Perioperative Temperature maintenance in Children.

Dr.R.Jayanthi,

Senior Consultant Anaesthesia,

KanchiKamakotiChildstrust Hospital, Chennai

Humans being homoeothermic ,maintain core body temperature within a narrow range. The thermoregulatory system can be thought to consist of three compartments – the central (core) compartment consisting of the vessel-rich group of organs (brain, heart, lungs, liver, kidneys, endocrine glands) and the peripheral compartment consisting of the musculoskeletal system which acts as a buffer between the central and shell (skin) compartment.

Body temperature is tightly controlled and maintained within a narrow range of 37 $\pm$ 0.2^{o} C. Several factors can challenge the thermoregulatory system in day to day life like when the body is exposed to extremes of heat and cold (with poor protection in the form of clothing).

Anaesthesia and surgery attenuate thermoregulation and so it becomes important to monitor body temperature in a cold operating room and also to institute appropriate measures to avoid and correct any changes in body temperature.

A core temperature of <36.1^{o} C and 97^{o} F is considered hypothermia. Hypothermia may be classified as follows.

Mild hypothermia	33.9 – 36^{o} C (93 – 96.8^{o} F)
Moderate hypothermia	32.2 – 33.8^{o} C (89.9 – 92.8)
Severe hypothermia	< 32.2^{o} C

Temperature Monitoring

Temperature is traditionally measured in ^{o} Celsius or Farenheit.

The conversion from one to the other being

$^{o}C = (^{o}F - 32) \times .56$

$^{o}F = (1.8 \times {}^{o}C) + 32$

Kelvin $-^{O}C + 273.15$.

The conventional mercury in glass thermometers have been replaced by thermistors and thermocouples in the Operating Room. The principle of the thermocouple - the change in electrical resistance caused by temperature change in the metal at the tip of the thermistor is used to measure temperature. A thermo couple consists of 2 different metals usually copper and constantan (an alloy of Cu, Ni, Mu, and Fe). At the junction of these two metals a current is generated. The voltage magnitude of the current depends on the temperature and can therefore be used to measure temperature.

Infrared Thermometers are suitable for use in PACU and wards. They are unsuitable where continuous monitoring is required as inthe OT. Despite a fast response time their clinical accuracy is not proven. Their main advantages are that they have a quick response time (typically <10sec.) and that they do not need to be in direct contact with the object to be measured. This makes them ideal for tympanic membrane and skin measurements.

Handheld infrared scanners assess central temperature via skin temperature measurement. They detect the highest temperature in the temporal or forehead region which is the skin in closest proximity to the temporal region.

Depending on the site of measurement the body temperature varies widely. Whilst the central tissues maintain a constant**core** temperature, the skin and peripheral tissues have a more variable temperature. Core temperature relates to the temperature of the hypothalamus and therefore is of clinical significance to us. The hypothalamus is believed to be the thermoregulatory controlcentre in the body. Core temperature can be measured at various sites namely the tympanic membrane, the nasopharynx, the esophagus, the pulmonary artery and the bladder and rectum. The tympanic membrane is considered the most ideal site to measure core temperature. Though it is enough for the temperature probe to be in the external auditory canal (not in touch with the Tympanic membrane) to measure the core temperature , reports of TM perforation have caused this site to fall into disfavor. Nasopharyngeal temperature probes when placed in the posterior nasopharynx close to the soft palate are the next best site for measuring core temperature. Nasal bleeding especially in children with adenoids is a cause for concern. Also uncuffed endotracheal tubes cause leak of gases and incorrect reading with a nasopharyngeal probe. Oropharyngeal probes are more inaccurate. Esophageal temperature probes are often combined with esophageal stethoscopes and can also be used. Axillary temperature is one of the widely used sites but very inaccurate .The rectum is another easily accessible site but limitations are that the probe should not be embedded in faeces . The least invasive site of course is the skin. It is also very unreliable to measure core temperature. Bladder temperature is an accurate reflection of core temperature if the urine volume is high.

Physiology of Thermal Regulation

Humans tolerate body temperatures as low as 13.7^{o}C but succumb to temperatures as high as only 40.5deg C to 43 above which denaturation of proteins occurs. Hence warm receptors outnumber the cold receptors ten fold. Afferent impulses from temperature sensitive cells in the brain, spinal cord, central core tissues (brain, lungs, liver, heart, kidney and endocrine glands), and skin are integrated in the hypothalamus which is the thermoregulatory center. Then the body operates through a negative feedback loop to maintain temperature within a narrow range of .7$^{o\,C}$ called the Inter threshold range. Afferent impulses are carried in the A delta and C fibers. Skin temperature triggers behavioural changes in response to changes in core temperature outside the thermo neutral range. Behvioural changes like seeking shelter, putting on a jacket or heating the home are much more efficient effector responses to changes in temperature than all the autonomic responses combined.

Thermal Regulation in Newborn

Preterm and full term newborns and infants who are small for gestational age have a large skin surface area to body mass ratio (neonate – 1.0; as compared to adult – 0.4). They lose heat more rapidly because of reduced subcutaneous fat and also because keratin content in the skin is reduced.

In a similar environment, infants lose more heat through their skin than adults. Their ability to generate heat is also poor.Efficacy of the thermo regulatory response is often inadequate. This predisposes the young infant to hypothermia. The same factors also facilitate a three to fourfold more rapid rewarming in infants compared to adults. In this context, the head of the neonate comprising 20% of BSA is the source for maximal heat loss. The thin skill bones, sparse scalp hair and close proximity of the highly perfused brain to the skin surface, favourlarge amount of heat loss from the head. This substantiates the practice of covering the infant's head to minimize heat loss. Exposing visceral surfacesof the chest and abdomen during surgery also contributes to evaporative heat and fluid loss.

Thermoregulation in the child or adult in the operating room setting is a balance between the mechanisms that cause heat loss and the heat generating mechanisms in the body. Let us first look at the mechanisms that contribute to heat loss in the operating room.

Heat loss mechanisms

The first step in the heat loss process is the redistribution of heat from central compartment (body core) to the periphery and the skin surface. The second step is transfer of heat from skin surface to environment and ultimately heat is lost by one of four mechanisms radiation, convection, evaporation and conduction. In the new born heat is lost 39% by radiation,34% by convection, 24% by evaporation and 3% by conduction.

Radiation

Transfer of energy between 2 objects that are not in direct contact but that differ in temperature is known as radiation.In both, awake &anaesthesia state radiation is the most important mechanism of heat loss in the neonate. Larger skin surface area to volume ratio in neonates and infants contributes to this.

Convection

Convective heat loss is the transfer of heat from a body to moving molecules like air or liquid.

In the OR changes in body posture and minute ventilation may also affect convective heat loss.

Evaporation

Evaporation is the vaporization of matter from the body or a mucosal surface which usesthe latent heat of evaporation as its source. Evaporation lossmainly occurs through skin and respiratory tract. Physical factors governing evaporation heat loss include relative humidity of the inspired air,

velocity of airflow and minute ventilation. Evaporative losses include sweat (sensible water loss) insensible water loss from skin, respiratory tract, open surgical wound and evaporation of liquids applied to skin such as preparation solutions. Although we are often worried about heat loss or hypothermia in the newborn at the other end of the spectrum, if the newborn reaches rectal temperature of 37^{o}5 to 37.9 ^{o}C and ambient temperature exceeds 35^{o}C, term newborns have the ability to sweat to dissipate heat. Premature infants with GA < 30 weeks show no sweating response due to poorly developed sweat glands.

Intraoperatively due to a higher minute ventilation compared to adults,in infants, respiratory heat loss is about a third of total heat loss and this can be reduced if the patient breathes warm moisturized gases as against cool dry gases, withthe use of a humidifier.Evaporative heat loss from a large surgical incision and skin contact with wet drapes are two other factors which contribute significantly to heat loss intraoperatively.

Heat generation

Conduction, radiation and convection can be used to passively warm a patient. The body actively produces heat through one of four mechanisms

1. Voluntary muscle activity
2. Non-shivering thermogenesis
3. Shivering (involuntary muscle activity)
4. Dietary Thermogenesis.

Voluntary muscle activity is non contributory to heat production in the perioperative period. Non-shivering thermogenesis is the main mechanism of heat production in the newborn whereas after 1 year of age shivering thermogenesis forms the main mechanism of heat production. This goes on to older

children and adults. Dietary thermogenesis plays a role if the patient has had a meal with high protein or fructose content before anaesthesia which is usually not the case, so this mechanism can be discounted

.

Non shivering Thermogenesis

This is defined as an increase in metabolic heat production – that is not associated with muscle activity. It refers mainly to the increased metabolism of brown fat. Brown fat is found in the human fetus between 26 to 30 weeks gestational age. It comprises 2 – 6 % of infant's body weight and is present in six areas – between the scapulae, in the axilla, in the mediastinum around the internal mammary vessels, around the kidneys and adrenals and around the vessels in the neck.

Brown fat is highly vascular and richly innervated with sympathetic fibers. The brown colour is contributed to by the abundance of mitochondria in the cytoplasm of its multinucleated cells. These mitochondria are unique in that they uncouple oxidative phosphorylation to produce heat and not ATP. The activation of Brown fat metabolism results in redirecting a major part of cardiac output through brown fat as high as 25% ,thereby facilitating direct warming of blood. All inhalationanaesthetics attenuate non shivering thermogenesis within 5 minutes of starting the agent and can be restarted in 15 minutes after switching off the anaesthetic.

NST does not appear to be functional or relevant in adults. On the other hand premature, full term neonates and infants are able to double their metabolic heat production with the help of NST. Newborns and infants have reduced ability to reduce heat loss through cutaneous vasoconstriction. Thus heat conservation is poor. Cold exposure during GA does not trigger NST. Inhaled anaesthetics also block it.

Shivering Thermogenesis

With increasing age shivering thermogenesis takes over a prominent role in thermo regulation. Neonates do not shiver and if they do so too, it is of minor significance for thermoregulation. They have immature musculoskeletal system and poor muscle mass thereby not producing enough heat by these processes.

Even short periods of shivering can cause a six fold increase in metabolic heat production and oxygen consumption in healthy young adults. Oxygen consumption and CO_2 production increase upto 400 to 600% for a brief period. The cardiac output also increases correspondingly, but with no haemodynamic compromise in healthy patients. In children with limited cardiac reserve, this increase in oxygen consumption can decrease mixed venous oxygen content and can precipitate tissue hypoxia. Shivering is not only unpleasant for the child, but can increase IOP& ICP. Though the incidence of post op shivering is inversely related to core temperature, shivering has also been reported in children who have been maintained normothermic under anaesthesia implying shivering may be triggered by other mechanisms like pain.

Dietary Thermogenesis

Stimulation of energyexpenditure and thermogenesis by certain nutrients is a well known phenomenon. In spite of a paralysis and decreased metabolic rate underanaesthesia infusion of small amounts of amino acid can cause up to5 fold increase in heat generation. Fructose administration seems to have a similar effect. The mechanism behind this form of thermogenesis has not been elucidated.

Effect of Anaesthesia on Thermoregulation

A combination of factors under anaesthesia predispose to a drop in core temperature of 1^{o} C to 3^{o} C.

Some of these factors are

1. A 30% reduction in metabolic heat generation during anaesthesia
2. Increase exposure to environment
3. Anaesthesiainduced central inhibition of temperature regulation.
4. Internal redistribution of heat

General effects of anaesthetics on Thermoregulation

1. Lowering of threshold Temperature for response to cold.
2. Increasing threshold temperature for response to heat
3. Widening of inter threshold range to approximately 2^{o} C to 4^{o} C.
4. Opioidsand Propofol reducethreshold temperature for vascoconstriction and shivering as a linear function of dose.
5. Volatile anaesthetics also produce inhibition of thermoregulatory defense mechanisms.
6. All volatile agents at comparative MAC values produce similar inhibition of thermo regulation.
7. N_2O decreases vasoconstrictionthreshold less than inhaled agents.

Under Regional anaesthesia central thermoregulation remains intact; thus protecting against hypothermia. But Regional anaesthesia blocks the afferent and efferent thermal sensory pathway preventing vasoconstriction and shivering in the blocked area. This causes internal redistribution of heat and increased heat loss to the environment contributing to hypothermia. So much so that hypothermia following a regional is almost as much as after a general anaesthetic. Having said that there are studies which show that caudal block in children does not affect thermoregulatory mechanism as well.

Anaesthethesia and Hypothermia

Hypothermia under anaesthesia usually develops in 3 phases:

1. Internal redistribution of heat
2. Thermal imbalance
3. Plateau or Rewarming phase.

Internal Redistribution

At rest the central compartment accounts for about 66% of total body mass (in adults). Under anaesthesia this expands to about 71% of body mass. The vessel rich group of organs which is part of the central compartment receives 75% of cardiac output. The peripheral compartment accounts for the remainder of the body mass and acts as a buffer to accommodate any changes in core temperature by vasoconstriction or vasodialatation. The skin compartment acts as a barrier between the first 2 compartments and the environment.

After induction of anaesthesia, peripheral vasodilatation increases the size of central compartment thus causing redistribution of heat over a larger volume. So during the first hour of anaesthesia drop in core temperature by .5^{o}C to 1.5^{o} C is largely due to redistribution of heat and partly due to reduced metabolism and overall total body heat loss (as a result of anaesthesia).

Thermal Imbalance

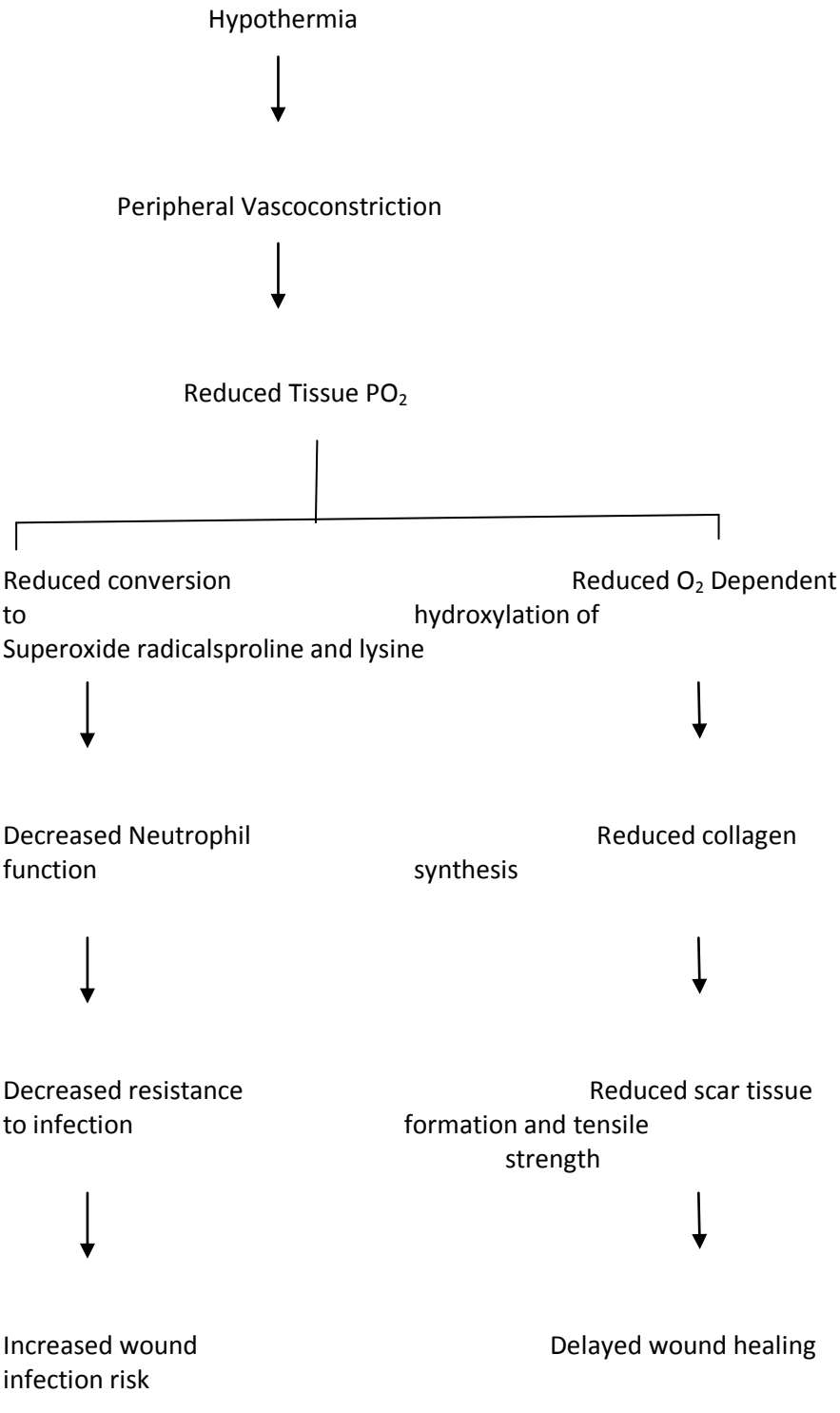
The combination of reduced heat production and increased heat loss to the environment leads to thermal imbalance. This phase lasts 2 to 3 hours. During this phase body heat is lost to the environment usually at a rate of .5^{o}C to 1^{o} C per hour. The loss depends on the gradient between the skin and the surroundings. As the child's temperature falls this gradient decreases and the heat loss from the body also decreases. This accounts for how switching off the AC in the operating room (for Newborns) can help prevent hypothermia.

Thermal steady state (Plateau or rewarmingl)

The third phase of the hypothermic response to anaesthesia in adults is the plateau phase. During this phase metabolic heat produced equals heat lost and the core temperature remains constant. This phase occurs between 34.5^{o}C to 35.5^{o} C. The infants and children this phase is a rewarming phase where due to intense vasoconstriction within the central and peripheral compartments the central compartment shrinks and the same heat is redistributed in a smaller volume.

Adverse effects of Hypothermia

If the normal core temperature is not reached or maintained by passive rewarming hypothermia may result in hypoventilation or even apnoea. Patients need much less anaesthetic so may have anaesthetic overdose. The increased O_2 demand can precipitate a pre existing cardiopulmonary deficiency. Sympathetic stimulation causing vasoconstriction causes acidosis, hypoxia and right to left pulmonary shunting. The long term adverse effects of hypothermia can be summarized as follows. Hypothermia plays an important role in reducing neutrophil function causing increased susceptibility to infections. It also reduces collagen synthesis and thus delays wound healing.



reduced coagulation and haemostasis.
Decreased myocardial function, enzyme activity, drug clearances and delayed awakening from anaesthesiaare some more problems occasionally seen with hypothermia under anaesthesia.

(Adapted from Smith's Anaesthesia for infants and children)

Prevention of Hypothermia

Operating Room Temperature

Much of the heat loss under anaesthesia is by radiation. Radiant heat loss depends on the temperature difference between patient and OT environment.OR temperatures of 22^{o}C to 25^{o} C are recommended for fullterm and preterm newborn respectively. It is important that each of the Operating rooms has an independent temperature control mechanism to adjust the OT temperature according to the patient.

The draft of air from the air conditioning unit can cause heat loss due to convection. Keeping patient covered can prevent this.Maintaining a humidity of 40 – 60% in the OR reduces evaporative heat loss from open body cavities and the respiratory tract.

Radiant Heaters

These are used prior to induction. They are useful in the postoperative wards and in the NICU. Prolonged use results in increased insensible water loss.

Reflecting Blankets

The effectiveness of this method depends on covering as large a surface area of the infant as possible. Potential build up of water vapor on the inside leading to condensation and wet skin is a problem. Simply covering the head with a plastic cover is a simple effective way of reducing heat loss by radiations, convection and evaporation.

Skin surface warming devices

Effective use of these devices induces peripheral vasodialatation and increases the temperature of the peripheral compartment. The result is an increased mean body temperature.

A variety of passive and active skin surface warmers are available. They are:

1. Hot water blankets – circulate warm water through a reusable blanket placed under child.
2. Infrared Radiant heaters
3. Convective forced air heaters – these blow warm air into a disposable blanket placed under the child which raises the effective ambient temperature immediately around the patient. This device is very effective to prevent hypothermia and to rewarm the patient who is hypothermic. These devices are convenient to use and can be easily moved from one location to another. They have a preset temperature. If used correctly with the blanket the chances of burns are low. In patients with decreased peripheral perfusion doe to high doses of vasoconstrictors, aortic cross clamping these warmers must be used with caution for limited periods only to avoid skin burns.

Warming of IV fluids

IV fluids and blood products must be warmed before administration in order to reduce chances of hypothermia. This is especially true in case of rapid transfusions. Various types of warming devices are available. Starting from the devices where the IV tubing goes through a temperature controlled water bath, to the more sophisticated warmer where the tubing is wrapped around an insulated heating coil, these devices are varied. Actual warming of the IV fluids before administration has the pitfall that at the relatively slow rates that we are giving fluids in children the warmed IV fluid would become cold before it reaches the patient.

Also irrigation solutions must be warmed prior to use.

Though much has been discussed about drying the baby after the antimicrobial preparatory solution has been applied, it is not advisable to heat iodine solution as it can inactivate the antimicrobial properties.

Humidification of inspired gases prevents tracheal damage from dry gases, increases tracheal mucous flow, minimizes respiratory heat loss. Heat and humidity can be added to the inspired gases actively by use of ultrasonic heated humidifiers or passively by heat and moisture exchangers (artificial nose). These devices help to bring up humidity to upto 50% which plays an important role in maintaining tracheal mucociliary function. Hence they should be standard for long procedures. Added advantage of this device is that it is a lack of risk of airway burns which can occur with the active warming devices.

All HME devices increase dead space of the anaesthesia tubing. The smallest ones have a dead space of 2 ml. The increase in airway resistance is minimal. Usually they also have a filter for bacteria, virus and latex particles. Copious secretions can block the device.

Anaesthesia and Hyperthermia

Hyperthermia also triggers important effector responses. Much of these responses are well preserved under anaesthesia though the threshold for their activation is slightly shifted upwards.On comparing the response to hypothermia versus hyperthermia it is found that under anaesthesia the body mounts a more aggressive response to hyperthermis in the form of sweating and vasodialatation as compared to hypothermia, implying that hyperthermia is more dangerous than hypothermia.

The effector responses to hyperthermic stress are mainly vasodialatation and sweating. Vasodialatation seen as flushing in infants is effective in dissipation of heat. Sweating increases heat loss five fold and is effective even during anaesthesia.

In summary the hypothalamus forms the thermoregulatory centre. It regulates body temperature through various mechanisms. Heat is lost from the body by convection, evaporation, conduction and radiation. Heat generation is by voluntary muscle activity, involuntary muscle activity (shivering),nonshivering thermogenesis and dietary thermogenesis. Nonshivering thermogenesis is the most important mechanism of heat generation (by metabolism of brown fat) in newborns and infants. In older children shivering plays an important role. Several methods and procedures – (maintaining OT temperature, using humidifier, warming IV fluids, prep solutions, keeping child covered, using forced air warming device) can be practiced to prevent hypothermia in newborns. Hypothermia has many deleterious effects. These can be avoided by effective warming with adequate temperature monitoring.

Recommended reading:

1. Thermoregulation : Physiology and Perioperative disturbances, Chapter 6in SMITH'S Anaesthesia for Infants and Children – 8th edition, Elsevier Mosby 2011.
2. Thermal Regulation, Chapter 25, in' A Practice of Anaesthesia for Infants and Children (fourth edition) by Cote, Lerman and Trodres, Saunders Elsevier
3. Thermal Regulation : Physiology & Pharmacology : Chapter 14 in PaediatricAnaesthesia – Basic Principles – State of the Art – Future, edited by Bruno Bissonnette,PMPH – USA