infection and 24 h major adverse cardiovascular events. The patient satisfaction was also enhanced by active warming interventions. Another Cochrane meta-analysis found similar results that active body surface warming reduced the incidence of postoperative surgical site infection, shivering and improve the patient satisfaction [78]. But in this study, the estimated blood loss and intravenous fluid administered was reduced by warming treatment, but not the amount of transfusion.

There are also some observational studies suggesting that intraoperative hypothermia is associated with prolonged length of hospitalization, arrhythmia, increased amount of estimated blood loss, intravenous fluid administered, and 30-day re-admission [79]. Some retrospective studies even suggested that unintended perioperative hypothermia was correlated with postoperative delirium [80]. However, a recent large-scale, multicenter, international RCT, compared an aggressive intraoperative warming intervention and routine management strategy, failed to find any difference of outcome when maintaining a body temperature of 37 °C or 35.5 °C, including cardiovascular events such as myocardial injury after noncardiac surgery, non-fatal cardiac arrest, mortality, and surgical site infection, transfusion requirement and hospital readmission [81]. Therefore, the clinical impact of intraoperative hypothermia might be determined by the severity degree of hypothermia.

INTRAOPERATIVE MONITORING OF BODY TEMPERATURE :

The NICE guideline recommends that the body temperature should be monitored before anesthesia, every 30 min during surgery, at the end of surgery and arrival at the recovery room, and every 15 min in the recovery room. The patients who should be monitored for temperature include those with general anesthesia longer than 30 min and those undergoing major surgery under neuraxial anesthesia [11]. The site of temperature monitoring is more important than the devices. Core temperature has been considered to be the target temperature that we aimed to maintain during surgery, and multiple sites have been used for temperature monitoring during surgery, including pulmonary artery, distal esophagus, nasopharynx with the probe inserted 10–20 cm, and tympanic membrane. Other sites include sublingual area, axilla, bladder, rectum and lateral forehead. Noninvasive forehead temperature monitoring (such as 3 M™ Bair Hugger™ device) has been demonstrated to be comparable to other core temperature monitoring approach, such as tympanic membrane [82], blood, bladder [83], esoph-agus, or rectum [84], and may be clinically convenient because this monitoring method is noninvasive and continuous. Trachea temperature monitoring, using a probe embedded into the cuff of the trachea intubation, has been also evaluated, but the result remains to be controversial [85–87].

ACTIVE WARMING :

After being exposed to cold ambient air in the preoperative period, nearly all patients arrive in the operating room with peripheral vasoconstriction and cold peripheral tissues. Thermoregulation keeps the core of the body warm in most of these patients. However, a small percentage of the patients are already hypothermic on arrival in the operating room [88–90]. Active prewarming may rewarm the cold periphery of a patient, thus reducing redistribution of heat after induction of anaesthesia and reducing the initial drop in core temperature after induction of anaesthesia. To realize the maximal benefit from active prewarming, the following points are helpful:

- Start active prewarming as soon as possible [91]. In daily practice, the time available for prewarming is very limited. Most hospitals do not accept time delays that are avoidable because the time in the operating room is so expensive [92]. This means that active prewarming must be commenced immediately after greeting the patient. All other activities before inducing anaesthesia can be performed alongside warming. This includes sign in, monitoring the patient, and inserting intravenous, arterial, or epidural catheters. The time needed for these essential activities is also the time that is available for active prewarming [93]. Dedicated holding areas are helpful in improving the perioperative work-flow. Properly designed, these holding areas can also be cost-effective.
- Do not skip active prewarming to save time. Do not skip prewarming because there is not much time for prewarming. Ten minutes of active prewarming can have a huge effect and can make a big difference in the incidence of hypothermia [94].
- Use a warming blanket. In general, the same warming blanket should be used for active prewarming and intraoperative warming. There is no need to pay for two different warming blankets. While intraoperative warming therapy is possible with many different blankets, it is advisable to use a blanket that covers the largest part of the body surface that would otherwise be exposed to the cold. The result is the largest change in the thermal balance and the highest efficacy [93]. If a small upper-body cover is used, it can be placed lengthwise on the patient for prewarming and be placed over the legs while a thoracic epidural catheter is inserted.
- Use the highest temperature setting recommended by the manufacturer. The heat transfer generated by forced-air warming blankets depends on several factors. One factor is the mean temperature gradient between the warming blanket and the skin [95]. There is no rationale for reducing this temperature gradient and reducing the efficacy of forced-air warming by using lower temperatures than recommended.

Active Warming during Anaesthesia:

During induction of anaesthesia, active warming should be continued. There is no need to stop warming for intubation or placement of arterial or central venous lines or gastric tubes. Only when inserting a bladder catheter does the blanket have to be put aside for a few minutes. There is also no need to stop active warming during washing and draping, as there is no evidence that this might increase the risk of infection [96]. Nevertheless, there is clear evidence that long interruption times in active warming therapy increase the risk for hypothermia. It also makes sense to insulate the parts of the body surface that cannot be actively warmed because insulation can reduce heat loss by 30% [97,98].

Infusion Warming:

In general, infusion warming is less important than warming of the body surface. It makes sense to use an infusion warmer only when large amounts fluids are expected to be used. If an infusion warming device is used, it should be used from the start of the procedure. A short tubing after the heat exchanger of the infusion warmer or placement of the tubing under the forced-air warming blanket prevents the fluid from cooling again while it gets from the heat exchanger to the patient.

If infusion warming devices are not available, the use of prewarmed infusions from a warming cabinet is also possible and effective [99].

Further Possibilities:

Although this approach permits the hypothermia rate to be reduced dramatically, some patients will still develop hypothermia. This may be due to long positioning times with the use of an extension table or because the body surface available for active warming is not large enough to achieve a good heat balance. Additional measures are possible and helpful to diminish this rate further in these high-risk patients:

- Use a second forced-air warming blanket, for example, to warm the patient's legs in addition to the upper body.
- Use an additional heating blanket under the patient's back.
- Use extended prewarming.

Other options, like the use of water mattress garments or intravascular heat exchanging catheters, are also possible and very effective but extremely expensive [100].

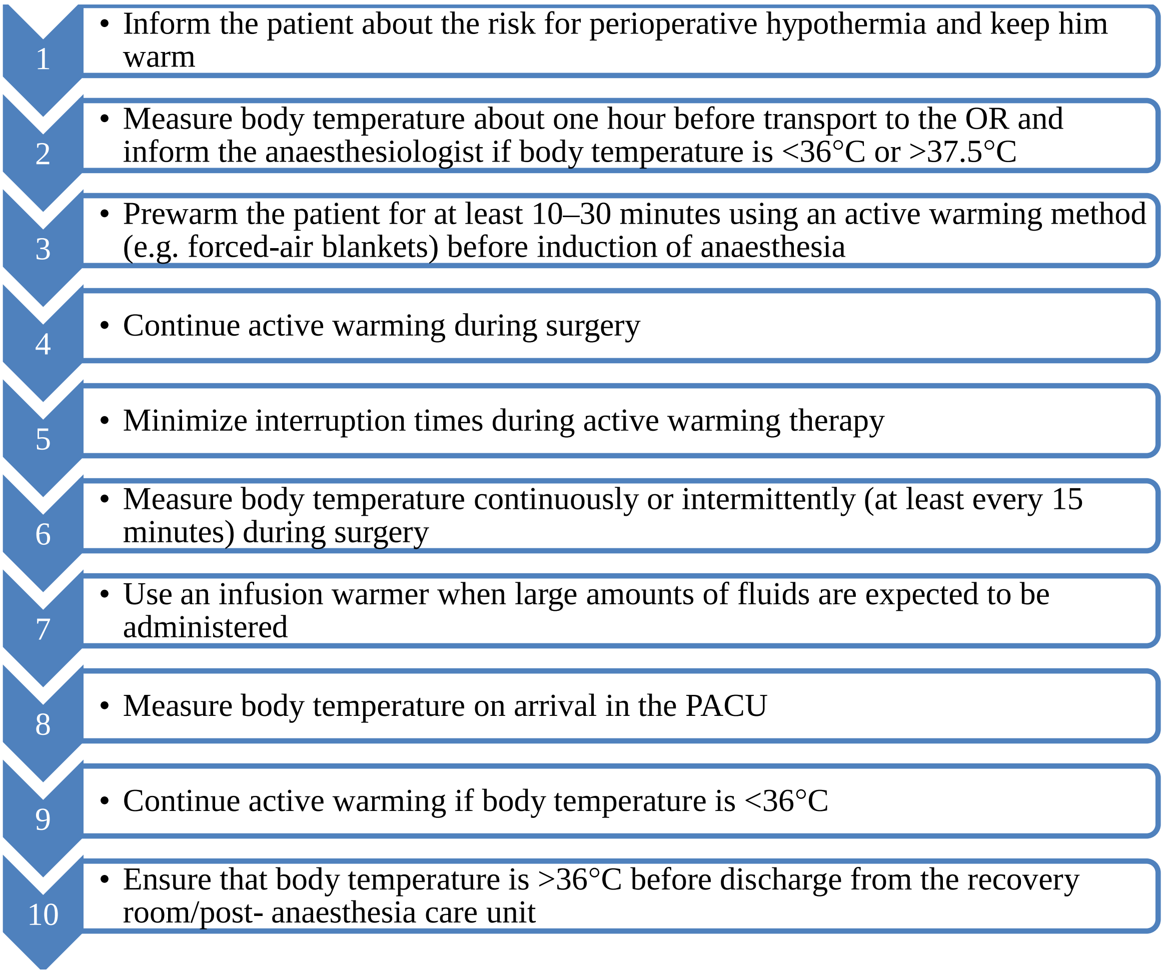

Fig. 2. Ten essential points to prevent perioperative hypothermia for surgery lasting >30 min.

II. CONCLUSION

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

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