16 Thermoregulation in Newborns, Neonates, and Premature

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16.1 Introduction

Human beings are homeothermic organisms, being able to maintain their body temperature within normal range by thermoregulatory defences, that are limited in neonates especially in preterms. Fluctuations in body temperature can significantly alter function at cellular and tissue level.

The axillary temperature of a newborn ranges between 36.5 and 37.4 °C (term and preterm), but heat loss starts soon after birth from exposure to external environment. Signals from cutaneous receptors signal the brain to initiate heat production by brown fat metabolism. In early days, baby utilizes fetal glycogen stores as energy substrate to maintain body temperature and other organ functions.

Thermoneutral temperature is the external temperature at which there is a balance between heat loss and heat gain, while **critical temperature** is that external temperature below which one cannot maintain core body temperature. Normal temperature zone is the range of temperature at which the metabolic need is at the minimum and temperature regulation is maintained through physiological process, such as vasodilation and vasoconstriction [1]. The **"upper critical temperature"** is that above which evaporative heat losses are initiated, and **"lower critical temperature"** is that below which heat generation through metabolism is initiated, such as shivering and nonshivering thermogenesis (NST) [2].

In a naked full-term neonate, this range is 32–35 °C at 50% humidity, but is >35 °C in preterm neonates and critical temperature is 23 °C and 28 °C, respectively. Neonates weighing more than 1500 g and without respiratory distress or hemodynamic instability can be cared for at incubator temperature of 30–32 °C.

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Table 16.1 WHO definition of temperature range [1]

Normothermia	36.5 °C–37.5 °C
Hypothermia	<36.5 °C
Mild Hypothermia	<36.0 °C–36.5 °C
Moderate Hypothermia	32.0 °C–36.0 °C
Severe Hypothermia	<32.0 °C
Hyperthermia	>37.5 °C

Hypothermia is the single most risk factor for predicting morbidity and mortality in neonates [3]. WHO defines different temperature ranges in neonates (Table 16.1) [1].

16.2 Physiology of Brown Fat Metabolism and Thermogenesis

Thermoregulatory defence mechanism plays a primary role in maintaining the temperature intraoperatively. Even though anaesthesia and the surgical procedure contribute to hypothermia, but the final thermoregulation depends on the effective thermoregulatory defences [4]. Neonates have thin skin with minimal subcutaneous tissue and large body surface area-to-mass ratio along with low glycogen stores. This causes lot of difference between heat production and heat loss thus making them prone to hypothermia.

A newborn baby's skin is wet and smeared with amniotic fluid and covered with vernix. The surroundings are cold as compared to warm uterine temperature, so the baby loses heat by evaporation, dropping the core temperature, which is difficult to measure. The head accounts for 85% of the total heat loss. The skull bones are thin with scanty hair, and brain is highly perfused and metabolically active [2]. Insulating the neonate's head is a prerequisite before any surgical procedure to minimise intraoperative heat loss.

Shivering is an important mechanism for production of heat in cold environment in older children and adults. This is absent in premature neonates and they are unable to generate activity-related heat. Neonates try to compensate for hypothermia by heat production by **NST or Brown fat metabolism, and increased cellular metabolism** [5].

NST: Shivering is a mechanism to increase heat production seen in older children and adults, on exposure to cold. Newborns and neonates cannot shiver because of immature musculature. Heat is produced by brown fat metabolism, present in the nape of the neck, and interscapular and perirenal regions.

Hormone surge (cortisol, catecholamines, and thyroid) at birth activates brown fat thermogenesis, alternative to the white fat of adults. Brown fat is about 5% of body weight of a newborn and is abundant around the kidneys, intrascapular and nuchal areas. It is highly vascular, has higher O_2 consumption, and is rich in iron containing mitochondria and unmyelinated nerves, providing sympathetic stimulation to the fat cells. It generates heat by uncoupling of oxidative phosphorylation in the mitochondria. This is a high O_2 and glucose consuming process and continuous cold stress results in hypoxia and hypoglycemia [6]. Anesthesia and anesthetic drugs inhibit brown fat thermogenesis, thereby increasing the risk of intraoperative and postoperative hypothermia after general anesthesia in neonates.

16.3 Mechanisms of Heat Loss

Body loses heat by four mechanisms:

1. **Radiation**: bare skin is exposed to the surroundings which is colder, but there is no direct contact between the two. It depends on the temperature gradient, the area exposed and the distance between the child and the object.
2. **Evaporation**: skin is wet with amniotic fluid making the newborn baby prone to heat loss to the surroundings. It depends on surface area of the baby exposed to the environment and the air velocity [7]. The heat loss is greatest by this route in a newborn.
3. **Conduction**: contact with a cool surface, such as tray or weighing machine. The amount of heat loss depends on the area in contact with cooler objects and the temperature gradient between the two.
4. **Convection**: flow of cooler ambient air of the surroundings carries heat away from the neonate (a fan).

Causes of Hypothermia in Neonates Can Be Enumerated as Due To:

1. **Greater heat loss:** relatively larger body surface-to-body weight ratio
2. **Poor heat conservation**: poorly developed thin subcutaneous tissue, and limited fat reserves
3. **Decreased heat production:** minimal motor activity, inability to shiver
4. **Immature central thermoregulatory control**
5. **High metabolic rate and energy needs**
6. Anesthesia-induced inhibition of the central control and on brown fat metabolism

16.4 Preterm Neonates

While all newborns are at danger of hypothermia, preterm and small for date babies are at a greater risk, more so in cold environment, because:

i. **They are poikilothermic**, i.e., they do not have the ability to control body temperature and adopt the ambient temperature.
ii. They have **less Brown Fat** as compared to term neonates and less heat production. Brown fat is deposited only after 28 weeks of gestation, so there will be no

developed NST in babies born earlier than 28 weeks. SGA neonates have NST mechanism but at a minimum level [8].

iii. Their body surface area-to-weight ratio is more **(BSA: BW: ↑↑)** which allows greater loss of heat from the exposed skin surface.
iv. Their **skin is poorly keratinized**, and thin with less subcutaneous tissue and fat, thus poor heat conservation.

16.5 Complications of Hypothermia (Cold Injury)

Hypothermia significantly increases morbidity and mortality, particularly after heat losing surgeries, such as exploratory laparotomy and thoracotomy. Compensatory brown fat metabolism escalates O_2 consumption, and proves to be deleterious in newborns, preterms, and those with respiratory insufficiency, with consequent tissue hypoxia, hyperkalaemia, metabolic acidosis, hyperbilirubinemia, and neurological damage. Extreme and prolonged hypothermia can cause life-threatening complications, such as DIC, RDS, sepsis, pulmonary and intracranial haemorrhage, and difficult resuscitation [3]. Effect of anesthetic drugs is more pronounced affecting recovery from anesthesia in hypothermic babies.

16.6 Temperature Monitoring

16.6.1 Core Versus Peripheral Temperature Monitoring

Temperature monitoring is essential in surgeries lasting for more than 30 min. Providing controlled thermal environment improves the chance of survival and quality of outcome, particularly in small (BW <1000 G), premature and critically ill neonates, by minimizing their oxygen and metabolic demands, and stress responses to cold or overheating.

Core temperature (Fig. 16.1a) depicts the thermoregulatory status of the body and is preferable for intraoperative monitoring. It best reflects the body temperature changes as it is maintained even with extremes of environmental temperature fluctuations and is not much influenced by thermoregulatory defences and vasomotor mechanisms. Core temperature is 2–4 °C higher than the peripheral temperature and is measured deep thoracic, abdominal or from CNS, the vessel rich organs.

Monitoring sites: core temperature measurement is an invasive technique and can be done by various routes, each with its own advantages and complications:

1. **Pulmonary artery catheter:** this is the gold standard for measuring core temperature, but is not feasible in all the cases. This is usually used in cardiac surgeries (especially open-heart procedures) and in very sick neonates in NICU settings.
2. **Tympanic**: the probe is placed in the middle ear and sealed. For accurate measurement of core temperature, there should be no air leak around the probe.

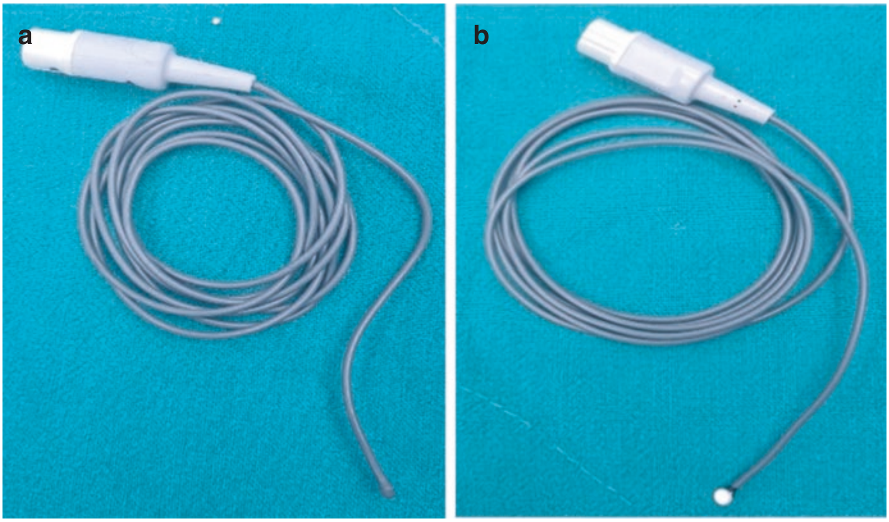

Fig. 16.1 (**a**) Core temperature probe. (**b**) Peripheral temperature probe

Besides, this is associated with a high risk of tympanic membrane perforation, and so is not used routinely in the OT in neonates.

3. **Lower oesophagus**: this measures the core temperature when the probe is put in lower 1/3rd of oesophagus. Readings are unreliable if the probe remains in the upper oesophagus when it will be affected by the temperature of the air leaking from around the uncuffed endotracheal tube (ET). Besides, there is risk of esophageal injury by improper insertion of the probe. The advantage is that there is less chance of dislodgment of a properly placed and strapped probe, and no interference with temperature monitoring. The probe should be introduced under direct vision during laryngoscopy, care being taken not to force it if resistance is felt.
4. **Nasopharyngeal**: it fairly represents the core temperature. It is put through the more spacious nostril and introduced up to the nasopharynx, but is influenced by expired warm gases leaking around the ET or LMA. Because of ease of access in any intraoperative position of the baby, this is used quite commonly. Complications associated are damage the nasal mucosa, nasal septum, and cribriform plate, and creation of false passage in the nasopharynx.
5. **Oropharyngeal**: the probe is placed in oropharynx through the oral route, and reflects core temperature, but this also is affected by the expired gases leaking around the ET.
6. **Rectal:** it truly reflects the core temperature, but is associated with the risk of damage to the rectal mucosa, and readings may be altered by soiling with faeces. Besides, it is not always feasible to place a probe in the rectum, as in intestinal, colonic, and rectal surgeries.
7. **Bladder**: this also reflects the core temperature but only when the urine output is adequate or high. If urine output is less, it will give falsely low readings.

Fig. 16.2 Zero heat flux (ZHF) Sensor

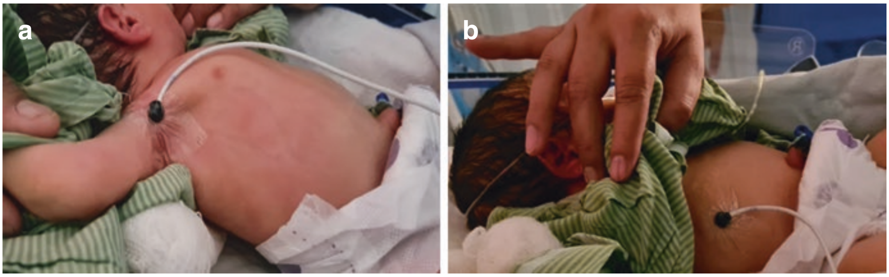

Fig. 16.3 (**a**) probe at axilla. (**b**) probe over right hypochondrium

8. **3M spot on sensor**: this is a new modality to measure core temperature through **zero heat flux principle** [9] (Fig. 16.2**).** An electrode is placed on the forehead and the skin underneath the electrode gets heated up by heat transfer from the core body heat. As the temperature equalises between the body and electrode, an isothermic tunnel is created. As the point of zero heat flux is reached (no more heat is transferred from core to skin), the temperature beneath the sensor represents the core temperature. This is noninvasive and an attractive option for measuring core temperature in neonates and small babies.

Peripheral temperature monitoring (Fig. 16.1b): peripheral temperature is dependent on the duration and area of exposure of peripheries or the external monitoring site to atmosphere, the temperature of the OT or environment and by the thermoregulatory mechanisms affecting heat distribution. This is usually 2–4 °C lower than the core temperature. Sites most used are axillary (Fig. 16.3a), temporal, and chest or hypochondrium (Fig. 16.3b):

1. **Axillary** site is the most convenient, but for accuracy, the probe must be kept over the axillary artery with the arm adequately adducted. It will not take correct readings in case of displacement.
2. The other site most used in neonates is **right hypochondrium** (Fig. 16.3b) as underlying is liver which is a highly perfused organ. There is a high likelihood of getting dislodged from the placement site, the position can get altered under the drapes, and the site may be exposed to ambient OT temperature, influencing the final readings.
3. **Chest:** it may get affected by exposure of the chest to the surroundings with no proper drapes over the chest.

The placement of peripheral probes at different sites does not show significant difference in hemodynamically stable neonate [10].

16.7 Hyperthermia

Passive hyperthermia: this **is** a rare entity in newborns and prematures due to the different thermoregulatory physiology as compared to infants and children. Hyperthermia (axillary temperature >37.4 °C or rectal temperature > 37.5 °C) can be due to pathological condition (infection, sepsis, and septicemia) or iatrogenic, from environmental factors. It may sometimes result intraoperatively due to active warming and excessive prolonged insulation by drapes.

Effects of Hyperthermia

- Vasodilatation and dehydration due to excessive insensible heat losses and hypotension shock, such as state, apnea, seizures, and neurological damage [11].
- It may also result in hyperkalaemia from increased muscle damage [7].
- Heat loss by radiation and secondary cold injury.

Associated excessive fluid losses should be supplemented and replaced adequately by Ryle's tube or intravenously (IV) [7].

Management: Methods to Lower Increased Body Temperature:

- **Stop active warming,** turning off heating devices and remove heating blankets.
- **Remove drapes** and expose baby to the surrounding OT temperature after the surgery is over.
- **Antipyretic** medications such as paracetamol may be given but not always be effective.
- While lowering temperature, **do not reduce lower axillary temperature to normal.**
- Avoid rebound hypothermia and **secondary cold injury**.
- **Maintain volume status, renal perfusion, electrolytes, acid base balance, and urine output.**

16.8 Effects of Anaesthesia

The core temperature is comprising of vessel rich organs receiving major part of cardiac output (75%) and is 22% of body weight in neonates. Mildly low core temperature (1–3 °C) is common and quite well-tolerated by them.

16.8.1 General Anesthesia (GA):

Induction of GA leads to vasodilation and thermal dysregulation by the following methods:

(a) Reduced metabolic heat production by 30% under anaesthesia.
(b) Thermal imbalance: occurs as heat loss to the surrounding atmosphere exceeds the heat production on exposure to surroundings. This process may last for 2–3 h.
(c) Central inhibition of thermoregulatory defences by GA.
(d) Internal redistribution of heat: from core to periphery and decrease in core temperature. GA causes loss of autonomic thermoregulation, with marked loss of cold response thresholds as compared to warm responses which are better preserved.
(e) Thermal steady state: this is reached when metabolic heat production is comparable to heat lost to the atmosphere. Either the heat production is increased, or the loss is reduced by vasoconstriction, thus striking the balance between the two.

Intraoperative blood sugar and SpO_2 must be monitored in neonates. Dextrose should be adequately supplemented intravenously in case of hypoglycemia and to maintain blood sugar >40–50 mg% [12] and adequacy of oxygenation maintained by adequate FiO_2 and assisted ventilation, to maintain the metabolic triangle of hypoxia, hypothermia, and hypoglycaemia and prevent related adverse consequences [13].

16.8.2 Regional anaesthesia (RA)

It is exceedingly difficult to determine hypothermia under RA as it is not possible to measure core temperature during these procedures (invasive monitoring), so it may go unnoticed and can be lethal. Prolonged RA, especially those surgeries having large evaporative losses, may lead to peripheral distribution of heat. RA per se contributes to heat loss and hypothermia by causing peripheral vasodilation. Caudal blocks do not alter thermoregulatory responses and can be used in premature and SGA neonates also.

Surgeries in newborns such as gastroschisis or omphalocele, neural tube defects, and exomphalos have high evaporative losses through the exposed gut and mucosa due to loss of skin integrity, with high chances of hypothermia [9]. Therefore, maintaining normothermia is a real challenge. Warming the IV fluid, use of warm humidified inspired gases, and covering the exposed gut with warm sterile gauzes or plastic sheets helps in reducing the heat loss. The gut should also be washed with, and abdomen irrigated with warm saline, keeping the duration of exposure to minimum.

16.9 Mechanism to Maintain Normothermia in the Perioperative Area

Main aim is to reduce heat loss, provide external heat, and reduce body energy consumption, by adopting following methods:

(a) **Reduce O_2 consumption:** avoid stress, pain, environment temperature fluctuations, hypoxia, respiratory, and hemodynamic disturbances.
(b) **Warm IV fluids** to be given through fluid warmers set at 37 °C (Fig. 16.4). They have complete casing for the IV set to prevent heat dissipation to the surroundings. They are electrically heated devices with integrated temperature sensors. Adequate temperature will be maintained only if fluid is given at a rate of 750 mL/h with a length of tubing ≤25 cm from the warmer to patient. However, this amount of flow is too high for a neonate, so length of the tubing should be kept to minimum. The diameter of the extension tube if used should be minimum; hence, pressure monitoring line should be preferred.
(c) **Forced air warming device/blanket**: (Fig. 16.5) this is an active warming device in which air is entrained through surroundings and heated through elec-

Fig. 16.4 Fluid warmer (Make: Barkey)

Fig. 16.5 Forced air warmer (Make: Bayer Hugger)

Fig. 16.6 Incubator

Fig. 16.7 Cling foil wrap in postoperative patient in NICU

tric coils. The blower delivers heat through a hose pipe either under sterile sheets or through blankets. It keeps the child warm through convection [14]. They have the risk of causing thermal burns if kept in close contact with the fragile skin of the neonate.

(d) **Radiant warmer/incubator**: incubators minimise the temperature gradient between the baby and the surroundings by maintaining adequate temperature of the air around. This minimises evaporative heat loss and metabolism as well. Double-walled incubators can prevent radiant heat losses. Prewarmed incubators are used during transport from OT to ward/ICU (Fig. 16.6). Radiant warmers increase convective and evaporative heat losses, but maintains radiant one, thus conserving net heat. It increases loss of insensible heat which proves to be the greatest disadvantage.

(e) **Occlusive plastic wrapping** (Fig. 16.7)**:** neonates and preterms requiring NICU admission are transported with cling foil wrapped around their body below the shoulders or those needing ventilator support are kept in NICU postoperatively with cling foil wrap over their cradle to prevent heat loss. This prevents evaporative heat losses from the thin skin of neonates, especially preterms.

(f) **Exothermic warming mattresses:** these are gel-based mattresses which are thermostatically controlled and deliver heat through conduction [14].

(g) **Heated and humidified air/gases** in the breathing circuit are provided to minimise heat losses. Active humidification is done through heated humidifier in the anaesthesia workstation or the ventilator in NICU. They add heat and moisture in the inspired gases. Passive humidification can be provided through heat and moisture exchanger (HME). They conserve the heat and moisture of the exhaled air from the patient and transferring to inhaled air.

(h) **Warm polythene caps** to minimise loss of heat from large surface area of the head and thin skin of the scalp over the whole perioperative period of the baby, particularly in preterm babies. Use of cling foil wrap in the postoperative period. (Fig. 16.7)

(i) **Ambient OT temperature** [15] should be maintained >28 °C (term neonates), 32 °C (birth–1 week), and 35 °C (premature neonates).

(j) **Supplement dextrose as energy substrate.**

A combination of these techniques should be used judiciously to prevent hypothermia, but at the same time, hyperthermia becomes a concern with the overzealous use of these modalities.

Pearls of Wisdom

1. Keep the OT adequately warmed before the neonate is taken in for surgery.
2. Keep OT table warm by forced air warmer set at normal body temperature.
3. Keep the neonate, particularly head adequately covered with warm blankets or plastic hats before beginning induction.
4. Always do temperature monitoring in surgeries of duration >30 min.
5. Give IV fluids or blood through fluid warmer.
6. Give dextrose containing IV fluids and high FiO_2 with assisted ventilation in babies at risk of hypothermia.
7. Coordinate with surgeons to use warm saline for washing body cavities.
8. Always transport the neonates to and from the OT in prewarmed incubator.

16.10 Conclusion

Newborns and neonates require special care to prevent hypothermia in the intraoperative period and also postoperatively. Prolonged and extreme hypothermia can have several metabolic effects, complications of cold injury, and even life-threatening complications. Various modalities are available and can be used according to the patient anesthesia and surgical requirements. Intraoperative temperature monitoring is necessary to maintain body temperature and detect impending hypothermia so that preventive and corrective measures can be taken.

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