The principles and conduct of anaesthesia

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Abstract

Anaesthesia is one of the younger specialties of medicine and has made immense advancement since its inception. The development of modern anaesthesia techniques, drugs, and monitoring methods has facilitated the development and advancement of surgical practice, which benefits patients. In this article, we provide an overview of the pharmacology and the conduct of a general anaesthetic. Regional anaesthesia has always been an integral part of the practice of anaesthesia and surgery. We discuss the essential components of the practice of neuraxial anaesthesia and peripheral nerve blocks. It is known that many surgical trainees are deficient in the knowledge of safe administration of local anaesthetics, which we have tried to address in this article.

Keywords Epidural anaesthesia; inhalational anaesthetics; intravenous anaesthetics; local anaesthetics; nerve blocks; spinal anaesthesia

Introduction

Every year 266–359 million operations are performed worldwide which need general anaesthesia, regional anaesthesia or deep sedation to control pain.[1]

There are many options available to a patient ranging from general anaesthesia, central neuraxial anaesthesia (spinal, epidural and combined spinal-epidural), peripheral nerve blocks and local anaesthesia, as a sole anaesthetic or in combination. The choice of an option depends on many factors such as the type and site of surgery, patient's premorbid conditions, and patient consent.

In the UK NHS hospitals, 700,000 central neuraxial blocks (spinals, epidurals, and combined spinal-epidurals), are performed every year. A rough estimate suggests at least 8–10% of all operations are performed under neuraxial anaesthesia in the UK.[2] Over 90% of caesarean sections, more than 60% of hip replacements and more than 50% of knee replacements are carried out under a central neuraxial block (CNB).

The use of ultrasound has improved the reliability and success rates of peripheral nerve blocks, and with the addition of adjuvants such as dexamethasone prolonged analgesia can be ensured keeping patients comfortable through to discharge home. Many upper and lower limb procedures can be performed as ambulatory surgery without the need for a general anaesthetic.

Many surgical procedures are performed under a general anaesthetic, particularly coelomic surgeries. Balanced anaesthesia refers to the concept of using a combination of anaesthetic drugs to provide optimal operative conditions. This approach reduces the dose of multiple anaesthetics drugs to a safer level. If only one drug was to be used to achieve good operative conditions, the chances of potentially harmful side effects are significantly higher.

General anaesthesia

The conduct of general anaesthesia has come a long way since the first anaesthetic delivered by Morton using ether in 1846 at Massachusetts General Hospital. Major strides in airway management and the discovery of new drugs have enabled delivery of what we today know as balanced anaesthesia.

Loss of consciousness, analgesia, and muscle relaxation are the three main components of a balanced anaesthetic.

General anaesthesia is defined as a state of controlled loss of consciousness using one or more anaesthetic agents. These agents can be broadly divided into intravenous and inhalational based on the mode of administration.

Intravenous agents

Injected intravenously, these agents bring about loss of consciousness usually within one arm-brain circulation time. They are fat soluble and penetrate the blood-brain barrier to exert their effect.

Propofol is the most commonly used intravenous agent. It is a phenolic derivative presented as a lipid soluble, oil-water emulsion. It is available as a 1% or 2% solution. Ease of administration, rapid onset and easy titratability has made propofol the drug of choice for induction of majority of general anaesthetics. It is also used for total intravenous anaesthesia (TIVA) and sedation during regional anaesthesia, patient transfers and on the intensive care unit. It obtunds upper airway reflexes and is ideal for use with supraglottic airways like laryngeal mask airways (LMAs). Its mechanism of action is believed to be by the reduction in the opening time of sodium channels. Common side effects include respiratory depression, apnoea, hypotension and pain on injection. Propofol infusion syndrome characterized by multiorgan failure leading to death, when high doses of propofol are used for sedation, had led to the withdrawal of its license for use in paediatric sedation.

Thiopentone or *thiopental sodium* is a barbiturate used as an IV induction agent. Dose ranges between 3 and 6 mg/kg. First used in the 1930s, it has stood the test of time and remains the most common induction agent used in obstetric anaesthesia. It is also used as an anticonvulsant and to reduce raised intracranial pressure in neuroanaesthesia and critical care. It is presented in powder form that needs to be diluted in sterile water. It exerts its effect by increasing the conductance of chloride ions into nerve cells through GABA (gamma-aminobutyric acid) channels resulting in neuronal inhibition through hyperpolarization. Common side effects include respiratory depression, apnoea, hypotension and tachycardia. It can precipitate a crisis in patients with porphyria. Crystallization and limb-threatening distal

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ischaemia due to precipitates have been reported with inadvertent intra-arterial injection.

Ketamine is a phencyclidine used as an IV induction agent on its own or in combination with other induction agents. It is unique as it can also be administered intramuscularly or orally. Ketamine has potent analgesic effects and has been used in the treatment of acute and chronic pain. It is commonly used in the obtunded or shocked patient as, unlike other induction agents it causes sympathetic stimulation, an increase in cardiac output, blood pressure and heart rate. Airway reflexes and respiratory depression are not as reliably suppressed as with other agents. It acts mainly through NMDA (N-methyl D-aspartate) receptors by antagonizing glutamate the excitatory neurotransmitter. The most common side effects include hallucinations and unpleasant emergence phenomenon. Ketamine is classed as a controlled drug due to its abuse potential.

Other less commonly used intravenous induction agents include etomidate, an imidazole compound, benzodiazepines (e.g. midazolam) and opioids (e.g. fentanyl). The latter two are more frequently used as co-induction agents rather than sole induction agents.

Inhalational agents

Inhalational agents were the first anaesthetic agents to be used. Humphrey Davy demonstrated the use of nitrous oxide in 1800. Ether was the first ever documented modern day anaesthetic agent used by Morton in 1846. Chloroform followed shortly in 1847. Neither of the two are today used as anaesthetic agents in the developed world, due to their side effects and availability of better agents.

Nitrous oxide has analgesic properties but not potent enough to be used on its own to produce anaesthesia. It is used as a carrier gas in combination with other volatile agents and as Entonox®, a 50:50 mixture with oxygen for labour analgesia and other painful procedures in the hospital and in the field. Common side effects include expansion of air-filled cavities, bone marrow suppression, and emetogenesis. Unlike other anaesthetic gases, its administration does not always need the presence of an anaesthetist.

The modern-day inhalational agents are halogenated hydrocarbons. They are mostly used for maintenance of anaesthesia. They require an accurately calibrated vaporizer to be administered safely. Their potency is measured in terms of the minimum alveolar concentration (MAC). Depending on the MAC used they cause respiratory depression and apnoea, vasodilatation and hypotension. All volatile anaesthetics can precipitate potentially fatal malignant hyperthermia (MH) in susceptible patients.

Halothane is a non-irritant volatile agent that can be used for inducing and maintaining anaesthesia. Its serious side effects include halothane hepatitis and cardiac arrhythmias. Its usage has declined due to its side effect profile.

Sevoflurane is a non-irritant agent commonly used for maintaining and inducing anaesthesia in children and adults where intravenous cannulation is not possible. It has a quicker onset and offset compared to halothane. It is less likely to be arrhythmogenic but theoretically can cause renal damage by the production of compounds in the breathing circuit.

Isoflurane is irritant to the airways it can only be used for maintenance of anaesthesia. A relatively slow offset of action can lead to longer recovery times compared to newer and more expensive agents like sevoflurane or desflurane.

Desflurane also irritant to the airways can only be used for maintenance of anaesthesia. It has a rapid offset and commonly used in cases where rapid awakening is required. It is more expensive compared to other agents and this usually limits its use.

Muscle relaxants

Muscle relaxation is indicated to facilitate tracheal intubation and provide optimal conditions for surgery. Muscle relaxants do not provide anaesthesia and should never be used in the absence of an anaesthetic agent. Not all patients having a general anaesthetic require muscle relaxation those that do not need tracheal intubation or that can be allowed to breathe spontaneously can be operated upon without the use of a muscle relaxant. A vast majority of modern-day ventilators will also support ventilation without the presence of muscle relaxation by synchronizing with the patient's respiratory effort.

All muscle relaxants act on the neuromuscular junction by inhibiting the propagation of the action potential from the nerve to the muscle, causing muscle paralysis.

Normally conduction of the action potential releases acetylcholine containing vesicles into the synaptic cleft. This, in turn, leads to an influx of sodium into the motor end plates and an endplate potential resulting in muscle contraction.

Historically muscle relaxants have been classified as depolarizing and non-depolarizing agents.

Depolarizing muscle relaxants: Suxamethonium chloride (or succinylcholine) is a rapidly acting muscle relaxant of short duration is simply two acetylcholine molecules joined by acetyl bonds. Due to its structure, it mimics the action of acetylcholine at the nicotinic acetylcholine receptors in the neuromuscular junction. However, unlike acetylcholine, it does not get hydrolysed by acetylcholine esterase and stays in situ causing prolonged depolarization and muscle relaxation. The muscle relaxes only after the calcium is removed from the muscle cell cytoplasm independent of repolarization. Serious side effects such as malignant hyperthermia, anaphylaxis, suxamethonium apnoea, arrhythmias, hyperkalemia, muscle pains have led to the decline in its use.

Non-depolarizing muscle relaxants:[3] These are competitive antagonists at the acetylcholine receptors. They occupy the receptors and competitively inhibit acetylcholine. As their concentration increases complete blockade of neuromuscular transmission occurs. Their action can be reversed by anticholinesterases like neostigmine which allows acetylcholine stores to increase at the neuromuscular junction. Neostigmine is given in combination with an anticholinergic such as glycopyrrolate to avoid the precipitation of muscarinic side effects such as bradycardia. It is also important to remember that neostigmine will only act as the block is wearing off, but will fail to work in a dense block. A newer reversal agent sugammadex is useful in the reversal of muscle relaxants that have the amino-steroid structure (e.g. rocuronium). Unlike neostigmine, sugammadex has a dose-dependent action and can be used even in a dense block.

Non-depolarizing muscle relaxants can be broadly divided based on their duration of action.

Short duration of action – *Mivacurium* was introduced in the UK in 1993 as a muscle relaxant for short elective procedures. It is a benzylisoquinoline ester molecule. It undergoes rapid degradation by cholinesterases. Patients deficient in pseudocholinesterase will exhibit an abnormally prolonged duration of action. It has weak histamine-releasing properties.

Medium duration of action – *Atracurium* is also a benzylisoquinoline ester, marketed in the UK since 1982. Part of it undergoes spontaneous degradation in the body (Hoffman degradation) and is useful in patients with hepatic or renal diseases. Part of it is also metabolized by lung and plasma esterases. It causes moderate histamine release; cardiovascular side effects are rare.

Rocuronium is an amino-steroid, first used in clinical practice in 1995. It has to some extent replaced suxamethonium in rapid sequence inductions as it acts almost as quickly in the appropriate dosage and can be reversed by sugammadex. It has a better side effect profile than suxamethonium. It has mild vagolytic effects.

Vecuronium has been available since 1980 and is similar in structure to rocuronium. It comes in powder form that needs to be reconstituted. Vecuronium is devoid of cardiovascular side effects and is the drug of choice in patients with atopy as it does not release histamine.

Long duration of action – *Pancuronium* is an amino-steroid available since 1967. It has a long duration of action. Tachyarrhythmias may be a problem for a select group of patients. Its use has declined in recent years.

Adjuncts to anaesthesia

Analgesia: Adequate analgesia is very important in the perioperative period. Balanced anaesthesia requires multimodal analgesia. The dosage of anaesthetic agents decreases considerably in the presence of optimal analgesia. Good pain control in the perioperative period decreases the potential harmful effect of sympathetic stimulation. It is also known to decrease the incidence of chronic pain. Commonly used systemic drugs include paracetamol, non-steroidal anti-inflammatory drugs, opioids and less commonly used ones like clonidine, ketamine, magnesium. Local infiltration, regional and central neuraxial methods are also widely used.

Antiemetics: Postoperative nausea and vomiting (PONV) is a well-researched complication with well documented contributory risk factors that include patient, surgical, anaesthetic factors. Antiemetics commonly used are 5-HT_3 antagonists (e.g. ondansetron), anticholinergics (e.g. cyclizine) and steroids (e.g. dexamethasone). These can be given prophylactically intraoperatively and as rescue postoperatively.

Good control over pain and postoperative nausea and vomiting is crucial to excellent patient experience and success of a day case service.

The conduct of general anaesthesia

Broadly this is classified as preoperartive, intraoperative or postoperative.

Preoperative: Once a patient is listed for an elective procedure, a preoperative anaesthetic assessment is scheduled and carried out by trained pre-assessment personnel. A detailed history, relevant examination and investigations are carried out. Any issues identified at this time are referred on to either the anaesthetist or a specialist that can advise on optimizing the patient. Elective patients will also be seen by the anaesthetist on the day of the procedure. In the case of an urgent or emergent procedure a patient gets assessed usually by the anaesthetist on the day of surgery. Any special arrangements, e.g. provision for difficult airway, blood loss, high dependency or intensive care need to be communicated to the team caring for the patient.

Intraoperative: Divided into three phases: Induction, maintenance, and emergence.

Induction of general anaesthesia is a critical phase; it involves the administration of potent drugs with life-threatening side effects in a short time interval. It is also a time when the airway is secured and failure to do so can be catastrophic. It could be the time of most hemodynamic instability and a trained assistant should always be available.

Maintenance of general anaesthesia involves the use of various agents to continue balanced anaesthesia. The anaesthetist monitors and maintains cardiorespiratory and anaesthetic parameters within the normal range. The Association of Anaesthetists for Great Britain and Ireland has set out standard monitoring that should be available for all patients undergoing an anaesthetic. Specialist monitoring will be indicated in patients that are medically or surgically complex (e.g. invasive arterial and central venous pressure).

Emergence from anaesthesia is more than the discontinuation of anaesthesia. Reversal of anaesthetic agents, e.g. muscle relaxant and extubation of the trachea in an intubated patient happens at this stage. Timing and assessing the patient for readiness for reversal are crucial to the delivery of a safe anaesthetic.

Postoperative: The majority of patients will be recovered in the post anaesthesia care unit (PACU), within the theatre suite close to where the patient was anaesthetized. This may be divided into a stage 1 recovery and a stage 2 recovery area or patients may be directly discharged to the ward from the stage 1 recovery area. Monitoring and management of any postoperative complications occur at this time; this may be analgesia, postoperative nausea vomiting, hypothermia or more serious complications like bleeding or organ failure. Once stable the patients are discharged to the ward.

High-risk patients that require intensive care or high dependency care postoperatively may bypass the post anaesthetic care unit and be admitted directly to their destination wards with specialized monitoring or adjuncts in situ.

Regional anaesthesia

Regional anaesthesia inhibits transmission of nociceptive impulses to the central nervous system by blocking nerves in a region of the body or at the level of spinal cord. The quality of pain relief provided by regional anaesthesia is superior to opioids. According to a Cochrane review, neuraxial anaesthesia, when used on its own, reduces the risk of perioperative mortality by 29% and the risk of pneumonia by 30–55%.[4] It may reduce the length of stay in the hospital after lower limb arthroplasty.[5]

Neuraxial block: spinal (subarachnoid), epidural anaesthesia and caudal anaesthesia

Spinal anaesthesia is used for providing anaesthesia and analgesia for the surgery of lower abdomen, pelvis and lower limbs. It is sited at a lower lumbar level (L3 and below) to avoid any potential damage to the spinal cord. Epidurals are sited at both thoracic and lumbar levels, commonly to provide postoperative analgesia but could be used as the main mode of anaesthesia (e.g. using an epidural sited for labour analgesia for a caesarean section). Caudal anaesthesia is essentially an epidural block used in the paediatric population mainly. It is relatively easy to perform and provides good analgesia for procedures in the distribution of lumbar and sacral nerves (e.g. herniorrhaphy and circumcision).

Local anaesthetics with or without opioids could be used for neuraxial blocks. Addition of opioids improves the quality of block, provides extended postoperative pain relief and reduces the side effects of local anaesthetics by reducing their dose (e.g. lower limb arthroplasty). Epidural infusion of a dilute local anaesthetic containing low-dose short-acting opioid is often used for labour analgesia and postoperative analgesia after procedures such as thoracotomy and laparotomy, for example bupivacaine 0.1% with fentanyl 2 μg/ml is often used for postoperative epidural infusions.

Complications of neuraxial anaesthesia

Immediate complications: *Nausea and vomiting* after a spinal anaesthetic are common, especially in the parturient population. Most commonly, this is due to hypotension secondary to sympathetic blockade. Other factors include the use of intrathecal opiates, exteriorization of the uterus, peritoneal stimulation.

Hypotension after spinal anaesthesia is primarily the result of blockade of preganglionic sympathetic fibers. The degree of hypotension is mainly related to the level of the sympathetic block but there are many other factors which could affect the drop in the blood pressure, e.g. preoperative hypovolemia, history of hypertension, high BMI, the urgency of surgery and chronic alcohol consumption. Spinal anaesthetic causes venodilatation reducing venous return (preload) significantly and arterial vasodilatation reducing the afterload leading to a fall in the cardiac output. A high block (sensory block higher than T5) could lead to bradycardia due to blockade of cardiac accelerator fibers (thoracic segments) and further fall in the blood pressure.

Postoperative hypotension in a previously stable patient is rarely due to an epidural analgesic infusion. A thorough clinical assessment of such patients establishing the segmental level of sensory block is the first step. Overlooking other important factors such as the fluid deficit, bleeding, sepsis, and adverse cardiovascular events could be catastrophic.[6]

High block and total spinal anaesthesia: sensory block above the level of T5 is likely to cause significant hypotension needing aggressive use of vasopressors and fluids to maintain adequate end organ perfusion. It may cause a feeling of dyspnoea and respiratory compromise if the local anaesthetic reaches cervical nerve roots. Total spinal anaesthesia leads to loss of consciousness, apnoea and severe hypotension and should be managed appropriately. It may be caused by overdosage of local anaesthetics, accidental subarachnoid injection of an epidural dose of a local anaesthetic, e.g. due to catheter migration or subdural injections.

Local anaesthetic systemic toxicity: a patient is likely to suffer local anaesthetic systemic toxicity if a large dose of local anaesthetic is injected intravascularly by accident. Such an event is more likely to happen while administering an epidural injection.

Shivering occurs due to core body hypothermia following widespread vasodilation and redistribution of core body heat from warmer areas such as the upper body to peripheral areas. Strategies such as forced-air warming, warm intravenous fluids, administration of intrathecal fentanyl, intravenous ondansetron or tramadol can reduce shivering.

Late complications: *Respiratory depression* could occur 12–24 hours after administration of long-acting intrathecal opioids (e.g. morphine), as it rises in the CSF and reaches the respiratory centre. The mainstay of treatment is oxygen supplementation and close monitoring of the patient.

Urinary retention occurs due to autonomic block especially in the elderly. It is commonly associated with the use of intrathecal opioids.

Pruritus occurs usually in the postoperative period and related to the use of intrathecal opioids. Simple antihistaminic drugs like chlorphenamine provide relief if the patient finds it too uncomfortable.

Post-dural puncture headache (PDPH) occurs mainly in young patients. The onset of headache is most commonly 48–72 hours after the procedure. It is severe in nature, distributed over the frontal and occipital region and radiating to the neck and/or shoulder area. PDPH typically gets worst on standing up and the patient gets some relief in the supine position. It could be associated with nausea, vomiting, tinnitus, vertigo and visual disturbances. Initial treatment is to encourage the patient to lie down in a comfortable position, rehydration, simple analgesics, anti-emetics and reassurance. Caffeine is a cerebral vasoconstrictor and caffeinated drinks may help if simple analgesics are not sufficient. A patient may eventually need an epidural blood patch if other methods of analgesia are proving inefficient.[7]

Other rare complications include spinal canal abscess, meningitis, and spinal canal hematoma.

Contraindication to neuraxial anaesthesia: *Absolute contraindications included* patient refusal, localized infection, raised intracranial pressure and untreated hypovolaemia.

Relative contraindications include coagulopathy, sepsis and fixed cardiac output states.

Peripheral nerve blocks

Peripheral nerve blocks are often combined with a general anaesthetic to provide intraoperative and postoperative analgesia. With the availability of high-quality ultrasound machine and expertise in interpretation of sonoanatomy success rates of nerve blocks have improved. Hence peripheral nerve blocks are a practical alternative to general anaesthesia, especially for ambulatory surgery. However, it is crucial to have a detailed discussion with the patient to set correct expectations for having surgery under regional anaesthesia. Providing reassurance and winning the patient's confidence is crucial for the success of this approach. A surgeon can often help in this process by initiating

this conversation in the clinic when the decision is made to go ahead with the surgery.

Upper limb blocks: Different approaches can be used to block the brachial plexus for providing anaesthesia and analgesia for upper limb surgery. Sympathetic denervation following a peripheral nerve block is often a desirable 'side effect' for microvascular surgery.

Interscalene brachial plexus block is performed in the neck around the nerve roots (C5–7) between the anterior and middle scalene muscles to provide analgesia and anaesthesia for surgery around the shoulder region and upper arm. Complications include blockade of the phrenic nerve, accidental intravascular injection, subarachnoid injection and nerve damage. An interscalene block could be used for awake shoulder surgeries such as subacromial decompression and arthroscopic procedures.

Supraclavicular brachial plexus block: As the name suggests, the local anaesthetic is injected above the clavicle close to the subclavian vessels around the trunks of brachial plexus. This block provides analgesia for the arm, forearm and hand surgery with or without a general anaesthetic. Possible complications are an incomplete block of lower trunk (C8–T1) and escape of ulnar nerve, phrenic nerve block (reported in 50% patients), Horner's syndrome and a rare risk of pneumothorax.

Infraclavicular brachial plexus block: The local anaesthetic is injected below the clavicle just medial to the coracoid process at the level of brachial plexus cords. This block provides good analgesia for arm, forearm and hand surgery. It is technically more challenging with injections around deeper structures. It is better suited for indwelling catheters for postoperative analgesia.

Axillary brachial plexus block is considered the safest approach for a brachial plexus block. The injection is performed at the level of the deltopectoral groove in the axilla around four terminal nerve of brachial plexus. Ultrasound guidance has improved the success rate of this block as a position of nerves is highly variable especially the musculocutaneous nerve. This approach is suitable for forearm and hand surgery with or without a general anaesthetic.

Lower limb blocks: These blocks provide good analgesia for surgery on the lower limb. Depending on the local anaesthetic and adjuncts used it can provide analgesia for up to 24 hours avoiding side effects such as urinary retention and sympathetic blockade seen with indwelling epidural catheters. Most lower limb blocks are often combined with a general anaesthetic for a patient to tolerate a thigh tourniquet.

Femoral nerve block provides analgesia for surgery of the anterior thigh, femur, and knee (e.g. femoral fractures). In combination with the sciatic nerve block, it can provide analgesia for the whole of the lower limb. With basic training, it is simple and easy to perform with minimal side effects.

Fascia iliaca block a fascial plane block aiming to provide analgesia in the distribution of the femoral nerve and the lateral cutaneous nerve of thigh. It has a lower risk profile than the femoral nerve block. This block is recommended for providing analgesia to all patients presenting with proximal femoral fractures.

Adductor canal block/saphenous nerve block: Injection of local anaesthetic in the adductor canal (sub-sartorial space) anaesthetizes saphenous nerve and other sensory nerves in this potential space. It provides good analgesia for procedures on the knee such as total knee replacement, procedure on the anteromedial leg, ankle and foot surgery. An adductor canal block may preserve the motor strength of thigh muscles better than the femoral nerve block.

Sciatic nerve block: A sciatic nerve block is used for providing analgesia for the leg, ankle and foot surgery in combination with the saphenous nerve block. This block can be performed using an anterior, trans-gluteal, or sub-gluteal approach. Most commonly the sciatic nerve is blocked in the popliteal fossa.

Obturator nerve block has very selective indications and used rarely clinically e.g. for relieving spasms in patients suffering from cerebral palsy and hemiplegia.

Ankle block: The Surgery on the midfoot and forefoot can be very painful postoperatively, and an ankle block provides excellent analgesia for such procedures. Two deep nerves (posterior tibial and deep peroneal) and three superficial nerves (saphenous, superficial peroneal and sural nerves) are anaesthetized with or without ultrasound guidance. Patients tolerate an ankle tourniquet very well after an ultrasound-guided ankle block and surgery can be carried out without the need of a general anaesthetic (Figure 1). It is a simple and safe block without any major side effects.

Trunk blocks for surgery: Apart from siting a thoracic epidural and an indwelling catheter, the following techniques could be used for postoperative analgesia after surgery on the trunk.

Paravertebral block: Paravertebral blocks are performed most commonly at the thoracic level due to the continuity of paravertebral space between T1 and T12 levels allowing the spread of injected local anaesthetic. Indwelling catheters can be sited for postoperative analgesia using dilute local anaesthetic infusion. It is used for analgesia after rib fractures, unilateral breast, thoracic and abdominal surgery. Possible complications are hypotension, pleural puncture, and pneumothorax. The epidural spread of injected drug may occur leading to a bilateral block.

Transversus abdominis plane (TAP) block is used to provide analgesia after surgery including the abdominal wall. A large dose of diluted local anaesthetic is injected in a plane just above the transversus abdominis muscle, often under ultrasound guidance. The aim is to anaesthetize intercostal, subcostal and L1 segmental nerves.

Rectus sheath block is used to provide analgesia for midline incisions of the abdominal wall. Possible complications include incomplete block, peritoneal perforation, and damage to the bowel.

Intercostal blocks have been used in the past to provide analgesia after rib fractures and breast surgery. They are falling out of favour due to a high risk of pneumothorax, and local anaesthetic toxicity due to rapid absorption.

PECS I and II, serratus anterior and erector spinae plane blocks are relatively new interventions for providing analgesia after breast surgery and rib fractures respectively. The evidence of their benefit is currently limited to a few studies and case reports.

Ophthalmic surgery: Retrobulbar, peribulbar and sub-tenon blocks are used to provide anaesthesia for eye surgery. Out of

Figure 1 A patient undergoing a hallux valgus correction under ankle block and sedation using an ankle tourniquet. (The patient and the staff consented to publication of this photograph.)

these three techniques, the sub-tenon approach is considered to be the safest. The risk of serious complications such as injuries to the globe, optic nerve damage and accidental subarachnoid injection is more with older techniques such as retrobulbar or peribulbar injection. With advances in technology cataract surgery is now possible under topical anaesthesia.

Cervical plexus block: Superficial cervical plexus block is performed most commonly for vascular surgery such as an awake carotid endarterectomy. The use of deep cervical plexus block has declined due to unfavourable risk profile and equivalence to superficial plexus block for this surgery.

Local anaesthetic agents

Basic pharmacology

Local anaesthetics can be classified as amides or esters depending on the connecting intermediate chain between the lipophilic (aromatic) and the hydrophilic (amine) parts of the molecule. Amides rarely cause allergic reactions while esters are more likely to precipitate such reactions due to the production of para-aminobenzoic acid (PABA) when metabolized.

Mechanism of action

Local anaesthetics act by two mechanisms preventing transmission of an action potential.

Blockade of Na^+ channels: Local anaesthetics bind to sodium channels holding them in an 'inactive' state preventing depolarization of neuronal cell membrane. This inhibits propagation of an action potential. They act from within the cell membrane; therefore, the molecules of a local anaesthetic must permeate through the cell membrane. The unionized form of the local anaesthetic molecule, which is lipid soluble, crosses the phospholipid membrane and becomes ionized intracellularly to exert its action.

Membrane expansion: The unionized form of local anaesthetic molecule is incorporated into the cell membrane disrupting Na^+ channel's function.

Many other factors affect the pharmacological properties of local anaesthetics. In an acidic environment such as around an abscess, a larger proportion of a local anaesthetic will exist as ionized fraction making it less effective. Highly lipid soluble molecules such as bupivacaine and ropivacaine are more potent than lidocaine which is relatively less lipid soluble. Highly protein-bound drugs such as bupivacaine and ropivacaine have a longer duration of action than lidocaine and prilocaine. Addition of adrenaline causes localized vasoconstriction which slows systemic absorption of the drug. It increases the duration of action and intensity of block produced by the local anaesthetic. Clinically, lidocaine is the drug most often used in combination with adrenaline.

Choice of a local anaesthetic

Many factors determine the choice of a local anaesthetic for a patient. One of the main ones being whether a patient needs a short-acting or long-acting anaesthesia. Other factors such as additives to a local anaesthetic should be considered e.g. adrenaline containing solutions are traditionally avoided for sites with terminal circulation such as a ring block for digits. However, evidence suggests the risk of digital necrosis is overstated and other factors may play a significant part in such an event.[8,9]

Table 1 provides a guide which could help in deciding about choosing a local anaesthetic.

Local anaesthetic systemic toxicity (LAST)

Local anaesthetic systemic toxicity (LAST) is seen when the peak plasma concentration of free drug goes above toxic levels. This can happen in two scenarios: inadvertent intravascular injection or rapid/extensive absorption of local anaesthetic especially from highly vascular sites.

Safe administration of local anaesthetics

It is imperative that functioning resuscitation equipment and additional help is readily available in an area where local anaesthetics are being used. The operator should be aware of the location of intravenous lipid emulsion solution. Secure intravenous access is a good standard of care to follow. Continuous communication with the patient while local anaesthetic is being injected may give an early indication of an impending problem. The slow rate of injection reduces peak plasma concentration of a local anaesthetic allowing early detection of inadvertent intravascular injection. Frequent aspiration while injecting the local anaesthetic helps in confirming the needle tip is not placed intravascularly or has migrated during the injection. Tachycardia while injecting adrenaline containing solutions could be due to inadvertent intravascular injection or normal response to a painful stimulus or anxiety.

The dose of a local anaesthetic: The choice and the dose of a local anaesthetic must be considered in advance. A senior plastic surgeon was overheard teaching a trainee '*use the minimum amount and most dilute solution you can…. it is often a case of waiting a bit longer than injecting more local anaesthetic*'.

The maximum safe dose often mentioned in a textbook provides a rough guide but are a good starting point (Table 2 and Box 1). The *British National Formulary* (BNF) clearly states these doses should be calculated based on ideal body weight to avoid overdosing an obese patient. The increased risk of toxicity is also associated with patient factors such as the elderly, paediatric and

Pharmacological and clinical features, and uses of commonly available local anaesthetics[3]

Name	Type	Onset	Duration	Clinical uses
Lidocaine	Amide	Fast (2–4 min)	Moderate (70–140 min after infiltration)	Topical Infiltration Nerve blocks Epidural anaesthesia
Prilocaine	Amide	Fast (2–4 min)	Moderate (70–140 min after infiltration)	Topical Infiltration Nerve blocks Spinal anaesthesia I.V. regional anaesthesia
Lidocaine and Prilocaine	Amides	Slow (60 min)		Skin cream before venepuncture Skin graft harvest site
Bupivacaine	Amide	Moderate (5–10 min)	Long (approx. 200 min after infiltration)	Infiltration Nerve blocks Spinal and epidural anaesthesia
Levo-bupivacaine	Amide	Moderate (5–10 min)	Long (approx. 200 min after infiltration)	Infiltration Nerve blocks Epidural anaesthesia
Ropivacaine	Amide	Moderate (5–10 min)	Long (approx. 200 min after infiltration)	Infiltration Nerve blocks Epidural anaesthesia
Tetracaine (Amethocaine)	Ester	Slow	Long (4–6 hours)	Ophthalmic anaesthesia Skin cream before venepuncture

Table 1

pregnant patient and in a patient with renal, liver and cardiac disease. The site of injection influences the rate of absorption of the drug and the consequent peak plasma concentration of the free drug. Rapid absorption can occur from sites such as intercostal blocks and topical anaesthesia while subcutaneous injections are relatively low risk.

Table 2 illustrates the recommended maximum safe dose of various local anaesthetics.

When a mixture of local anaesthetics is used their toxic effects are additives and the dose of each local anaesthetic used should be reduced accordingly. One suggested method is if half the maximum safe dose of drug A had been used then no more than half the maximum safe dose of drug B should be used.[10]

Management of local anaesthetic systemic toxicity (LAST)

The Association of Anaesthetists of Great Britain & Ireland (AAGBI) published excellent step by step guidance for management of local anaesthetic systemic toxicity (LAST) in 2010. These guidelines are endorsed by the Australian and New Zealand College of Anaesthetists (ANZCA).

Recognition: One of the most important factors in preventing serious adverse events related to local anaesthetic systemic toxicity (LAST) is the awareness of this possibility and early recognition. It is a rare event but is potentially fatal if not managed appropriately and quickly.

Signs and symptoms: The onset of signs and symptoms of LAST could occur at any time from one minute to more than an hour after the injection. Most commonly described symptom in the text is of perioral numbness. However, patients present with a range of signs and symptoms such as tinnitus, feeling 'strange', '*metallic tongue*', anxiety, panic attacks, severe agitation, and confusion. These symptoms can quickly degenerate into seizures and loss of consciousness. Cardiovascular signs such as

The recommended maximum safe dose of various local anaesthetics

	With adrenaline (mg/kg)	Without adrenaline (mg/kg)	Maximum recommended dose for a field block (BNF)
Lidocaine	7	3	200 mg; 500 mg for solutions containing adrenaline
Prilocaine	6		400 mg
Bupivacaine	2	2	150 mg
Ropivacaine	3	3	225 mg
Levobupivacaine	2	2	150 mg

Table 2

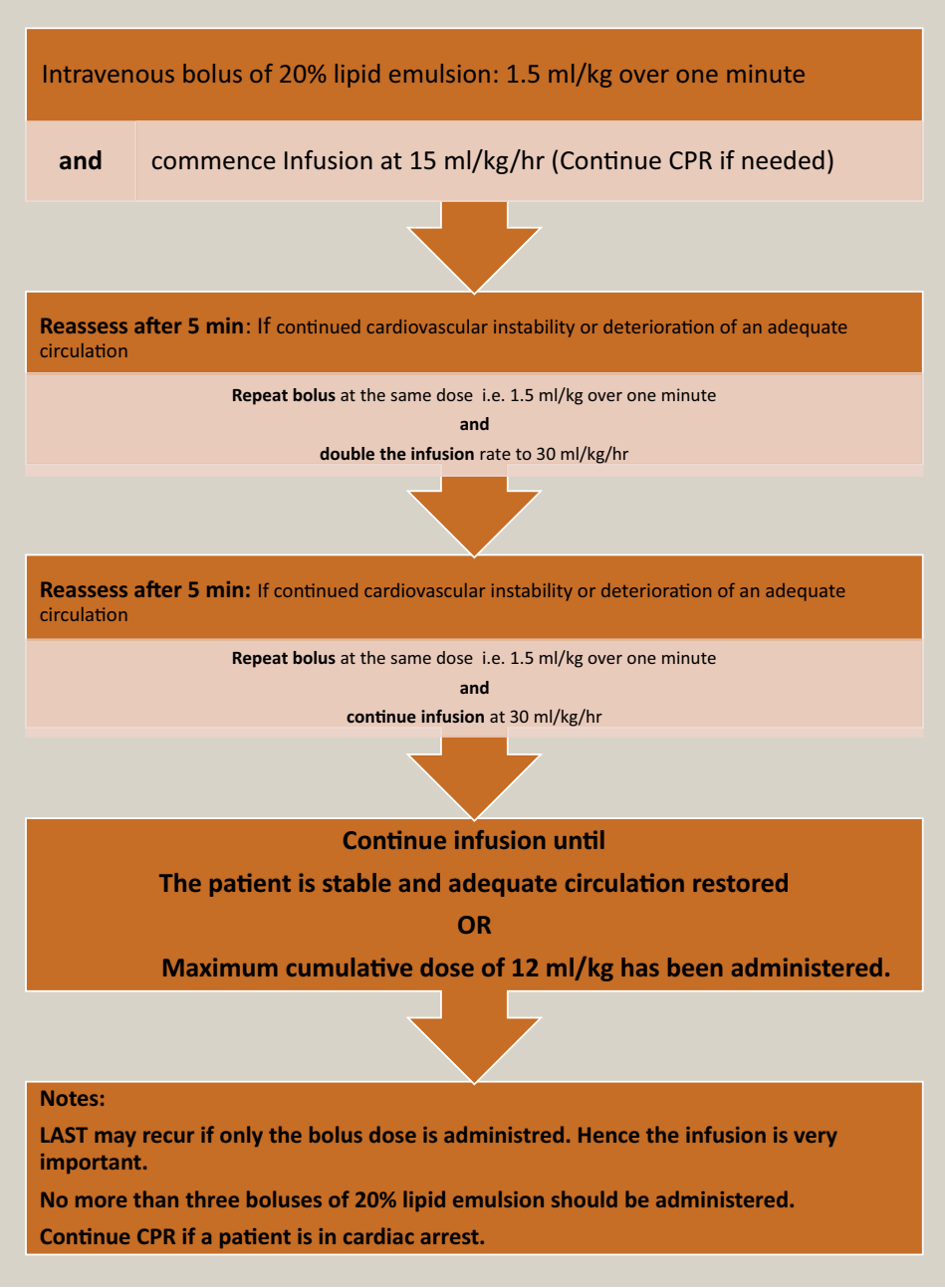

Figure 2 Suggested regimen for intravenous lipid emulsion for treatment of local anaesthetic systemic toxicity (AAGBI 2010).

tachycardia and hypertension followed by bradycardia and hypotension may occur. Virtually any kind of arrhythmia such as conduction blocks, ventricular arrhythmias and asystole may ensue.

Immediate management: Immediate management requires stopping administration of local anaesthetic and using the 'ABC' approach to manage this medical emergency. Anyone managing this situation will need assistance, and a call to the cardiac arrest team should be considered especially if symptoms are progressing rapidly. Patients should be given 100% oxygen and may need endotracheal intubation if they lose consciousness. Specific treatment for symptoms manifested should be used, e.g. benzodiazepines or thiopentone or propofol in small doses to control seizures. Cardiovascular monitoring should be available throughout.

Treatment:

Patients in cardiac arrest – Despite good management of early signs of toxicity, the symptoms may progress to cardiac arrest which should be managed as per the standard ALS

protocol for CPR and manifesting arrhythmias. The treatment of cardiac arrest due to LAST may need prolonged CPR and arrhythmias could be refractory to treatment. The patient should be given intravenous lipid emulsion (20% solution) as per the suggested regimen in Figure 2.

Patients without cardiac arrest – Patients should be treated for their symptoms such as bradyarrhythmia, tachyarrhythmia and hypotension using standard treatment options. Administration of 20% lipid emulsion should be considered for this group of patients as well. It may prevent the progression of CNS symptoms and prevent cardiac arrest.[11]

Follow up

Once stable the patient should be transferred to an area where appropriate monitoring facilities and skilled staff is available for further recovery, e.g. a high dependency unit. Intravenous lipid emulsion administration may trigger pancreatitis which needs to be monitored by clinical review and/or imaging along with amylase and lipase measurement. The local critical incident reporting system should be alerted. www.lipidrescue.org is an excellent international resource to share your experience with the medical community worldwide. As LAST is a rare event, any such reporting helps immensely in building the evidence base.

An example to illustrate how to calculate an indicative maximum safe dose of a local anaesthetic for a patient

Sheila has been listed for bilateral carpal tunnel decompression under local anaesthetic. Sheila is 37 years old, weighs 60 kg and does not have any renal, hepatic or cardiac disease. The pregnancy test conducted for Sheila has come back as negative. How much levobupivacaine 0.5% can be used safely for this patient?
The total volume of a LA which can be given safely to any patient can be calculated as:

$$\frac{\text{Recommended maximum dose (mg/kg) x body weight (kg)}}{\text{Concentration of LA solution (mg/ml)}}$$

A drug solution of 0.25% contains 2.5 g/100 ml, i.e. 2.5 mg/ml of the drug salt.
Practically, it can be calculated as 1% solution = 10 mg/ml or 2% solution= 20 mg/ml or 0.5% solution = 5 mg/ml and so forth.
Hence, Sheila can safely have up to a maximum of 24 ml of levobupivacaine 0.5%.

Box 1

Summary

Anaesthesia is a medical specialty requiring different training and skill set from surgeons. However, it is important for surgeons to have a good understanding of the basics of anaesthesia including the use of local anaesthetics. Surgeons and anaesthetists work closely in a team to deliver the treatment a patient needs. A mutual understanding of requirements to provide the best possible care will make surgery safer, theatres more efficient and improve patient experience. ◆

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