INTRODUCTION

Cesarean section is a common surgical procedure in which incisions are made through a mother's abdomen (laparotomy) and uterus (hysterotomy) to deliver one or more babies. It is usually performed when a vaginal delivery would put the baby's or mother's life or health at risk; although in recent times it has been also performed upon request for childbirths that could otherwise have been natural.[1]

Anaesthesia for cesarean section (CS)

Either regional or general anaesthesia is an acceptable approach for providing anaesthesia for cesarean delivery.[2]

Choice of anaesthetic approach

The anaesthetic plan for cesarean delivery should take into account the well-being of two subjects the mother and the fetus. In the United Kingdom regional anaesthesia is the most common method of anaesthesia for delivery because it allows the mother to be awake and immediately interact with her baby. It is also safer for the mother than general anaesthesia: a population-based study of anaesthesia related maternal deaths in the United States reported that maternal mortality associated with regional and general anaesthesia was 2 and 32 per million cases, respectively.[3]

In the United Kingdom general anaesthesia is less desirable for cesarean delivery because the mother is unconscious, thus unable to interact with her newborn. Two potential serious complications associated with general anaesthesia are failed intubation and pulmonary aspiration of gastric contents. Inhibition of upper airway reflexes and alterations of gastrointestinal function increase the risk of pulmonary aspiration. Airway reflexes are compromised by the loss of consciousness that occurs with induction of general anaesthesia. An advantage of regional anaesthesia is that the woman is awake and airway reflexes are maintained. However, aspiration may also occur during regional anaesthesia if airway reflexes are compromised by injudicious sedation. Furthermore, if the regional anaesthetic is inadequate, it may be necessary to induce general anaesthesia.[4]

The three main regional anaesthetic techniques are spinal, epidural, and combined spinal epidural (CSE).[5] In United Kingdom spinal and CSE anaesthesia are the most common regional anaesthetic choices for planned cesarean delivery. Many practitioners prefer these techniques over epidural because they have a rapid onset and lower incidence of failed block. Their use for cesarean birth was facilitated by the popularization of pencil-point needles, which dramatically reduced the incidence of postdural puncture headache.[6] Spinal anaesthesia is more desirable than epidural because the onset of the block is faster with a spinal approach.

Spinal Anaesthesia

Anatomy of Spinal Cord

Surrounding the spinal cord in the bony vertebral column are three membranes (from within to the periphery): the pia mater, arachnoid mater, and dura mater. The pia mater is a highly vascular membrane that closely invests the spinal cord (and brain). The arachnoid

mater is a delicate non-vascular membrane closely attached to the outermost layer, the dura. Between these two innermost membranes is the space of interest in spinal anaesthesia, the subarachnoid space. In this space are the CSF, spinal nerves, a trabecular network between the two membranes, and blood vessels that supply the spinal cord and the lateral extensions of the pia mater and the dentate ligaments. Although the spinal cord ends at the lower border of L1 in adults, the subarachnoid space continues to S2. The third and outermost membrane in the spinal canal is the longitudinally organized fibroelastic membrane, the dura mater. This layer is the direct extension of the cranial dura mater and extends as spinal dura mater from the foramen magnum to S2, where the filum terminale (an extension of the pia mater beginning at the conus medullaris) blends with the periostium on the coccyx.[7]

Posterior to the epidural space is the ligamentum flavum (the "yellow ligament"), which extends from the foramen magnum to the sacral hiatus. Immediately close to the ligamentum flavum are either lamina and spinous processes of vertebral bodies or the interspinous ligaments. Extending from the external occipital protuberance to the coccyx, posterior to these structures, is the supraspinous ligament, which joins the vertebral spines.[8, 9]

The sacral canal contains the terminal portion of dural sac, which typically ends cephalad to a line joining the posterior superior iliac spines, or S2. In addition to the dural sac, the sacral canal also contains a venous plexus, which is part of the valveless internal vertebral venous plexus.[10]

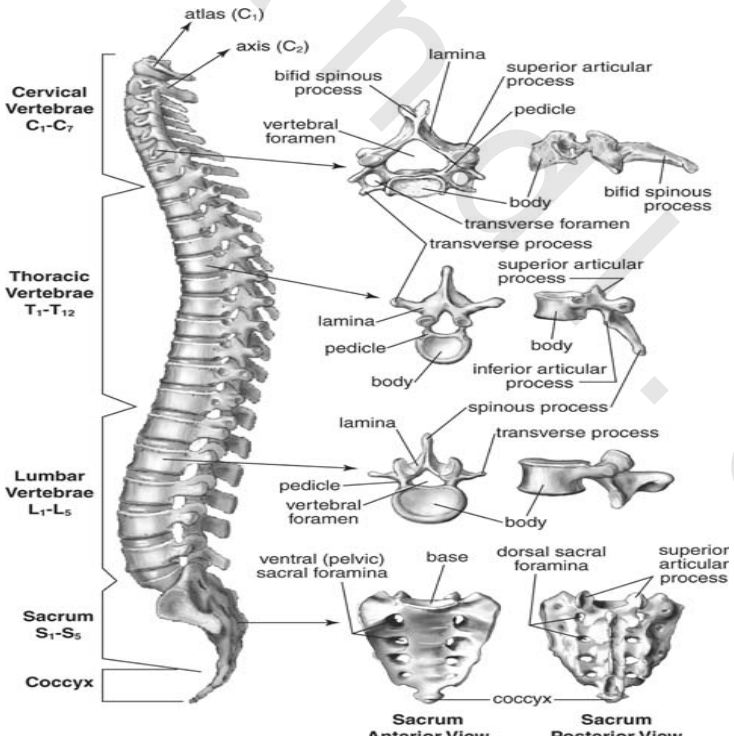

Figure (1): The vertebral column and the common features of the vertebrae.[7]

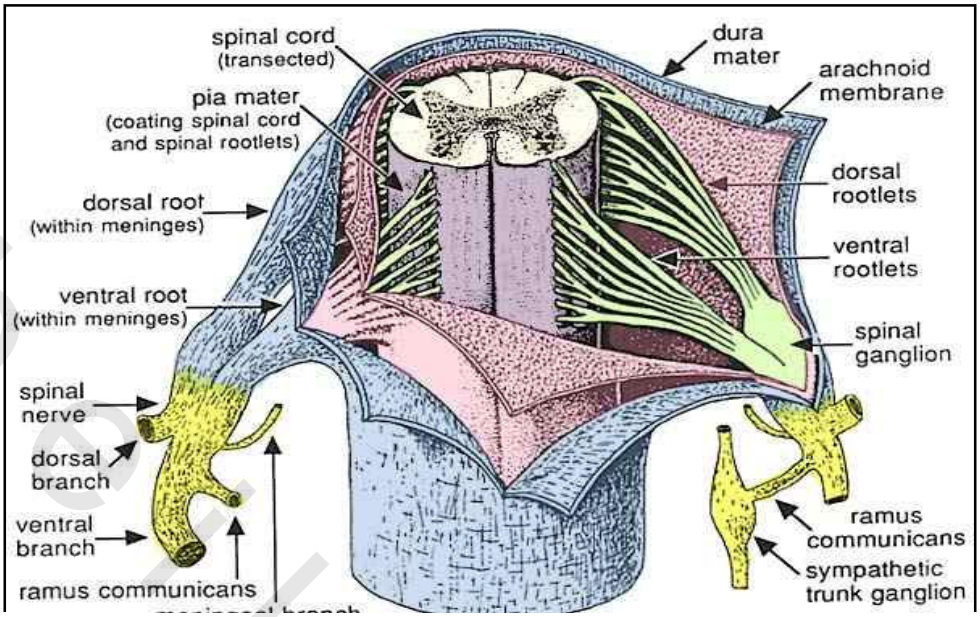

Figure (2): The coverings of the spinal cord.[11]

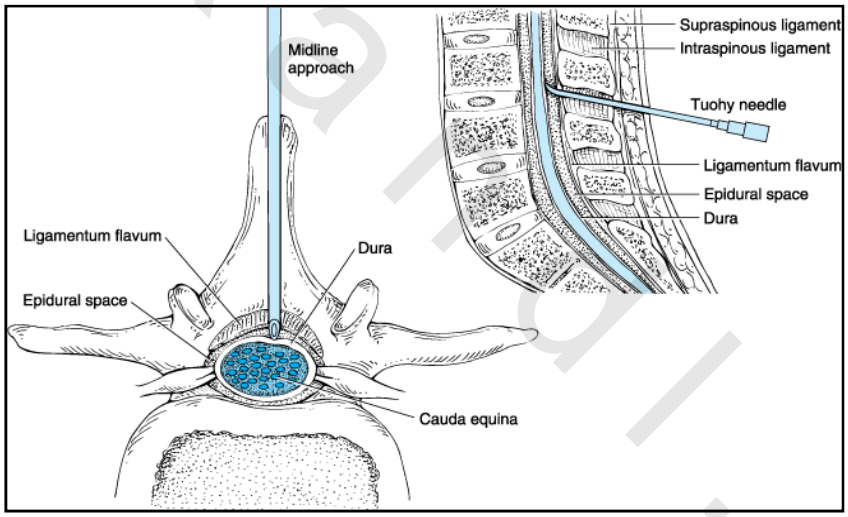

Figure (3): Structures pierced by an advancing spinal needle in the midline approach.[12]

Physiologic Effects of Spinal Anaesthesia

Central Nervous Effects

The sympathectomy that accompanies spinal anaesthesia is dependent upon the height of the block, with the sympathectomy typically described as extending for two to six dermatomes above the sensory level with spinal anaesthesia. This causes both venous and arterial vasodilatation, but because of the large amount of blood in the venous system (approximately 75% of total blood volume), the venodilatation effect predominates because of the limited amount of smooth muscle in venules, whereas the vascular smooth muscle on the arterial side of the circulation retains a considerable degree of autonomous tone.[13]

Cardiovascular Effects

After spinal block-induced sympathectomy, if normal cardiac output is maintained, total peripheral resistance should decrease only 15 to 18 percent in normovolaemic healthy patients, even with near-total sympathectomy. In elderly patients with cardiac disease, systemic vascular resistance may decrease almost 25 percent following spinal anaesthesia, whereas cardiac output decreases only 10 percent.[13]

Heart rate during high spinal block typically decreases as a result of blockade of the cardio-accelerator fibers arising from T1 to T4. Additionally, the heart rate may decrease as a result of a fall in right atrial filling, which decreases outflow from intrinsic chronotropic stretch receptors located in the right atrium and great veins.[14]

When coronary artery blood flow and myocardial metabolism were determined in humans during spinal anaesthesia to T4 in both hypertensive and normotensive patients, decreases in coronary blood flow paralleled the decrease in mean arterial blood pressure and the percentage extraction of myocardial oxygen was unchanged .The extraction of oxygen was unchanged because myocardial work, as expressed by myocardial utilization of oxygen, paralleled the decrease in mean arterial pressure and coronary blood flow .[15]

Hypotension during spinal analgesia is a result of sympathetic blockade leading to decreased venous return and decreased systemic vascular resistance. The major factor of development of hypotension is the level of block. Once arterial blood pressure decreases to a level for which treatment is believed necessary, ephedrine can be given. Ephedrine is a non-specific adrenergic agonist, and increases blood pressure mainly by increasing cardiac output (β-effect) with a smaller contribution from vasoconstriction (α-effect). Ephedrine's action is mainly indirect, via stimulating release of norepinephrine from sympathetic nerve terminals.[16]

The extent to which arterial blood pressure decreases with spinal anaesthesia is obviously dependent on multiple factors, including patient age, intravascular volume status and the number of spinal segments blocked.[17]

Respiratory Effects

Alterations in pulmonary variables in healthy patients during neuraxial block are usually of little clinical consequence. Tidal volume remains unchanged during high spinal anaesthesia, and vital capacity decreases slightly.[18] This decrease in vital capacity is a result of a decrease in expiratory reserve volume related to paralysis of abdominal muscles necessary for forced exhalation, rather than a decrease in phrenic or diaphragmatic function. This minimal impact on pulmonary function also holds for elderly patients undergoing lumbar and thoracic epidural anaesthesia.[19]

The rare respiratory arrest associated with spinal anaesthesia is also unrelated to phrenic or inspiratory dysfunction, but rather, is related to hypoperfusion of the respiratory centers in the brain stem. Supportive evidence for this concept is observed after resuscitation, when apnea almost always disappears as soon as pharmacologic and fluid therapies have restored cardiac output and blood pressure. This would not be the case if phrenic paralysis due to high levels of local anaesthetic were the cause of apnea.[20]

Gastrointestinal Function

Nausea and vomiting may be associated with neuraxial block in up to 20 percent of patients and is primarily related to GI hyperperistalsis due to unopposed vagal activity. Accordingly, atropine is effective in treating nausea associated with high (T5) subarachnoid anaesthesia.(21)

An advantage of regional anaesthesia in patients with compromised GI function (e.g., hepatic dysfunction) is that less physiologic impairment is possible as compared with general anaesthesia. Nevertheless, it appears that if intra-abdominal surgery is performed, the magnitude of decrease in hepatic blood flow parallels the site of operation, rather than anaesthetic technique chosen. Additionally, the decrease in hepatic blood flow during spinal anaesthesia parallels the decrease in mean arterial blood pressure.(22)

Renal Function

Renal function has a wide physiologic reserve. Despite predictable decreases in renal blood flow accompanying neuraxial block, the decrease is of little physiologic importance. One aspect of genitourinary function, that is of clinical importance, is the belief that neuraxial blocks are a frequent cause of urinary retention, which either delays discharge of outpatients or necessitates bladder catheterization in inpatients. It is clear that lower concentrations of local anaesthetic are necessary for paralysis of bladder function than for motor nerves to lower extremities.(23)

Bupivacaine hydrochloride

Bupivacaine has probably had the greatest influence on the practice of regional anaesthesia since the introduction of lidocaine. It is three to four times as potent as lidocaine and considerably longer lasting. It has been used for all manner of blocks when prolonged analgesia is required.(24)

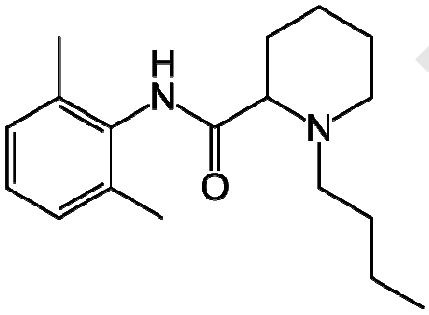

Figure (4): Structural formula of bupivacaine hydrochloride (24)

Chemically, bupivacaine is an anilide, 1-n-butyl DL piperidine-2-carboxylic acid 2-3 dimethyl anilide HCl. Its molecular weight is 302, pKa 8.1, partition coefficient 560 and protein binding percentage 95%. It was the first local anaesthetic that combined the properties of acceptable onset, long duration of action, profound conduction blockade and significant separation of sensory anaesthesia and motor blockade, and it is used in concentrations of 0.125%, 0.25%, 0.5% and 0.75% for various regional anaesthetic procedures, including infiltration, peripheral nerve blocks, epidural and spinal anaesthesia.

The average duration of action of bupivacaine varies approximately from 3 to 10 hours. Its longest duration of action occurs when major peripheral nerve blocks such as brachial plexus blockade are performed. In these cases, average duration of action of 10 to 12 hours has been reported.[24]

The possible pathways for metabolism of bupivacaine include aromatic hydroxylation, N-dealkylation, amide hydrolysis conjugation. The urinary excretion of bupivacaine as dealkylation and hydroxylation metabolites account for more than 40% of the total anaesthetic dose administered.[25]

Bupivacaine appears to be more cardiotoxic than other agents, because it is more potent and has high lipid solubility and high binding state. It can produce sino-atrial suppression resulting in nodal and ventricular arrhythmias at levels far below those detected for CNS toxicity (serum ratio of CVS: CNS toxicity is 4:1). Even though bupivacaine is 4 times more potent than lidocaine, yet it is 16 times more cardiotoxic. The cardiotoxicity is due primarily to blockade of cardiac muscles' sodium channels. Generally, lidocaine has a fast in, fast out binding characteristic while bupivacaine has a fast in, slow out characterisitic (about 10 times slower than lidocaine). One of the specific features of bupivacaine is that accumulation of the drug in plasma may be absent until a fairly late stage because of its high affinity for plasma protein binding sites (alpha-1 acid glycoprotein and albumin). The free concentration of the drug in plasma remains low until all the protein binding sites are fully occupied after which it increases rapidly leaving a significant mass of unbound drug available for diffusion into the conducting system of the heart. Thus, toxicity can occur without the patient exhibiting signs of central nervous system toxicity before cardiovascular collapse. The cardiotoxic plasma concentration of bupivacaine is 8-10 µg/mL.[26]

Thermoregulation

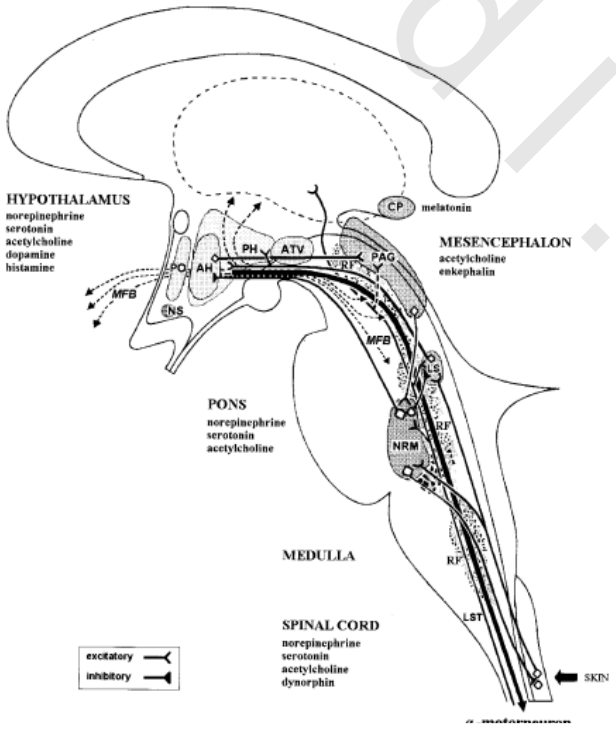

Figure (5): Neural pathways in the control of shivering.[27]

Afferent input

Temperature information is obtained from thermally sensitive cells throughout the body. Cold-sensitive cells are anatomically and physiologically distinct from those that detect warmth. Warm receptors increase their firing rates when temperature increases, while cold receptors do so when temperature decreases.[28]

Cold signals travel primarily by Aδ nerve fibers and warm information by unmyelinated C fibers, although some overlap occurs. C fibers also detect and convey pain sensation, which is why intense heat cannot be distinguished from sharp pain.[29]

Most ascending thermal information traverses the spinothalamic tracts in the anterior spinal cord, but no single spinal tract is critical for conveying thermal information. The hypothalamus, other parts of the brain, deep abdominal and thoracic tissues and the skin surface each contribute roughly 20% of the total thermal input to the central regulatory system.[30]

Central control

Temperature is regulated by central structures (primarily the hypothalamus) that compare integrated thermal inputs from skin surface, neuraxis and deep tissues with threshold temperatures for each thermoregulatory response. It is likely that some regulatory responses can be mounted by spinal cord alone.[31]

Efferent responses

The body responds to thermal perturbations (body temperature differing from the appropriate threshold) by activating effector mechanisms that increase metabolic heat production or alter environmental heat loss. Each thermoregulatory effector has its own threshold and gain, so there is an orderly progression of responses and response intensities in proportion to the need. In general, energy-efficient effectors such as vasoconstriction are maximized before metabolically costly responses such as shivering are initiated.[32]

Effectors determine the ambient temperature range that the body will tolerate while maintaining a normal core temperature. When specific effector mechanisms are inhibited (e.g. shivering prevented by administration of muscle relaxants), the tolerable range is decreased. Still, temperature will remain normal unless other effectors cannot compensate for the imposed stress.[33]

Quantitatively, behavioral regulation (e.g. dressing appropriately, modifying the environmental temperature, assuming positions that oppose skin surfaces, and voluntary movement) is the most important effector mechanism. Cutaneous vasoconstriction is the most consistently used autonomic effector mechanism. Nonshivering thermogenesis increases metabolic heat production (measured as whole-body oxygen consumption) without producing mechanical work. Metabolic heat is lost primarily through convection and radiation from the skin surface, and vasoconstriction reduces this loss.[34]

Decreased muscle mass, neuromuscular diseases, and muscle relaxants all inhibit shivering, which increases the minimum tolerable ambient temperature. Similarly,

anticholinergic drugs inhibit sweating, which decreases the maximum tolerable temperature.[35]

Thermoregulation of neuraxial anaesthesia

Epidural anaesthesia and spinal anaesthesia each decreases the thresholds triggering vasoconstriction and shivering (above the level of the block) by about 0.6˚C. Also, regional anaesthesia blocks all thermal inputs from blocked regions, which in the typical case is primarily cold information. The brain may then interpret decreased cold information as relative leg warming. Because skin temperature is an important input to the thermoregulatory control system, leg warming proportionately decreases the vasoconstriction and shivering thresholds. Painful stimulation slightly increases vasoconstriction thresholds. Consequently, thresholds are somewhat lower when surgical pain is prevented by simultaneous local or regional anaesthesia. Furthermore, the reduction in thresholds is proportional to the number of spinal segments blocked.[36,37]

Neuraxial anaesthesia is frequently supplemented with sedative and analgesic medications. With the exception of midazolam, all significantly impair thermoregulatory control. Such inhibition may be severe when combined with the intrinsic impairment produced by regional anaesthesia and other factors, including advanced age and preexisting illness.[38]

To conclude, neuraxial anaesthesia inhibits numerous aspects of thermoregulatory control. The vasoconstriction and shivering thresholds are reduced by regional anaesthesia and further reduced by adjuvant drugs and advanced age. Even once triggered, the gain and maximum response intensity of shivering are about half normal. Finally, behavioral thermoregulation is impaired. The result is that cold defenses are triggered at a lower temperature than normal during regional anaesthesia, defenses are less effective once triggered, and patients frequently do not recognize that they are hypothermic. Because core temperature monitoring remains rare during regional anaesthesia, substantial hypothermia often goes undetected in these patients.[39,40]

Heat balance

Hypothermia is defined as a core body temperature less than 36°C, heat loss is multifactorial: 60% by radiation, 20% by evaporation (humidification of inspired gases and fluid loss from the surgical field, especially if the abdomen or thorax is opened), 5% by conduction (contact with the operating room table), and 15% by convection (warming of air flowing over the skin).[41]

Hypothermia is common during regional anaesthesia and may be nearly as severe as general anaesthesia. Core temperature typically decreases 0.5˚C to 1.0˚C shortly after induction of anaesthesia. However, the vasodilatation induced by regional anaesthesia only slightly increases cutaneous heat loss. Furthermore, metabolic heat production remains constant or increases because of shivering thermogenesis. This rapid decrease in core temperature, similar to that noted after induction of general anaesthesia, also results from an internal core-to-peripheral redistribution of body heat.[42,43]

Subsequent hypothermia is simply due to heat loss exceeding metabolic heat production. Not only is the vasoconstriction threshold centrally impaired by regional

anaesthesia, but more importantly, vasoconstriction in the legs is also directly prevented by nerve block.[44]

The physiological body responses to hypothermia

1. Vasoconstriction

Vasoconstriction occur secondary to sympathetic stimulation. General anaesthesia reduces the threshold for vasoconstriction. Vasoconstriction is more or less an "on-off" response.[45]

2. Shivering

The threshold for shivering is decreased by general anaesthetics even more than that for vasoconstriction. Two types of shivering are described. One type is a tonic pattern, resembling normal shivering, with a 4–8 cycles per minute waxing-and-waning component. The second is a phasic, 5–7 Hz bursting pattern resembling clonus, which is specific to the post anaesthesia care unit (PACU). This latter type of shivering is secondary to volatile anaesthetics and probably results from anaesthetic-induced disinhibition of normal descending control over spinal reflexes. Shivering can increase the oxygen consumption by 300–500%, thus leading to myocardial ischemia in susceptible patients. It can also increase the serum potassium level.[46]

3. Nonshivering thermogenesis

Nonshivering thermogenesis can double the metabolic heat production in infants but it plays an unimportant role in adults. It is inhibited by general anaesthesia.[46]

The different sites at which temperature can be monitored:

Body temperature may be monitored via the oral, rectal, esophageal, nasopharyngeal, and tympanic membrane sites. It can also be monitored via a pulmonary artery catheter (PAC) or a urinary bladder catheter.

Each monitoring site has advantages and disadvantages. The tympanic membrane theoretically reflects brain temperature because the auditory canal's blood supply is the external carotid artery. Trauma during insertion and cerumen insulation detract from the routine use of tympanic probes. Rectal temperatures have a slow response to changes in core temperature. Nasopharyngeal probes are prone to cause epistaxis but accurately measure core temperature if placed adjacent to the nasopharyngeal mucosa. The thermistor on a pulmonary artery catheter also measures core temperature. There is a variable correlation between axillary temperature and core temperature, depending on skin perfusion. Liquid crystal adhesive strips placed on the skin are inadequate indicators of core body temperature during surgery. Esophageal temperature sensors, often incorporated into esophageal stethoscopes, provide the best combination of economy, performance, and safety. To avoid measuring the temperature of tracheal gases, the temperature sensor should be positioned behind the heart in the lower third of the esophagus. Conveniently, heart sounds are most prominent at this location.[45]

Complications of mild intraoperative hypothermia

Coagulation is impaired by mild hypothermia. The most important factor appears to be a cold-induced defect in platelet function. Interestingly, the defect in platelet function is related to local temperature, not core temperature.[47]

Hypothermia can contribute to wound infections both by directly impairing immune function and indirectly triggering thermoregulatory vasoconstriction, which in turn decreases wound oxygen delivery. It is well established that fever is protective and that infections are aggravated when naturally-occurring fever is inhibited.[48]

Furthermore, hypothermia delays wound healing and prolongs the duration of hospitalization by 20%, even in patients without infection.[49]

Thermal comfort is markedly impaired by postoperative hypothermia. Patients, being asked years after surgery, often identify feeling cold in the immediate postoperative period as the worst part of their hospitalization, sometimes rating it worse than the surgical pain.[50]

Postoperative thermal discomfort is also physiologically stressful because it elevates blood pressure, heart rate, and plasma catecholamine concentrations. These factors presumably contribute to what may be the most important consequence of mild perioperative hypothermia; morbid myocardial outcomes.[51]

As might be expected from the pharmacokinetic and pharmacodynamic effects of hypothermia, the duration of post anaesthetic recovery is significantly prolonged, even when temperature is not a discharge criterion.[52]

Lastly, hypothermia causing shivering may be responsible for increased intracranial and intraocular pressure.[53]

Intra-operative shivering is very uncomfortable for patients and may interfere with monitoring of electrocardiogram, blood pressure, and pulse oxygen saturation by pulse oximetry. Its incidence has been reported to be 50%-60% in different reports.[54,55] It increases oxygen consumption, heart rate, cardiac output and carbon dioxide production. It causes lactic acidosis, haemodynamic changes and increases pain at the site of operation; thus, it may cause distress to patients with low cardiopulmonary reserve.[56]

The modalities to prevent and treat hypothermia

a. Redistribution is best prevented by initiating skin warming before induction.[41]

b. Radiation heat loss is proportional to the fourth power of the difference between the absolute temperatures of the surfaces and can be limited by increasing the room temperature. Radiant warmers are only used for infants, facilitate keeping the patient warm while still visible, and preclude the need to increase the room temperature. However, radiant warmers become less effective as the distance to the patient increases. In addition, they do not decrease convection heat loss.[57]

c. Fluid heating has limited efficacy. Fluid warming should be used if a large volume of fluid is administered. One liter of crystalloid at room temperature or one unit (250 mL) of refrigerated blood will decrease the temperature by about 0.25°C. [58]

d. Insulation will decrease heat loss by only 30% with one layer of fabric (sheet or blanket), with little additional benefit from additional layers.[57]

e. Overall, forced-air warming (e.g., Bair Hugger blankets) is the most effective warming and rewarming method. It is more effective when patients are vasodilated. It is, therefore, better to maintain normothermia from the start of the procedure rather than to rewarm postoperatively. Rewarming a vasoconstricted patient can lead to hypotension secondary to vasodilatation if the volume status is not maintained.[58]

f. Circulating-water mattresses placed on the operating room table have little efficacy, since 90% of the heat is lost from the surface of the body that is exposed and is not in contact with the table. Never use hot-water bottles! They are the leading cause of perioperative thermal injury according to the ASA Closed-Claims database.[59]

The same drugs that are effective for post anaesthetic tremors are also useful for shivering during regional anaesthesia; these drugs include pethidine (25 mg intravenously), clonidine (0.075 mg IV) and magnesium sulfate (30 mg/kg IV).[60]

Many studies confirmed that the combined use of warm parenteral fluids and warm local anaesthetics significantly reduced the incidence of shivering. Some researchers have studied the effects of local anaesthetic temperature after injection into the epidural space on shivering.[61]

The result of another study suggested the existence of thermosensory mechanisms in the spinal canal and the effect of warming epidural anaesthetic solutions prior to injection to reduce the incidence of shivering.[62]