Methods to prevent intraoperative hypothermia

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Abstract
Inadvertent intraoperative hypothermia is by far the most commonly occurring anaesthesia-related complication. It can increase the risk of unfavourable events perioperatively. Higher rates of surgical site infections and blood transfusions, coagulation and drug metabolism disturbances are said to be the most relevant issues linked to this phenomenon. Although they have been available for several years now, dedicated systems designed to prevent it are still not part of routine anaesthesia conducted in Poland. This review aims to discuss the factors which may potentially increase the risk of hypothermia, and to present tools that are readily available and effective in perioperative temperature management

Key words: thermoregulation, disorders; anaesthesia, complications, intraoperative hypothermia; intraoperative hypothermia, prevention

Intraoperative hypothermia, defined as a core body temperature lower than 36°C, can develop in over half of all anaesthetic procedures and is associated with an increased incidence of perioperative complications. This disorder of homeostasis increases the risk of coronary incidents, increases the incidence rates of surgical site infections, causes clotting disturbances and prolongs the action of the drugs used during anaesthesia [1–3]. The loss of normothermia during surgery results from several factors, such as the use of drugs that impair thermoregulation, the low temperature of the operating room and disinfection of the operative field.

With increased awareness of the essence and magnitude of perioperative hypothermia, methods of its prevention have aroused widespread interest. It is no longer sufficient to ask whether hypothermia should be prevented; the question has become how to prevent hypothermia. Hypothermia should be prevented most effectively, considering the efficacy and cost-effectiveness of the measures used, as the maintenance of core body temperatures above 36°C becomes one of the standards of perioperative care [4].

The human body exchanges heat with the environment by radiation (60%) as well as conduction, conversion and vapourisation. The excessive loss of heat via each of the above-mentioned methods is unfavourable and should be eliminated. There are various methods to treat and prevent hypothermia, which can be generally divided into active and passive methods (Fig. 1). Passive prevention of hypothermia involves a reduction in heat loss using “surgical drapes” (un-heated) to isolate the patient’s body from the surroundings, i.e., the trunk, limbs and head, and the placement of a heat and humidity exchanger in the respiratory system of the anaesthesia machine. Active methods include methods to supply additional heat from the outside, which together

Figure 1. Hypothermia prevention methods
with endogenous production aim to equalise heat loss. The combination of several methods, which eliminates several mechanisms leading to hypothermia, is the most effective practice used.

TEMPERATURE OF THE OPERATING ROOM

Conditions in the operating room should be comfortable for all members of the team but mostly for the patients. The setting should ensure comfort before the induction of anaesthesia and should not be the factor increasing the risk of complications during surgery and anaesthesia. Thanks to the availability of air-conditioned rooms, hence the possibility to provide complete control of air temperature and humidity, precise action can be taken. The optimal temperature of the operating room is difficult to define, mainly due to clashing needs of several groups. Surgeons opt for one optimum range of temperature, whereas anaesthesiologists or scrub nurses are in favour of some other range. The opinions regarding physical conditions in the operating room have repeatedly changed since 1924, when some started to advocate that traditional, warm and humid operating rooms should be abandoned. In the days before the introduction of widespread sterilisation, it was generally believed that warmer surroundings decreased the risk of sepsis and pneumonia and should be provided despite the inconveniences experienced by those involved. [5]. In the 1950s and 1960s, with the development of surgical and anaesthetic techniques, the attitude towards the operating room conditions during surgeries was reversed. The notion of ergonomics as well as the comfort and effectiveness of work became increasingly popular; therefore, the search for optimal conditions inevitably focused on a compromise between the surgeon’s comfort and patient’s cooling. Despite substantial differences in the range of temperatures desired for the general population depending on the geographical location, the range of temperatures desirable for operating room teams appear to be globally similar: 21–24°C in the United States and 18–21°C in Great Britain [6]. However, these data do not mean that individual medical specialities prefer the same range of comfort; according to the British study performed in the 1960s, anaesthesiologists explicitly preferred significantly higher temperatures (by over 1°C) than surgeons from the same operating room, whereas the remaining personnel chose ranges between those extremes. The operating room, however, remains the place where the desired temperature oscillates approximately 20°C. This temperature is far from the comfort range for patients who are deprived of suitable clothes before the induction of anaesthesia. Making provisions for the increased comfort of patients in the preoperative period is another difficult task for anaesthetic personnel [7].

PASSIVE METHODS OF HYPOTHERMIA PREVENTION

There are two basic types of thermally isolating coverings: mass coverings, isolating due to the arrest of air between the fibres of the material of which the covering was made, and reflecting coverings, which decrease the heat loss via radiation by re-reflection of heat radiation to the warmer surface (body), allowing only slight dispersion. In clinical practice, mass isolators include surgical drapes and prefabricated surgical coverings. Air is an excellent physical isolator; therefore, the larger the amount of air the covering can hold, the better the thermal isolation. The air between fibres directly affects the quality of isolation, whereas the type of fibre seems of no importance [8]. Moreover, the fact that a single-layer covering markedly reduces heat loss (by 33%) can be relevant; the use of additional layers results in only slightly better results (additional 18% with three layers) [9], which is undoubtedly attributable to air arrest between the skin and the covering.

Considering the operating room temperature, the loss of energy in the form of heat through exposed skin is always substantial; the greater the difference in the skin and surrounding temperatures, the bigger the loss [10]. The covering of the skin reduces this loss, largely via decreased radiation and convection. The initial phase of core temperature decrease during anaesthesia results from its redistribution to the peripheral compartment, whereas the loss through the skin and airways remains constant (the heat reserves of the body do not change). In the initial phase of hypothermia, thermal isolation of integuments only slightly affects the development of hypothermia and therefore is not capable of preventing it. During the next phase of temperature decrease associated with excessive loss and reduced production of heat, prevention of excessive heat transfer to the surroundings is essential attaining the thermal plateau. The initial heat loss through the skin is approximately 100 W during the first hour of anaesthesia, which can be reduced to approximately 70 W when the entire surface is covered [8]. Because approximately 70 W are produced by the mechanically ventilated patient and because heat loss through the loss through the surgical field is only approximately 5 W, theoretically, isolation methods should be sufficient to achieve thermal equilibrium [11]. Unfortunately, proper covering of the suitable body surface is typically infeasible, and the loss through the airway reaches 50% of the total heat losses [12]. Therefore, passive methods are insufficient to maintain normothermia.

ACTIVE METHODS OF HYPOTHERMIA PREVENTION

Thanks to the development of modern surgical and anaesthetic techniques, long procedures lasting many hours can be performed but are associated with difficulties in
maintaining homeostasis when it becomes necessary to support or replace the protective mechanisms abolished by anaesthesia. With respect to temperature, it is easier to prevent temperature changes than to treat undesirable changes; an elevation in the core temperature of the patient already cooled to the normal value under post-anaesthesia in a surveillance room setting is considerably more difficult than the prevention of its decrease in the operating room. The ineffectiveness of warming the body surface at this stage likely results from the isolation of the peripheral compartment due to shrinkage of the peripheral vessels [8, 13]. However, prevention of hypothermia is relatively effective, assuming that suitable devices are available and properly used [14, 15].

The patient’s heat reserve decreases during surgery, predominantly via the loss through the skin, the expenditure of energy used for vapourisation from the surgical site and for the warming of transfused intravenous fluids, and through the airway (albeit to a minimum extent). Because the surgical site cannot be altered, hypothermia can be effectively prevented only by the prevention of heat loss through the skin and by transfusion of pre-warmed fluids. The passive methods described above reduce the heat loss yet do not eliminate it. Only the elimination or reversal of the gradient of temperatures between the skin and its direct surroundings and the use of warmed infusion fluids can inhibit the heat escape or even enable its supply to the body.

WARMING OF INFUSION FLUIDS

The unfavourable effects of infusions of intravenous fluids cooler than the patient’s body temperature were reported in the 1960s. A decrease in core temperature by 0.5 to 1.0°C was observed after transfusion of 500 mL of cold blood, and massive transfusions were found to be associated with marked hypothermia and a high risk of sudden cardiac arrest (SCA) [16, 17]. In a 1964 study, transfusions of more than 3000 mL of cold blood at a rate of 50–100 mL min⁻¹ resulted in cardiac arrest in 12 out of 25 cases; transfusion of the same volume of warmed blood led to SCA in 8 out of 118 cases [18]. Since that time, the attitude to therapy with fluids and blood preparations has substantially changed, which is visible in the guidelines published and periodically updated; however, the physical properties of these drugs and transfusion-induced thermoregulation disturbances can persist in modern times [19, 20]. It is possible to estimate energy expenditures related to the supply of cold fluids. To increase the temperature of 1 kg of water by 1°C, 1 kcal of energy is needed (the heat capacity of water is 1 kcal); thus, the body needs 16 kcal of energy to “warm” 1 litre of crystalloids from room temperature (21°C) to body temperature (37°C) (assuming that their heat capacity equals that of water). Based on the above data, to warm 3.7 litres of crystalloids from room temperature, the anaesthetised patient’s body has to use the energy it produces during one hour of anaesthesia using substitutive ventilation (approximately 60 kcal h⁻¹ ~ 70 W). The transfusion of 1 litre of full blood at 4°C requires approximately 30 kcal of energy for warming; the transfusion of 2 litres is likely to decrease the core temperature by 1–1.5°C [21]. The available systems of warming blood, blood preparations and transfusion fluids use various technological solutions, e.g., a water bath (Hotline, Smiths Medical), forced-air warming (Bair Hugger, 3 M, USA), conductive warming with metal surfaces (enFlow, GE Healthcare, USA) or microwave technology (MMS ThermoStat, Meridian Medical Systems, USA). Most of the systems provide a wide range of temperatures in a marked range of flow velocities and include devices preventing excessive warming and air-detection. A relevant issue is the upper limit of temperature to which blood preparations and infusion fluids can be warmed. Based on numerous observations related to extracorporeal circulation, temperatures of 42°C are safe for blood preparations [22]. Polish legal regulations allow the warming of blood solely in the device designed for this purpose with suitable systems for measuring temperature and alarm systems; however, the safe limit of temperatures has not been defined. The directive of the Minister of Health nm September 19, 2005 recommended blood warming in cases of transfusions of more than 50 mL min⁻¹ in adults and 15 mL min⁻¹ in children, in cases of exchange transfusions in newborns and in recipients with clinically significant cold antibodies [23]. The desirable temperature of crystalloids and colloids should depend on the clinical situation; there are, however, reports about the safe supply of crystalloids of 54°C [24].

FORCED-AIR WARMING SYSTEMS

Active prevention of intraoperative hypothermia using warmed air has been used for several decades. Such systems were initially used postoperatively (to treat hypothermia); gradually, these systems began to be used in operating rooms (to actively prevent hypothermia) and preoperatively (to reduce the risk of hypothermia) [25]. The systems operate by forcing warmed air through the warming device to the container, which is in direct contact with the patient’s skin, (usually a two-layer blanket). The blanket shape is tailored to the needs, i.e., it contacts the largest possible surface of the body, depending on the patient’s position and location of the operative field. The air forced inside escapes through the pores of blanket fabric, forming a specific, warm microclimate around the individual being warmed. The lack or reversal of the temperature gradient between the environment (warming blanket) and the skin inhibits heat loss through radiation as well as overheating. Additionally, there is no loss through convection. The extent of heat
transfer predominantly depends on the surface of contact with the patient’s skin [26]; the small thermal capacity of the carrier (air) is the limiting factor and necessitates its quick exchange. Considering the operating conditions, a duvet enabling warming of the upper body is most frequently used intraoperatively; pre- and postoperatively, the systems warming the largest possible surface of the body can be used. The effectiveness of these systems also depends on the gradient of temperatures between the blanket and skin surface. The higher the gradient in favour of the warming blanket (air warmer than the skin), the bigger the heat flow to the body surface is. The systems based on this technology have been and continue to be the basic methods of perioperative hypothermia prevention; therefore, numerous studies have assessed their efficacy and safety. The findings demonstrate their satisfactory efficacy in preventing intraoperative hypothermia once several conditions are met. The choice of a properly shaped warming blanket, its appropriate placement and the use of a suitably high warming temperature are not always sufficient. An important factor is the initial warming of the patient before induction, which substantially reduces the redistribution-induced decrease in core temperature [27]. The effectiveness of the hypothermia-prevention system is markedly lower when used after the induction of anaesthesia [28-30]. Over the past 20 years, the warm airflow systems have been used in over 100 million cases and remain the most readily chosen systems in Western Europe.

**MATTRESSES AND ELECTRIC BLANKETS**

An alternative for forced-air warming systems are systems using electric resistance for heat production. These systems belong to the group of devices whose effectiveness is based on conduction. Therefore, the systems are sufficiently effective only when the warm surface directly contacts the surface to be warmed, as opposed to warm airflow systems, in which a heat carrier leaves the warming blanket and delivers heat to the body surface. The physical elements in favour of such devices include the following: the small heat capacity of air requires a continuous supply of warmed air to maintain its pre-set temperature, whereas the material used as a heat carrier in electric mattresses and blankets warms and cools more slowly. Moreover, these conduction systems operate noiselessly, which for many working in operating rooms is the key argument weighing in favour of electric systems compared with forced-air warming systems (even modern warming devices emit noise at a level of 45–50 decibels). It should be stressed that the use of electric mattresses alone is not recommended, as the loss through the body surface contacting the operating table is negligible, and the amount of heat that can be supplied using such mattresses low [26, 31, 32]. To prevent intraoperative hypothermia effectively by reducing the loss and supplying heat from the outside, it is necessary to secure the largest possible surface through which the body can potentially loose heat. Therefore, the electric systems presently produced include warming blankets of various shapes made of carbon fibre or polymers. The forms of the blankets are adjusted to surgical needs. The study findings regarding their efficacy vary from poor efficacy in earlier studies [33] to efficacies comparable with those of forced-air warming systems in recent studies [15, 31, 34–36]. The economic implications associated with their use are complex. On the one hand, the systems can be used any number of times; on the other hand, variants of high efficacy are extremely expensive.

**WATER MATTRESSES AND COVERS**

The idea of a heat carrier in continuous motion in the warming system is also used when water is used as a carrier. Mattresses filled with warm water have been applied for many years, but their use is associated with numerous technical problems, and their efficacy in preventing hypothermia is found to be low. However, because both warm and cold fluids can be used for their filling, these mattresses have found application in special situations when the body temperature is reduced intentionally (Intensive Cardiac Care Units, cardiac surgery) [37]. Because water has a markedly higher heat capacity than air, it can be potentially assumed that when water circulates in the warming system, the amount of heat supplied can be large. The only condition is the provision of direct contact with the largest possible skin surface; thus, specially shaped covers filled with warm water were designed in which the limbs and intraoperatively available trunk parts are wrapped (Energy Transfer Pads, Kimberly Clark, USA; Allon ThermoWrap, MTRE Advanced Technologies, Israel). Such a system was found to be more effective than forced-air and electric systems [38–40] (particularly in extensive procedures in which the peritoneal cavity is opened) yet comparable to the combined use of force-air warming systems and the water mattress [41]. Unfortunately, the factor limiting the widespread application of the system is its price and technical problems related to its use — large dimensions and potentially extremely troublesome consequences of malfunction during use.

**SUMMARY**

Perioperative hypothermia is only one of a number of potential problems perioperative medicine has to face but is nonetheless critically important. The available study findings and guidelines provide some instructions useful in the prevention of hypothermia:

— Active methods of hypothermia prevention should be used in surgeries longer than 30 min.
— Warming should be applied before the induction of anesthesia.
— In long procedures and in high-risk patients, heat loss should be prevented with more than one active method.

The use of several systems of hypothermia prevention during one surgery is neither time-consuming nor troublesome; in the majority of cases, it is also not excessively costly. Thus, there is hope that their routine use is only a matter of time.

References:

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