Introduction
Inadvertent perioperative hypothermia can occur in up to 40% of surgical patients so it is essential for theatre practitioners to know what causes it and how to prevent it.

Perioperative hypothermia is usually defined as a drop in core body temperature to less than 36°C and is caused by the effects of the anaesthetic drugs and exposure of the body for long periods during surgery, both of which impair the body’s ability to maintain its normal temperature.

As well as being very stressful and uncomfortable for patients upon waking, it has many negative consequences including delayed drug metabolism, wound healing and increased infection rates.

Note: deliberate induction of hypothermia, as used in cardiac surgery, is not covered in this module.
How does the body regulate temperature?

Core temperature is one of the body’s most closely maintained physiological parameters as most cellular functions are temperature dependent. This includes enzymes which are essential for metabolism and have a narrow temperature range in which they function efficiently.

Thermoregulation begins with input from heat and cold sensors found both peripherally, and centrally in the spinal cord, brain stem, and the hypothalamus area of the brain. The hypothalamus tries to maintain the body’s core temperature within a narrow range of 36.7°C and 37.1°C* although core temperatures are usually slightly greater in women than in men, and are lower at night than during the day.

When the core temperature moves outside this range the body initiates homeostatic and behavioural mechanisms to return the body to normothermia as fast as possible.

It is useful to remember when considering heat regulation that the body has a central core comprising the major organs and brain, where temperature is tightly regulated, and a peripheral compartment where temperature can vary widely depending on the environment. The peripheral temperature is typically 5°C–7°C cooler than the core, although at hospital ambient temperatures this difference can be as little as 2–4°C.

The peripheral tissues act as a thermal buffer, absorbing or dissipating heat as necessary to protect the core and preventing activation of thermoregulatory defences in response to small changes in ambient temperature. This difference between core and peripheral body temperature is maintained by vasoconstriction of the blood vessels leading to the peripheral tissues.

* These temperatures vary considerably between various publications, books etc.

Diagram 1: the core temperature response to temperature changes
How does the body produce heat?

The body produces heat as a by-product of normal metabolic activity. When this is not enough and a person is cold, the first mechanisms activated are vasoconstriction, reducing blood flow through the skin and protecting the core. This is along with behavioural changes such as using clothing and shelter to keep warm.

These are followed by non-shivering (NS) thermogenesis and then finally shivering. NS thermogenesis is the production of metabolic heat from brown adipose tissue without muscular activity. It can double heat production in neonates, who do not have enough muscle mass for shivering, but has little significance in adults. Shivering uses involuntary muscle movements to generate heat and this can increase heat production up to six times more than the resting rate.

When the core body temperature is too high, the hypothalamus triggers methods of cooling such as sweating, an increased respiration rate and vasodilation. This happens along with appropriate behavioural changes such as shedding layers of clothing and seeking shade.

Diagram 2: how the body maintains normal body temperature

What are the effects of anaesthesia on heat balance?

Under general anaesthesia the temperature control system is compromised. Firstly, behavioural responses (i.e. using clothing and shelter to keep warm) are completely abolished. Secondly volatile agents, propofol and opioids all substantially impair thermoregulatory control by widening the activation threshold (see diagram 3).
The normal activation range where the body tries to neither heat nor cool the core is 0.4°C (36.7 – 37.1°C) but under general anaesthesia this range increases to 4.0 °C. The temperature at which the brain responds to cooling with vasoconstriction and shivering is significantly lowered by 2-3°C. This means instead of vasoconstriction starting when the core temperature drops to 36.7 C will not start until the core temperature drops to 34.5 C. Shivering starts even lower at just above 33 C.

This can be reduced even further in elderly patients. The result of this is an inability of the body to respond to the multiple causes of heat loss during anaesthesia and surgery.

[Diagram 3: Altered activation range due to general anaesthesia]

**How fast do you lose heat under anaesthesia?**

The combination of anaesthesia-induced thermoregulatory impairment, cool operating theatres, and exposure during surgery makes most unwarmed surgical patients hypothermic.

Heat loss under anaesthesia is typically conforms to a tri-phasic pattern.

**Phase I Redistribution** - In the first hour following induction of anaesthesia, there is a rapid reduction of 1.0-1.5°C in the core temperature. This called redistribution hyperthermia as anaesthetic-induced vasodilation leads to cool blood from the peripheries entering the core circulation. This vasodilation is caused by both the direct effect of anaesthetic agents (volatile anaesthetics, propfol, opiates) and the indirect consequences of the lowered activation threshold.

**Phase II Linear**: The more gradual second linear phase occurs as heat loss to the environment still exceeds heat produced from metabolism. The body’s metabolic rate is reduced by 15-40% during general anaesthesia. This reduces the amount of heat that can be generated, coupled with the increased heat lost through exposure during surgery, leads to a negative heat balance and continuing heat loss.
**Phase III Plateau**: The plateau begins, once core temperature falls below the reduced activation threshold and peripheral vasoconstriction is finally initiated to limit the heat loss from the core. This usually happens around 34.5°C during general anaesthesia. When core heat production equals heat loss to the periphery, the core temperature reaches a plateau and stabilises.

This phase may not be achieved during combined general/regional anaesthesia as vasoconstriction is further blocked due to the effects of the regional anaesthetic. In this situation the plateau phase may not occur and serious hypothermia could occur. This can also occur in diabetics with autonomic neuropathy and impaired vasoconstriction.

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**Diagram 4: The tri-phasic pattern of anaesthesia**

**How is the heat lost?**

Intraoperative heat loss occurs by the following four mechanisms:

**Radiation - thermal** (40%) – Radiation is the transfer of heat by infrared waves from the body to cooler objects (not in physical contact with the body) in the surrounding area, and constitutes the major method of heat loss. An example of this is the sun transferring heat to the earth through radiation.

Heat loss by radiation is proportional to the environment/core temperature difference to the power of four ($n^4$). If the operating room temperature is decreased by 2°C, heat loss will be increased by a factor of 16 ($2^4$).

**Convection** (30%) - Normally, a thin layer of still air adjacent to the skin acts as an insulator and limits convective heat loss to the surrounding air. When air currents disrupt this layer, the insulating properties are markedly diminished and heat loss increases. This is the basis for the concept of the wind chill factor, at the same temperature on a windy day it will feel cooler than a calm day. This is exacerbated in the operating theatre by rapid air changes and laminar flow.

Convective heat loss is considered the second most significant source of heat loss in theatre. Forced-air warming devices, such as Bair Hugger, Bair Paws and Warm Touch, counter this by surrounding patients with circulating warm air, warming by convection.
Evaporation (25%) - Heat is lost as a result of the latent heat of vaporization. Examples include evaporation from exposed bowel, wound surfaces and skin preparation fluids. During a major laparotomy, evaporation from the open abdomen can contribute up to 50% of the total heat loss. Respiratory losses accounts for a small amount of the total heat loss, although this can be avoided by using heat and moisture exchanger (HME) filters and low flow circle systems. Loss of heat through this route becomes important when high fresh gas flows are used, especially in small children.

Conduction (5%) - Caused by a transfer of heat from a warm object in direct contact with a cooler object, for example, contact with a cold theatre table/mattress. Conduction plays a minor role in heat loss during surgery if the patient is in direct contact with a foam insulating mattress on the theatre table. Resistive heating mattresses can provide warming through conduction.

What affect does regional anaesthesia have?
First, hypothermia does not provoke as much thermal discomfort as would be expected in the presence of neuraxial blocks. Patients having epidural or spinal anaesthesia do not complain of feeling cold, even when they are hypothermic. The reasons are unclear, but possibly the brain (hypothalamus) interprets lack of cold signals from the legs as relative warmth.

Regional anaesthesia also blocks the ability of the body to shiver and vasoconstrict below the level of the block, it is though this is also because of blocked input from the lower peripheral thermal centres.

Initial hypothermia occurs by redistribution of cooler peripheral blood to the core, because of the vasodilation induced by regional anaesthesia, but vasoconstriction above the level of the block can compensate to some degree. Finally, epidural and spinal anaesthesia reduce the vasoconstriction and shivering activation thresholds in a similar way to GA, but not to the same extent. The reduction is a linear function of block height—ie, higher blocks produce more thermoregulatory impairment. The mechanism of this is not fully understood but again possibly results from the anaesthetic blocking cold signals from the lower body.

The greatest risk of heat loss is during combined regional and general anaesthesia.
What are the risk factors for perioperative hypothermia?

Patients should be managed as high risk if two or more of the following apply:

- ASA 3-5 patients (the higher the grade, the greater the risk)
- Preoperative temperature <36.0°C (and preoperative warming is not possible because of clinical urgency)
- Combined general and regional anaesthesia
- Undergoing intermediate or major surgery
- Prolonged surgery. NICE recommends warming all patients undergoing surgery of duration more than 30 minutes.
- At risk of cardiovascular complications
- Low BMI
- Lower theatre temperature i.e. orthopaedics and cardiac
- Age, children and elderly patients are at more risk

Are children at more risk?

Children (especially neonates) are at particular risk of perioperative hypothermia. Children lose more heat than adults via conduction and radiation because they have a higher surface area to volume ratio and less insulating subcutaneous adipose tissue.

Risk factors for perioperative hypothermia in paediatrics are young age, length of surgery >30 min, major surgery and temperature <36.5°C before induction of anaesthesia.

What are the consequences of perioperative hypothermia?

The consequences of perioperative hypothermia include an impact on morbidity, mortality, and length of hospital stay. Most cellular functions are temperature dependent and hypothermia provokes systemic responses, some of which are potentially harmful. Although few patients are susceptible to all potential complications, most are susceptible to at least some. Furthermore, patients describe being cold and shivering in the PACU as one of the most distressing aspects of their surgery. Consequences include:

Surgical site infection

The increased risk of surgical site infection caused by hypothermia is well established. NICE (UK) reports surgical site infection rates are three-to-five times higher in hypothermic patients. Vasoconstriction leads to decreased blood flow and decreased oxygen delivered to the tissues. Also hypothermia reduces the body’s immune system activity and decreases the action of key wound healing cells such as macrophages.

Wound healing

Wound healing is delayed among hypothermic surgical patients as vasoconstriction leads to a reduction in tissue perfusion around the wound site and a reduction in collagen synthesis.

Drug metabolism

Hypothermia leads to longer post anaesthetic recovery due to altered drug metabolism. Some examples are:

- More volatile anaesthetic is absorbed by the body’s tissues, causing delayed recovery. There is a decrease in mean MAC of 5% for every one degree decrease in core temperature.
- Drug metabolism in the liver is reduced, leading to the prolonged action of propofol and opiates.
- Longer action of neuromuscular block is caused by reduced metabolism and decreased rate of Hoffman degradation. The duration of action of vecuronium is doubled by 2°C hypothermia.
**Increased bleeding and transfusion requirements**
There is increased perioperative bleeding and coagulopathy problems, as the clotting cascade is enzymatic and platelet function is temperature dependent. Even 1°C of hypothermia significantly increases blood loss by about 20%.

**Increased rate of cardiac events including myocardial ischaemia and arrhythmias**
Cardiac complications are the principal cause of morbidity during the postoperative phase. For this reason treating factors that lead to ischaemia, such as low body temperature, is important. Hypothermia increases the release of catecholamines (adrenaline, noradrenaline, dopamine) leading to increased blood pressure which increases the myocardial workload.

**Shivering**
This increases postoperative pain and makes monitoring unreliable. Shivering also independently increases carbon dioxide production, catecholamine release, and cardiac output. Patients often comment on their shivering upon awakening from anaesthesia as one of the most uncomfortable immediate postoperative experiences.

**Is there a risk of overheating?**
Intraoperative hyperthermia is rare. The body’s overheating defences are relatively well preserved during general anaesthesia and frequent or continuous core temperature monitoring will detect hyperthermia. Pathological causes of active hyperthermia such as malignant hyperthermia, sepsis, adverse reactions to a drug or blood transfusion should always be considered. Infants and children are most at risk of overheating.

The consequences of overheating include increased peripheral blood flow, increased capillary permeability, and oedema. Patients sweat in an attempt to lose heat. Hyperthermia increases the minimum alveolar concentration (MAC) of inhaled anaesthetic agents and reduces the duration of action of neuromuscular blockers. Passive overheating is easily preventable by vigilance and treated by removing the warming device or insulation.

**Where is the best place to measure a temperature?**
Temperature should be recorded every 30 minutes in patients undergoing surgery. This should include patients having regional techniques. There are various devices available and several anatomical sites that can be used to measure temperature. The optimal site for monitoring temperature in the preoperative, intraoperative, and postoperative periods is an area of debate, typically depending on patient age.

**Preoperative**
In the preoperative period, oral temperature is traditionally used for adults, oral or axillary temperature used for paediatric patients, and axillary temperatures are used for neonates. The classical sublingual temperature remains a good estimate of core temperature although this have largely been replaced by infrared tympanic and forehead thermometers.

**Intraoperative**
Intraoperatively the core temperature should be measured by an oesophageal temperature probe (inserted to approximately 40 cm) whenever possible. This method is low risk and low cost and provides the most accurate assessment of thermal status. Additionally, this measure is most accurate for large changes in temperature.
A nasopharyngeal probe (inserted to approximately 10-20 cm) is the next preferred option. Rectal temperatures normally correlate very closely with core temperatures however during cases of hypovolaemia, heat stroke and malignant hyperthermia the temperature readings lag behind.

Unfortunately, oesophageal measurement is not realistic in regional anaesthesia cases and in the postoperative period. The relatively new 3M™ Bair hugger™ core temperature system which accurately measures core temperatures through a forehead sticker (zero heat flux technology) is but it has not yet been widely adopted, maybe due to cost concerns.

**Postoperative**

In the awake patient, many of the sites available give only an indirect estimate of core temperature. These include infra-red tympanic and temporal artery thermometers that use a correction factor before displaying the final temperature. These devices are not accurate to within 0.5°C and are also prone to user error. Aural readings are affected by ear debris and measurement of the ear canal temperature instead of that of the tympanum. Low readings can be checked in the opposite ear. If a reading is questionable, then alternative technology should be used to confirm hypothermia. Digital oral (sublingual) temperatures or 3M™ Bair Hugger™ (deep forehead) are more accurate.

**Diagram 6: 3M™ Bair Hugger™ core temperature system**

**Preventing preoperative temperature drops on the ward**

Communication and patient empowerment is essential; patients (and their families and carers) should be educated about the potential to feel cold in hospital and advised to bring something to keep themselves comfortably warm and to communicate thermal discomfort to staff. Extra attention should be taken for patients with communication issues.

**Why should we warm in the anaesthetic room?**

Until recently, patient warming has focused on the intraoperative phase, with warming devices being applied once the patient had been anaesthetised and transferred to the operating table. However, evidence shows this is too late and patients are already hypothermic at this stage due to the rapid drop in temperature caused by the anaesthetic. Even with a warming device in place, it can take up to two hours for a patient’s temperature to increase to 36°C.
Warming patients preoperatively has been shown to act as a buffer, protecting them from the rapid decrease in core temperature caused by anaesthetic-induced vasodilation. This preoperative warming does not increase the core temperature, but absorbed heat does increase the temperature of peripheral tissues, thus reducing the normal core-to-peripheral tissue temperature gradient. (See Diagram 7). The updated NICE guidelines now recommend 30 min pre-warming as a way of minimising the incidence of perioperative hyperthermia in all patients.

There is evidence that even 10 min warming before induction of anaesthesia decreases the incidence of perioperative hyperthermia. This can be started in the anaesthetic room whilst preparing the patient.

Diagram 7: Effect of anaesthesia induced vasodilation on core and peripheral temperatures

Warming during surgery
A single layer of passive insulation (i.e. a blanket) reduces heat loss by 30% at typical operating room temperatures. The type of insulation matters little, since the barrier is provided by the layer of still air trapped below the insulator. A 30% reduction in heat loss is clinically important and roughly compensates for the anaesthesia-induced reduction in metabolic heat production. Of course, the effect of insulation is restricted to covered surfaces. Adding additional layers of insulation provides little additional benefit. Most surgical patients will become hypothermic with insulation alone, and require active intraoperative heating to maintain normothermia.

A forced air warming device is the recommended method of active warming during surgery; it is more efficient than passive warming and has been shown to be superior to resistive devices such as heating mattresses. It prevents heat loss both by convection and radiation.

There is ongoing controversy surrounding the use of forced air warmers and the potential for disruption of laminar flow, particularly in orthopaedic theatres. There is mixed evidence for this problem, but if a forced air warmer is unsuitable, a resistive heating mattress is recommended.

Ideally, both these warming technologies should be used together in patient groups at high risk, such as those having combined regional and general techniques.
Fluid warming cannot warm patients because warmed intravenous or irrigation fluids only slightly exceed core temperature. However, patients can be cooled considerably by infusion of unwarmed fluids. One litre of fluid at room temperature or one unit of blood at 4 °C can decrease core body temperature by 0.25 °C. Intravenous fluids (500 ml or more) should therefore be warmed before administration and blood products should be warmed to 37°C using a fluid warming device.

**Treatment of post-anaesthetic shivering**

Shivering is a recognised consequence of both general and regional anaesthesia; it can occur independently of temperature (i.e. due to pain), but should never be treated independently of temperature. Shivering after anaesthesia is distressing for the patient and can increase pain by involuntary movement of muscles at the surgical site. Even though oxygen consumption is increased by shivering, it does not cause hypoxemia.

Pharmacological treatment of shivering works by lowering the shivering threshold, therefore it would compound hypothermia if not addressed simultaneously. As above, the most efficient way of warming a hypothermic patient is with a forced air warmer. Drugs used commonly to treat shivering include pethidine, clonidine, ketamine and doxapram.

**NICE guideline 65: hypothermia - prevention and management in adults having surgery.**

The first NICE guideline was published in 2008 and was updated in December 2016. It provides a useful summary of the prevention and treatment of inadvertent perioperative hypothermia at each perioperative step.

**Strategies for the prevention of perioperative hyperthermia**

**Before surgery**

- Identify patients at high risk of perioperative hyperthermia. Active warming should be started before surgery in hypothermic or high-risk patients
- Measure the patient’s core temperature
- Patient should not be transferred to theatre unless their core temperature is >36°C
- Patient should be encouraged to walk to theatre where possible (This increases heat generated by metabolism)
During anaesthesia and surgery

- Induction of anaesthesia should not be started until the patient’s core temperature is >36°C unless clinically urgent.
- Active warming is recommended for all high-risk patients regardless of the length of the procedure, and for all patients with total anaesthesia time >30 min.
- Ambient temperature should be >21°C while the patient is exposed to reduce heat loss by convection and radiation. Thereafter, the ambient temperature can be reduced for staff comfort.
- Warm i.v. fluids. (Prewarmed fluids are as effective if given within 30 min of removal from warming cabinet).
- Humidification of respiratory gases. Although only a small amount of metabolic heat loss occurs through the respiratory tract, the use of a heat moisture exchanger filter or alternative humidification device is recommended.
- The patient’s temperature should be measured at least every 30 min and active warming titrated to effect. This is useful to monitor for both hypothermia and hyperthermia. This includes patients having regional techniques.

After surgery

- The core temperature should be measured on admission to PACU and then every 15 min. Forced air warming should be continued if the patient is hypothermic (warm blankets offer comfort, but do not actively warm the patient) The patient should stay in PACU until the core temperature is >36°C.
- Patients should be kept comfortably warm for 24 h after surgery with a duvet and blankets.

Summary

It is possible to avoid perioperative hypothermia, especially if all sources of potential heat loss are minimised. This needs to start preoperatively and continue for the whole perioperative journey. Short surgical cases are also at risk of hypothermia and pre-warming is needed for high-risk patients if redistribution hypothermia is to be avoided.

If active warming is used evidence shows that forced-air warming blankets are the most effective. This combined with pre-warming, warmed fluids, and temperature monitoring can reduce inadvertent intraoperative hyperthermia rates close to zero.

Finally, not measuring temperatures doesn’t mean your patients are not hypothermic. It just means you chose to ignore it.

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References


