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Prevention and treatment of unintentional perioperative hypothermia

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Abstract

Human body central temperature is an important monitored value for anesthesiology and intensive care practice. Present anesthetic agents influence on the central temperature regulation and lead to its decrease in the perioperative period. Inadvertent perioperative hypothermia accompanies various surgeries with general and regional anaesthesia. It considerably increases the risk of cardiac and infectious postoperative complications, and against its background blood loss and necessity for blood transfusions also increase. Patients with hypothermia wake up slower and the postoperative shivering may often occur. Perioperative hypothermia increases the length of hospital stay and the nosocomial mortality. In this regard, prevention of inadvertent perioperative hypothermia is an important part of anaesthesia assistance in all fields of surgery. Maintenance of normal temperature during the surgery is an important component of all programs of patient's early postoperative activation.

Keywords: hypothermia, perioperative warming, temperature.

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As a rule, surgical interventions are performed in operating rooms with an adjustable air conditioning system that maintains a cool ambient temperature to create comfortable working conditions for the operating team. In addition, surgical interventions are accompanied by the infusion of cold solutions and evaporation from open surfaces. Physiologically, these factors usually do not lead to hypothermia in the patient. On the contrary, the mechanisms of thermoregulation should effectively maintain the central temperature of the body constant under the influence of stress factors.

The development of hypothermia in the intraoperative period is primarily due to a failure in the proper functioning thermoregulatory mechanisms, which are affected by both general and local anesthetics. Thus, understanding the special aspects of the influence of anesthetics on the existing mechanisms of thermoregulation is the key to solving the problem of perioperative temperature fluctuations, because it is the direct action of anesthetics (much more so than the cold in the surgery room) that causes most of the temperature problems that occur in surgical patients.

The problem of perioperative hypothermia is extremely widespread. According to S. Moola et al., between 25% and 90% of patients who underwent planned surgeries suffer from unintentional perioperative hypothermia (UPH), that is, a decrease in the central body temperature of less than 36°C [1]. The Russian data concerning this problem are not presented in medical periodicals. Unfortunately, physician awareness of UPH and the importance of its elimination and prevention remain inadequate.

Interesting data were published by authors from Turkey, who conducted a survey of 1380—anesthesiologists who participated in the national congress in 2012. The authors note the sufficient knowledge of physicians regarding the problem of thermoregulation in the perioperative period and knowledge of its potential solutions; they emphasize the need to create a national guide on perioperative thermoregulation [2]. In the Russian Federation, the orders of the Ministry of Health №919n and №915n regulate the presence of thermostabilizing mattresses for surgery rooms, intensive care units, and convective-type systems for surgery rooms [3, 4].

The concept of temperature and its distribution in the human body. Temperature (from Latin *temperatura*—proper mixing, normal state) is a physical quantity characterizing

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a thermodynamic system and quantitatively expressing an intuitive concept of the varying degrees of the heating of bodies.

Living beings are able to perceive sensations of heat and cold directly, with the help of the sense organs. However, with an accurate determination of the temperature, it is necessary to measure it objectively using devices. Such devices are called thermometers and measure the so-called empirical temperature.

To date, it is well known that the central temperature depends on the biorhythms that vary depending on the time of day and season. Metabolism of the whole organism through the production of heat contributes to the maintenance of body temperature and depends on physical activity and hormone levels. In this regard, the normal body temperature differential can be determined to be between 36.0°C and 37.5°C [5]. It follows that the central temperature of 36.0°C should be regarded as a hypothermia threshold, which corresponds to the data set forth in international guidelines.

Body temperature is not uniform: usually, the temperature in the depth of the thoracic and abdominal cavities, as well as in the central nervous system (the so-called central temperature), is 2°C–4°C above the temperature of the limbs; the temperature of most of the skin surface is even lower. Unlike the central temperature, the permanence of which is strictly maintained, skin temperature alters significantly with changes in the environment. The temperature of peripheral tissues (mainly limbs) depends on the temperature of the environment, on the value of the central temperature, and on the thermoregulatory vasomotor reactions. The central temperature, although it cannot in any way be a comprehensive characteristic of the content and distribution of heat in the body, serves as a reliable indicator of the temperature status of the human body.

As early as 1860, a therapist from Leipzig named Karl Wunderlich used a mercury thermometer and established a paradigm for the average normal body temperature of 37°C, based on measurements of axillary temperature in thousands of patients [6]. The pioneer of body temperature measurement in anesthesiology, as an element of intraoperative monitoring, was the distinguished American neurosurgeon and anesthesiologist Harvey Cushing, who performed the first temperature measurement during anesthesia in 1895 [7]. In anesthesiological practice, body temperature is still one of the most important routinely monitored parameters; indeed, it was Wunderlich who suggested using temperature monitoring to control the course of disease.

Temperature measuring devices. Localization of the places of measurement of the central temperature in the perioperative period. Mercury thermometers are slow and cumbersome. As such, their use is rather limited in anesthesia practice, and in fact, they are only practical during the postoperative period. In addition, spilled mercury is toxic, which greatly limits the use of mercury thermometers. Despite these disadvantages, mercury thermometers are the standard for calibrating other types of thermometers.

The most common types of electronic thermometers are thermistors and thermocouples. Thermistors are semiconductors that are sensitive to temperature changes; thermocouples are based on the appearance of a very weak electric current between two different connected metals. Both types of devices are accurate enough for the purposes of clinical practice and are inexpensive enough to be disposable. However, the signals received from these types of thermometers are naturally nonlinear, so they must be linearized with the use of calibrated compensating devices.

Another popular type of thermometer is an infrared sensor, which works by registering the infrared radiation emitted by all surfaces that have a temperature above absolute zero. The registration of infrared radiation from the tympanic membrane actually corresponds to the indications of the central temperature [8]. However, when measuring the temperature of the tympanic membrane by infrared sensors, in addition to the temperature of the membrane itself, the sensor can record both the temperature of the skin of the ear canal. And, in case of tortuosity of the ear canal, it is not possible to visualize the tympanic membrane. These results have a wide variation, such as a deviation by 1°C–2°C from the central temperature, and also depend on the person who is conducting the measurement. With standard use, that is, when targeting the ear canal or the temporal artery, the infrared systems are not accurate enough for the needs of clinical practice [9, 10]. Taking into account the described disadvantages, it is difficult to understand their popularity.

All of the above sensors have one important disadvantage, which is the level of invasiveness necessary for measuring the central temperature of the body. In this study(?), attempts were made to create non-invasive sensors measuring the central temperature. The zero-heat-flux technology is based on measuring the temperature of tissues deeper than 1–2 cm from the skin surface. In well-vascularized areas, such as the forehead region, this technology can reliably and continuously record the central temperature [11].

The essence of the technique consists of connecting the heater and the thermal flow sensor (which in fact can be represented as two thermometers separated by a known thermal insulator). The heater is driven by the servodrive to the state when the flow becomes zero. At this point, the temperature of the sensor and the temperature of the skin must be the same; otherwise, there would be a flow of heat outside. According to the same logic, at that moment, there is no flow of heat from the surface of the skin to deeper tissues; otherwise, the heat would accumulate, which contradicts the second law of thermodynamics. Unfortunately, these temperature sensors are still not available in Russia.

The oral cavity is another, less invasive optimal location for measuring temperature. Usually, patients are asked to keep the thermometer under the tongue, which is not feasible during surgical intervention. Also, mucosal inflammation, air circulation, and feedings can affect the measurement results. A prolonged continuous measurement of the temperature in this region is not possible [12].

Direct measurement of temperature of the tympanic membrane is possible with the use of special ear sensors with probes located at their end, directly touching the tympanic membrane and surrounded by ear isolators. However, this method can at the very least cause unpleasant sensations, pain, and in extreme cases, damage to the tympanic membrane.

To measure rectal temperature, the temperature sensor is passed through the anus into the rectum by a few centimeters. A serious disadvantage of this method lies in the delay in starting the measurement of the central temperature, which depends on the amount of contents of the ampoule. There is also the probability, though insignificant, of the perforation of the rectum. Despite many disadvantages, the measurement of rectal temperature is actually a minimally invasive method [13]. However, it is less accurate in comparison with such invasive localizations as the bladder and esophagus.

As a rule, temperature measurement in the nasopharynx is possible only in sedated patients. The sensor is inserted through the nostrils and led to the lower nasal sinus above the hard palate. Movement of the temperature sensor within 10–20 cm deep from the nostrils is considered optimal and is sufficient for accurate determination of the central temperature [14].

Temperature measurement in the esophagus is also possible only in sedated patients. The sensor should be placed in the lower third of the esophagus in the immediate vicinity of the heart. A high reliability of data obtained from the esophageal sensor is noted [15]. Thus, this method, along with the temperature measured in the pulmonary artery, is used as a reference for comparison with temperatures from other areas. Measurement of temperature in the bladder is possible with the installation of a urethral catheter with a temperature sensor located at the end of the catheter. Long-term temperature monitoring is possible in patients who require prolonged catheterization of the bladder. A number of studies indicate that increased urination can affect the accuracy of measuring central temperature [16].

The measurement of temperature in the pulmonary artery is the most accurate and is considered to be the gold standard; it is possible with the installation of a catheter such as Swan–Ganz catheter. For known reasons, the installation of this catheter is limited to cardiac surgery, which restricts the use of this method.

Methods for measuring the central temperature, the location of its measurement, and their advantages and disadvantages are presented in Table 1.

Until now, the degree of accuracy of temperature measurement necessary in clinical activity has not been clearly established. A good practical recommendation, which has proved its effectiveness in many studies, suggests considering the total measurement error (the error of the thermometer + the error of the “near-center” of the measurement site) of no more than 0.5°C as acceptable. One of the bases of this recommendation are data indicating that it is 0.5°C, which is the minimum significant change in temperature that can lead to complications associated with hypothermia [17].

Perioperative temperature measurement. The central temperature of the body is a vital factor in life support. Intraoperative measurement of the central temperature enables the detection of such abnormalities as hyperthermia and hypothermia. Intraoperative hyperthermia may result from malignant hyperthermia, excessive warming, infection, the ingress of blood into the IV ventricle of the brain and the transfusion of incompatible blood. Because the causes of hyperthermia are very serious, any perioperative hyperthermia requires diagnostic attention.

Table 1. Methods for measuring central temperature, measuring sites, and advantages and disadvantages

Localization of temperature measurement	Method	Advantages	Disadvantages
Pulmonary artery	Thermal sensor on Swan-Ganz catheter	Reference accuracy	Invasiveness of manipulation
Distal section of esophagus	Installation of thermal sensor	High accuracy	Invasiveness, the need for sedation
Nasopharynx	Installation of thermal sensor	High accuracy	Invasiveness, the need for sedation
Oral cavity (sublingually, orally)	Installation of thermal sensor	Average accuracy	Unacceptable in sedation of patients
Tympanic membrane	Infrared sensor	Non-invasiveness, accessibility	Low accuracy
	Thermal sensor	High accuracy	Invasiveness, the need for sedation
Bladder	Thermal sensor on the urethral catheter	High accuracy	Invasiveness, dependence of accuracy on the rate of urination
Rectum	Thermal sensor	Low invasiveness	Low accuracy
Axillary cavity	Thermal sensor, thermometer	Low invasiveness	Small accuracy
Forehead	Thermal sensor with technology (zero-flux)	Low invasiveness, high accuracy	High cost

Obviously, the most common type of temperature change in the perioperative period is unintentional perioperative hypothermia (UPH). For early diagnosis and the prevention of changes in the central temperature, measurements should be taken 1–2 h before the onset of anesthesia and upon arrival in the surgery room. Permanent intraoperative monitoring of central anesthesia is recommended. The periodic measurement of temperature is permissible, every 15 min intraoperatively. This means that anesthesia equipment should include devices for measuring body temperature, although modern regulations impose such requirements only for pediatric practice [18].

Epidemiological and pathophysiological aspects of perioperative hypothermia. After induction, the thermoregulatory center in the hypothalamus is adjusted to a lower temperature. There is an expansion of the temperature range, which leads to the breakdown of the normal mechanisms of thermoregulation. There is also a shutdown of vasoconstriction, as a result of which, the heat from the central regions passes into the peripheral tissues. Patient cooling is a consequence, first of all, of the redistribution of heat after the induction of anesthesia together with the release of heat (net loss of heat).

Neuroaxial anesthesia seems preferable from the point of view of heat preservation, because it does not affect the center of thermoregulation. However, the vasosympathetic dilatation resulting from the administration of local anesthetics provokes the redistribution of heat from the central part to the peripheral one. Also notable is that the additional administration of sedatives and narcotic analgesics also disrupts the central thermoregulation.

Further heat losses are similar for both general and regional anesthesia. They include four mechanisms.

1. Radiation (50%–70%).
2. Convection (loss of heat through the surrounding air flows, 20%–30%).
3. Evaporation through the skin and mucous membranes (5%–20%).
4. Conduction (loss of heat through direct contact between surfaces, 3%–5%).

Temperature equilibrium is achieved in approximately 2–3 h from the onset of anesthesia and is maintained by inclusive temperature maintenance mechanisms. However, they are no longer able to keep the central temperature around 37°C. The central temperature decreases by 2–3°C [19].

A questionnaire of anesthesiologists in Europe revealed that only 40% of all patients undergoing surgical interventions under general anesthesia were intraoperatively warmed and that intraoperative temperature measurement was performed in only 20% of cases. Among patients operated under conditions of regional anesthesia, only 20% were intraoperatively warmed, and in only 6% of cases was the temperature measured [20]. Given this, it can be said that the problem of preventing UPH is not exclusively a problem of Russian healthcare—it is a problem of the perioperative management of patients on a global scale.

Risk factors of UPH. As early as the 1950s, the English therapist George Pickering expressed the opinion that the most effective way to cool a patient is to bring the body under general anesthesia. This side effect of general or regional anesthesia is hypothermia, although the degree of its severity is determined by factors characterizing the patient, type of anesthesia, surgery, medications used, and the environment. Thus, the following factors of the increased risk of UPH occurrence were identified.

1. Elderly age (over 60 years).
2. Low nutrition, asthenia.
3. Conditions that worsen thermoregulation (diabetes mellitus in combination with polyneuropathy, hypothyroidism, intake of sedatives or psychoactive drugs).
4. Anesthetic risk according to the scale of the American Association of Anesthesiologists (ASA) higher than 1. The increase in the risk on the ASA scale is associated with an increase in postoperative mortality.
5. Previous hypothermia (that is, existing before surgery) is an independent risk factor for the further lowering of body temperature [21].
6. General anesthesia combined with regional anesthesia (especially epidural and subarachnoid, reducing sympathetic regulation) increases the risk of the intraoperative lowering of body temperature. A duration of anethesia of more than 2 h and intraoperative infusion of large volumes of unheated solutions or transfusion of unheated blood products also increases the probability of UPH.
7. The type, extent, and duration of surgical intervention are factors that influence the risk of hypothermia. Large volumes of cool liquids used for lavage and irrigation of cavities increase the probability of UPH.
8. The temperature in the surgery room also has a decisive influence on the patient's body temperature, which is much higher in a warm surgery room (21°C–24°C) than in a cold one (18°C–21°C). For these reasons, the temperature regime in the surgery room should be maintained at least at 21°C for adults and at least 24°C for pediatric patients [22].

Complications of UPH. The most serious complications associated with UPH are cardiac, such as arrhythmias and myocardial ischemia [23], coagulation disorders with increased bleeding and increased need for transfusion [24], deteriorated wound healing, wound infections, and pressure ulcers [25].

In addition to this, the effect of anesthetics is continued, and the concentration of potassium in the blood plasma decreases [26]. The oxygen partial pressure in the periwound areas also decreases because of cold vasoconstriction [27]. This worsens the phagocytic activity of oxygen-dependent polymorphonuclear granulocytes and increases the risk of postoperative wound infection.

Postoperative tremor observed in UPH may be associated with the excretion of an anesthetic from the body. It is believed that this is due to the physiological mechanism of heat production, but is experienced by patients as a very unpleasant phenomenon; it also increases oxygen consumption by approximately 40% [28].

Summarizing the above, it can be said that UPH has negative consequences in terms of postoperative outcomes and course of the disease, even increasing the duration of hospitalization and the cost of treatment [29].

Possible preventive measures. The warming of patients before surgery (preliminary warming) is considered as the earliest measure that can prevent and reduce UPH. The concept of preliminary warming of patients is based on a simple model in which the peripheral parts of the human body are considered a “thermal buffer.” In the waking state, the natural temperature gradient between the central and peripheral (skin) parts lies within 5°C–8°C. Warming the surface of the body reduces this gradient and increases the total heat content in the body, so that the initial temperature drop due to the redistribution after induction of anesthesia decreases. Preliminary warming should last from 10 to 30 min. Before spinal and epidural anesthesia, the preliminary warming of patients is also necessary [30–32].

Active warming of patients during surgical intervention. Convection warming with the use of a heating supply and exhaust blankets is very effective and should be started from the moment when most of the patient's heat begins to be lost through radiation and convection. Warm air spreads through the blanket over the surface of the patient's skin.

The heating devices must be cleaned and used with filters according to the manufacturer's instructions, because they can be contaminated with bacteria [33].

A further increase in efficacy is associated with a combination of preliminary and intraoperative warming of patients [34].

During the intraoperative period, that is, from the moment of induction to the end of the surgical intervention, all patients, who are scheduled for anesthesia lasting more than 30 min, should be actively warmed. Patients pre-warmed in the preoperative period do not need intraoperative warming if the anesthesia lasts less than 1 h [35].

Conductive methods of warming (heat transfer through direct contact) can be used to save heat as an alternative to the convective method. To do this, the blankets should be placed on the upper part of the body. The warming blankets placed under the patient's back should only complement the blankets covering the patient [36].

Passive warming. Thermal insulation serves as an external (passive) path, actively reducing radiation and convection heat loss through the skin. Various materials reduce the loss of heat to 30% [37]. In addition to active warming, the most open (not actively heated) areas of the body should be covered. Thermal isolation without active warming is usually insufficient to maintain normothermia intraoperatively. Only active warming increases body temperature by 0.5°C–1.0°C compared with passive warming through insulation [38].

Infusion of warm blood solutions and preparations. The prescription of large volumes of cold infusion solutions or blood products reduces the central temperature of the body. Therefore, intraoperative warming of infusion preparations and blood preparations at an infusion rate above 500 mL/h of blood should be included in the intraoperative temperature maintenance program [39]. Warming infusion solutions in special in-line heaters is very effective. In cases with small volumes of liquid infusions, the isolated use of infusion heaters is not sufficient to maintain normothermia [40].

Warming of irrigation solutions. Fluids for intraoperative irrigation should be preliminarily warmed to 38°C–40°C [41].

Special patient groups: children. Newborns have a higher central temperature than older children because their thermoregulation is still immature, and they have a relatively large body surface with respect to body weight. Consequently, they cool down more quickly. The normal central temperature in children under 5 years is in the range from 36.5°C to 38.0°C. Up to 2 years, the rectal measurement of central body temperature is recommended [42].

Postoperative period and measures in case of postoperative tremors. Muscle tremor, which is the main physiological mechanism of thermoregulation, is aimed at maintaining central body temperature during hypothermia; this occurs in 10%–60% of cases after general and regional anesthesia. In such cases, active warming is necessary. Additional drug therapy in the form of clonidine and pethidine is possible, although there are no direct indications for their use when attempting to arrest tremors [43].

After the termination of anesthesia, the physiological mechanisms of thermoregulation are quickly restored. When entering the intensive care unit for postoperative supervision, it is necessary to measure the central temperature. Patients with UPH should be actively warmed to achieve normothermia. During active warming, the central temperature should be measured at least every 15 min.

Conclusions. UPH is a widespread problem that accompanies surgical intervention under both general and regional anesthesia. Currently, despite the well-known facts of the undesirable consequences of hypothermia, anesthesiologists-resuscitators and surgeons pay insufficient attention to this problem. Measures aimed at prevention and treatment of UPH should be undertaken on the basis of the amount and duration of surgical intervention and under monitoring of central temperature. Continuous monitoring of the central temperature of the body, the introduction of minimally invasive methods for its measurement, and patient warming of patients enable us to effectively support thermoregulation in the perioperative period.

The authors declare no conflicts of interest.

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