An Anesthesiology Primer for SIU medical students

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Part 1. What do anesthesiologists do?

Anesthesiologists are experts in perioperative medicine. On a simplistic level, we put patients to sleep and wake them up. But really we are in charge of the patient's entire operative experience, including preoperative assessment and medical optimization, intraoperative management of medical problems, and postoperative care including pain management. The field of anesthesiology is closely aligned with critical care medicine. Knowledge of cardiopulmonary support is key to a successful anesthetic. In addition, we function as the patient's primary care provider during surgery and must be able to manage both common and rare medical issues that may emerge.

Anesthesiologists provide services throughout the hospital. In addition to operating room procedures, we also provide patient assessment and management of procedural care for labor and delivery, radiology, gastroenterology, and ECT. Because of our expertise in airway management, we may be consulted emergently by the ED or ICU for endotracheal intubation in a patient with a difficult airway, or for other procedures such as vascular access, pain blocks, or epidural blood patches.

Anesthesiologists can also be fellowship trained in a variety of subspecialties like chronic pain management, critical care, pediatric anesthesia, and cardiac anesthesia. Most large teaching hospitals have at least one ICU that is run by the anesthesiology service.

Part 2. Preoperative Evaluation

Prior to anesthesia, every patient receives a complete preanesthesia evaluation. This begins with a history and review of systems in which we focus on cardiopulmonary issues as well as neurologic, gastrointestinal, and renal diseases that may impact management. We also perform a quick physical exam focused on cardiac, pulmonary, and airway findings.

<u>Airway Exam</u>

In general, we examine a patient's airway to predict whether they will have respiratory issues during an anesthetic. We look for signs suggestive of sleep apnea and difficult mask ventilation and/or intubation. An airway exam consists of the following components:

1. Mallampati score – Instruct the patient to gently extend their neck, open their mouth, and stick their tongue out. A patient is assigned a score of 1 if you can visualize their entire uvula, 2 if you can only see the top of the uvula, 3 if you can see some of the soft palate, and 4 if you can see none of these things. A higher score predicts a difficult airway.
2. Thyromental distance – Measure from the top of the thyroid cartilage to the tip of the chin. A short distance (less than ~4cm) indicates an anterior airway that may lead to difficulty with intubation, but not necessarily mask ventilation.
3. Neck extension – In order to perform direct laryngoscopy effectively, patients must be placed in the "sniffing position" in which the neck is fully extended. This may be compromised in patients with limited mobility or pain during extension.
4. Mouth opening – Obviously patients with limited mouth opening will be difficult to intubate simply due to less space for instrumentation. Patients with an overbite will be more difficult to intubate because the upper incisors may be in the way.
5. Dentition – Airway manipulation can lead to dental injury in patients. Poor dentition predisposes patients to dental issues if teeth are already broken or loose. Removable prostheses, such as dentures or partials should be identified and removed to decrease the risk of damage during intubation, or coming loose during the anesthetic and causing airway issues.

<u>ASA Physical Status</u>

After completing the preop evaluation, a physical status score is assigned to the patient. This is a score of overall fitness for anesthesia that helps to quickly communicate a patient's risk and comorbidities. Score range from 1-6. The letter E is added if the procedure is considered an emergency. Below are definitions with some examples.

1. A healthy patient with no medical problems.
2. A patient with mild medical problems that are well-managed and asymptomatic.
    - HTN, controlled DM, asthma
    - Smoker
    - Morbid obesity

3. A patient with major systemic medical problems that are currently compensated with mild or no symptoms.
    - ESRD on dialysis
    - CHF
    - COPD with daily inhalers
4. A patient with major systemic medical problems that are decompensated and pose a threat to life.
    - A patient with ARDS on the ventilator
    - A patient with necrotizing fasciitis and DKA
    - A patient with sepsis and hypotension in the ICU
5. A patient with major acute problems in which survivability is in question
    - Ruptured AAA
    - Gunshot wound to the chest
6. A patient undergoing organ harvest in which anesthesia is consulted for hemodynamic and pulmonary management during the harvest

<u>NPO Status</u>

Patients are asked to follow NPO guidelines prior to anesthesia to reduce the risk of aspiration. Aspiration can happen when stomach contents (food, bile, acid) are regurgitated into the pulmonary tree. Patients are at risk under anesthesia because they lose their protective airway reflexes and are unable to clear their own secretions. The guidelines are as follows:

Clear liquids - 2 hours. (Any liquid without particulate matter – water, tea, black coffee, soda, Gatorade)
Breast milk – 4 hours
Infant formula – 6 hours
Non-human milk – 6 hours
Light meal – 6 hours. A light meal is defined as dry toast and clear liquids.
Heavy meal – 8 hours or more. A heavy meal is any meal that contains fried or fatty food.

Even if patients have followed the guidelines, they may still be at risk for aspiration. Medical issues such as diabetic gastroparesis and severe GERD can increase risk. Gastric emptying can also be delayed in patients with severe pain, morbid obesity, active labor, and trauma. Therefore, NPO guidelines often need to be individualized for patients.

<u>Medication Review</u>

Patients should be counselled prior to surgery which medications to continue and which to hold. Any necessary medications that were not taken can be given prior to surgery with a sip of water.

Continue the following medications:
- Most cardiac medications (NOT diuretics or ACE-inhibitors/ARBs)
- All respiratory medications
- PPIs/H2 blockers
- All neurologic medications (especially anticonvulsants and myasthenia gravis meds)

- Pain medications (surgeon may request no NSAIDs prior to surgery due to antiplatelet function)
- Thyroid medication (especially for hyperthyroidism)
- Long acting insulin (evening dose is generally cut in half)
- Psychiatric medications

Discontinue the following medications:

- Diuretics: May lead to dehydration and electrolyte abnormalities while NPO
- ACE inhibitors/ARBs: Can lead to profound anesthetic-induced hypotension
- Oral hypoglycemic agents
- Metformin (rare cause of lactic acidosis in fasting patients)
- Particulate antacids (TUMS, Mylanta, etc): can increase aspiration risk
- Blood thinners (length of time depends on drug, surgery, and CV risk factors – often advised by cardiologist prior to surgery)

Part 3. Anesthetic Drugs

Sedatives and Induction agents

Propofol – A GABA receptor agonist, propofol can be given as a large bolus to induce general anesthesia (~2mg/kg) or as an infusion for sedation (50-100mcg/kg/min). A bolus will cause anesthesia in about 10 seconds and will last for 4-8 minutes. The drug goes immediately to the brain and other vessel-rich organs. Patients may become apneic briefly. Its clinical effect ceases as it is redistributed to other body compartments (muscles, then fat) resulting in the patient waking up. Propofol has no analgesic properties, so patients will exhibit tachycardia/hypertension if undergoing a painful procedure and may continue to have pain on emergence. The drug is not water soluble and is dissolved in substances that are venous irritants, so there is often significant pain on injection. Unlike most other anesthetics, propofol has mild antiemetic properties. It causes modest vasodilation and myocardial depression that can manifest as hypotension, especially in frail or volume depleted patients.

Etomidate – Also a GABA receptor agonist, etomidate is usually given as a bolus to induce general anesthesia (~0.3mg/kg). It does not cause hypotension like propofol and barbiturates, so it is often selected for patients with compromised cardiac function or signs of hypovolemia. It is often used in the ED for the undifferentiated patient that needs to be intubated. It can cause myoclonic jerking as the patient falls asleep. Etomidate causes transient adrenal suppression that may be significant in septic patients.

Ketamine – An NMDA receptor antagonist, ketamine can be given as a large bolus to induce general anesthesia (1-2mg/kg IV) or in small doses for sedation or pain management (10-20mg at a time). Ketamine is unique in that it does not cause respiratory depression. It has potent analgesic properties but may cause incomplete amnesia. Notably, it can cause significant visual hallucinations which are often unpleasant for patients. It is recommended to combine ketamine with another agent to ensure amnesia (propofol or a benzodiazepine). Ketamine tends to activate the sympathetic nervous system so hypotension generally isn't a problem. It can be given intramuscularly for patients that need sedation without an IV.

Dexmedetomidine - A presynaptic alpha2 agonist, dexmedetomidine (trade name Precedex) is used for sedation or as an adjunct during general anesthesia to lower opioid and volatile anesthetic requirements. Like ketamine, dexmedetomidine preserves respiratory drive at mild-moderate doses. It is commonly used for patients on mechanical ventilation, as a sedative for patients undergoing "awake" fiberoptic intubation (see Part 4), and for patients with a history of combativeness or severe pain in the recovery room after surgery.

Benzodiazepines – These drugs are GABA receptor enhancers usually given in small doses for anxiolysis and amnesia. Midazolam is commonly used prior to a procedure at a dose of 1-2mg. Small doses generally don't cause respiratory depression unless combined with opioids. Can also be given in large doses to induce general anesthesia, although the duration of action is prohibitively long for most surgical procedures. Can be reversed with flumazenil.

Volatile Anesthetics

Sevoflurane, isoflurane, and desflurane are hydrofluorocarbons used to induce or maintain general anesthesia. They are supplied as liquids that are vaporized in a special chamber, then introduced into the fresh gas flow of an anesthesia machine. Despite having been used for decades, the exact mechanism of action remains unknown. They are dosed as a percentage of gas that the patient inhales. The percent that the patient exhales is also measured. This "end tidal" concentration is reflective of the actual "dose" that the patient is getting. Volatile anesthetics are popular because they are inexpensive and easy to dose. They are potent hypnotic and amnestic agents, but also have mild-moderate analgesic and muscle relaxant properties. They are smooth muscle relaxers that cause vasodilation (and thus mild hypotension) as well as bronchodilation. They may potentiate existing arrhythmias, but by themselves do not cause arrhythmias such as PVCs and atrial fibrillation. Importantly, they *do not* cause respiratory depression. In fact, they usually cause elevated respiratory rate with decreased tidal volume. Minute ventilation may decrease slightly. While anesthetized with a volatile anesthetic, patients will continue to breathe spontaneously, although they may need airway support as they gradually lose upper airway tone. To wake a patient up from a volatile anesthetic, the gas is simply turned off. The agent will leave the brain along its concentration gradient as more of the drug is exhaled. Anesthesia can also be induced with a volatile anesthetic, but the smell is pungent and the induction often takes several minutes. During this time patients can enter an excitable stage of anesthesia in which airway reflexes are heightened. Intravenous induction is generally preferred because of the speed of onset. An inhalation induction is usually reserved for pediatric patients in which IV placement would be traumatic. All volatile anesthetics are triggers for malignant hyperthermia in susceptible patients.

Opioids

Opioids exert their effects on different types of opioid receptors. Their affinity for each type of receptor determines their clinical activity. Opioids are used primarily for their analgesic properties, although sedation may not be an undesirable side effect during surgery. The most important consideration for the anesthesiologist in determining which opioid to use is the pharmacokinetic properties of each drug. Short acting drugs may be useful for brief but intense surgical procedures whereas long acting drugs will be needed to cover pain into the PACU and beyond. Below are some considerations for different commonly used intravenous opioids:

- Morphine: relatively long acting when given intravenously. May cause significant histamine release. Can be given neuraxially for long acting (~24 hours) pain relief.
- Fentanyl: relatively short acting (1-2 hours) when given intravenously. One of the most commonly used opioids in anesthesia.
- Meperidine: Rarely used now for analgesia, only given in low doses to treat post-op shivering from anesthesia. Overall has poor analgesic qualities. Causes more euphoria than other opioids.
- Hydromorphone: Longer acting than fentanyl, typically used in PACU for pain control.
- Alfentanil: very short acting (5-10 minutes), useful for placing nerve blocks or given prior to a painful procedure like intubation.

- Remifentanil: very short acting (5-10 minutes) and extremely potent, often used as an infusion during general anesthesia in which profound analgesia is necessary but not required after the surgery is over (eg brain surgery). Wears off quickly even after long infusions.

Muscle Relaxants

Skeletal muscle relaxants are used for two purposes – to facilitate intubation by relaxing the vocal cords, and to enhance surgical conditions by paralyzing the patient (as in most intra-abdominal and intrathoracic procedures). All muscle relaxants work by occupying the nicotinic acetylcholine receptor at the neuromuscular junction, making it impossible for acetylcholine to bind. Succinylcholine is a depolarizing agent, in that the acetylcholine receptor is activated causing muscle depolarization (manifest as fasciculation) prior to paralysis. All other muscle relaxants are nondepolarizing.

Succinylcholine is the relaxant with the fastest onset so it is very valuable in rapid sequence intubation (in which anesthesia is induced and the patient is intubated as quickly as possible to prevent aspiration). It is metabolized by the enzyme pseudocholinesterase, which is found in the blood stream and renders succinylcholine inactive after 5-10 minutes. Patients with pseudocholinesterase deficiency should not be given succinylcholine because there is no effective reversal agent for it. Succinylcholine causes a transient rise in serum potassium, so it should be used in caution in patients with hyperkalemia or those who may not be able to clear potassium (ESRD). The increase in potassium may be exaggerated in patients with abnormal or upregulated acetylcholine receptors (paraplegics, muscular dystrophy, CVA induced hemiplegia, history of severe burns). Succinylcholine is a trigger for malignant hyperthermia in susceptible patients.

Examples of nondepolarizing agents are rocuronium, vecuronium, pancuronium, atracurium, and cis-atracurium. All can be reversed with cholinesterase inhibitors (neostigmine or physostigmine) which increase the availability of acetylcholine at the neuromuscular junction to outcompete the muscle relaxant. However, this can lead to a cholinergic crisis at muscarinic receptors including profound bradycardia or asystole, so an anticholinergic (glycopyrrolate or atropine) must also be given. Rocuronium and vecuronium have a specific reversal agent called suggamadex, which is a large cyclodextran molecule that simply binds the muscle relaxant and carries it away from the active site.

Depth of muscle relaxation is monitored with a train-of-four monitor usually placed on the ulnar nerve. A series of 4 impulses are delivered over 2 seconds and strength of the muscle response is recorded. Muscle relaxants should be reversed before waking a patient up. True intraoperative awareness can occur when a patient is paralyzed with inadequate anesthesia. This is a rare phenomenon that is usually due to human error, but may also occur in sick patients (trauma, cardiac surgery) who can't tolerate much anesthesia.

Local Anesthetics

Local anesthetics are sodium channel blockers that inhibit action potential propagation along neurons. There are two classes: esters and amides. Amides have the letter "i" in the prefix (bupivacaine, mepivacaine, lidocaine, prilocaine, etidocaine) whereas esters do not (procaine, benzocaine, tetracaine, chloroprocaine). True allergies to local anesthetics are rare, but tend to happen more frequently with esters.

Understanding local anesthetic systemic toxicity (LAST) is important as most physicians will be using local anesthetics during their career. Sodium channels are present throughout the central nervous system and cardiac conduction tissues. Higher doses of local anesthetic increase the chance of the drug getting into the plasma, thus making its way to the CNS or heart. Transient neurologic symptoms (tinnintus, perioral numbness, metallic taste, dizziness) are early signs of LAST and indicate that the injection should be stopped. As plasma concentrations increase, symptoms may progress to seizures, respiratory arrest, and finally cardiac arrest. Treatment is supportive, including airway management and CPR. Toxicity can be reversed by giving a lipid emulsion (brand name Intralipid) that serves as a binding agent, carrying the anesthetic away from sodium channels.

Local anesthetics come in different concentrations that affect the density of a block. To determine how many milligrams of a drug is in solution, move the decimal point of the concentration one place to the right. For example, 0.5% bupivacaine is 5mg/mL. Multiply this by the total volume to determine total dose.

Adding epinephrine to local anesthetic causes local vasoconstriction, increasing duration of action and toxic dose threshold. It can also help as an early warning for LAST, as patients will become tachycardic from the epinephrine entering the circulation.

Toxic doses of the two most common types of local anesthetic:

- Lidocaine = 5mg/kg (7mg/kg with epinephrine)
- Bupivacaine = 2.5mg/kg (3mg/kg with epinephrine)

Part 4. Airway Management

The goals of airway management vary based on patient and type of anesthesia chosen, but always include adequate oxygenation, adequate ventilation, and airway protection. During the preoperative evaluation, an airway examination is performed to predict risk factors for airway issues (see part 2). Once the type of anesthesia is chosen, we must then decide how to manage the patient's airway. This is based on several factors:

- Sedation vs. general anesthesia
- Spontaneous breathing vs. artificial respiration
- Aspiration risk
- Patient positioning
- Predictors of difficult airway

<u>Airway Support</u>

A patient undergoing light to moderate sedation (ie midazolam +/- fentanyl +/- propofol infusion) can often maintain their own airway. However, almost all anesthetic drugs can affect upper airway tone, even when the patient maintains their drive to breathe. A loss of upper airway tone (as is common in patients with sleep apnea) can lead to difficulty breathing and the patient may need airway support. This can often be accomplished with simple maneuvers such as turning the head, extending the neck and tilting the chin up, or giving a jaw thrust. Oxygenation is supplemented with a nasal cannula or a simple oxygen mask.

Examples of common procedures requiring airway support

- Colonoscopy/EGD
- Cataract extraction
- Sedation for procedures under local anesthesia (lipoma removal, basal cell, carpal tunnel, etc)
- Sedation during a surgery in which regional anesthesia has been performed

<u>Mask Ventilation</u>

Patients who go apneic during deep sedation or after an induction dose of an IV anesthetic often require mask ventilation. This is positive pressure ventilation delivered by a mask attached to the anesthesia machine that is part of a pressurized circuit. In the ED, ICU, or PACU, mask ventilation may be accomplished with an AmbuBag. Simply placing the mask over the patient's mouth and squeezing the bag is usually insufficient to ventilate the lungs. The patient's airway needs to be opened by extending the neck and lifting the jaw while the mask is pressed firmly around the mouth and nose so no air leaks out. Successful mask ventilation takes skill and practice, and some patients can be extremely difficult even for highly trained clinicians.

If having difficulty with mask ventilation, there are several steps that can help. Providing jaw thrust at the angle of the mandible (near the ears) can open the back of the oropharynx. Even better is using two hands to do this; one on each side of the jaw. In order to do this, you will need a second person to squeeze the bag for you. This is called two-person mask ventilation. An oral airway can also be highly effective in opening the patient's airway when a second person is not available to help. These are rigid, curved pieces of plastic available in various sizes that can be placed between the tongue and the palate. The patient needs to be under deep sedation or general anesthesia to tolerate this. It is unpleasant and causes gagging/choking in awake or lightly sedated patients. A nasal airway (also called a nasal trumpet) is a soft, flexible, curved silicone tube introduced behind the soft palate via the nares. These are more comfortable in awake or lightly sedated patients. One drawback is that these can cause epistaxis that can obscure or compromise the airway. If none of these maneuvers are effective, an advanced airway, such as an LMA or endotracheal tube can be placed (see below).

Examples of scenarios in which mask ventilation is employed

- After IV induction but before intubation (while waiting for muscle relaxant to take effect)
- ECT
- Myringotomy tubes in pediatric patients without an IV

Laryngeal Mask Airway (LMA)

A patient undergoing general anesthesia can either continue breathing spontaneously or may need to have their ventilation controlled, such as if they are going to be paralyzed. The mask attached to the anesthesia circuit may be used to deliver volatile anesthesia with spontaneous respiration, but it will require constant airway support and the gases have a high chance of leaking into the operating room. A better option is to use a laryngeal mask airway (LMA). The LMA is a tube with a soft air-filled bladder that is inserted into the back of the oropharynx, ultimately seating into place above the glottis. The tube end is attached to the anesthesia machine circuit. These airways provide a conduit for oxygen and anesthetic vapors to enter the airway while holding soft tissue aside so the patient can achieve adequate ventilation. They are typically easy to insert and are (usually) less traumatic than an endotracheal tube. One important factor is that the LMA sits above the glottis and does not separate the airway from the esophagus. Thus, patients at risk for aspiration (such as those who are not NPO) are not candidates for an LMA. Although gentle positive pressure can be given, it is preferred that patients breathe spontaneously while an LMA is in place. High positive pressures (>20cm H20) can open the upper esophageal sphincter leading to gastric distension.

Examples of common surgeries in which an LMA would be used:

- Knee arthroscopy
- Hand/elbow surgery
- Hysteroscopy
- Inguinal hernia repair
- Cystoscopy/kidney stone manipulation
- Lumpectomy/axillary lymph node dissection

Endotracheal Intubation

Intubation is considered the gold standard for airway management. It has several benefits over mask ventilation and LMAs including the ability to completely control ventilation parameters and the ability to protect the airway (from aspiration). Intubation is mandatory in the following scenarios:

- High risk of aspiration
- Muscle relaxation needed for surgical procedure
- Certain patient positions (ie prone)
- Certain surgical locations (airway/jaw/facial sugery)

Intubation is a skill that takes practice to perform safely. Risks include sore throat (common), dental injury (rare), and airway/vocal cord trauma (very rare). The most common route for intubation is the transoral route, but patients can also be intubated transnasally for certain maxillary/mandibular/dental procedures. Several instruments are available to perform intubation:

- Direct laryngoscopy: Performed with either a curved (Macintosh) or straight (Miller) laryngoscope blade. The patient is placed in the "sniffing position" in which the neck is fully extended. The blade is inserted into the oropharynx either into the vallecula (Macintosh) or under the epiglottis (Miller) then the epiglottis is lifted up exposing the vocal cords.
- Video laryngoscopy: Performed with a curved blade with a camera at the end. The patient's neck does not need to be extended as much. A special stylet that is curved to match the shape of the laryngoscope blade is inserted into the endotracheal tube to help it pass through the vocal cords.
- Fiberoptic scope: Also called indirect laryngoscopy, a fiberoptic scope is passed through an endotracheal tube, then passed through the patient's vocal cords (either via their mouth or nose). The endotracheal tube is then passed along the scope, using it as a conduit for intubation. This is often useful in patients with extremely limited neck mobility (or an unstable C-spine), limited mouth opening, or altered anatomy that can make traditional laryngoscopy difficult.

<u>Awake Fiberoptic Intubation</u>

This procedure used to be fairly common before the advent of video laryngoscopy. Now it is performed rarely. The patient is either completely awake or given sedation that will minimally affect breathing. The tongue, oropharynx, and larynx are anesthetized with topical anesthetic and a fiberoptic intubation is conducted. The goal is to ensure that patients are able to maintain and protect their own airway until intubation is successfully performed. Possible indications for this technique are:

- Previous history of difficult airway
- Suspected difficult airway based on physical exam findings, especially if also an aspiration risk
- Altered airway anatomy from previous surgery/radiation/etc
- Impending airway compromise (glottic tumor, angioedema, etc)

<u>Endotracheal Tubes</u>

Endotracheal tubes (ETTs) are sized by internal diameter in millimeters. For most males, a 7.5 or 8.0 is used, and a 7.0 is used for most females. These may be decreased in particularly small patients, or those who have had airway surgery before. For children, charts or formulas may be used to determine correct size. A common formula is (age/4) + 4 which gives the size of an uncuffed ETT, then subtract 0.5 for the cuffed ETT size. Uncuffed tubes used to be popular because of the perceived risk of subglottic stenosis from inflating the balloon on the tube, but modern cuffs are low pressure and are almost always used in children. The ETT is inserted to a depth of 22-24 cm (measured at the teeth) in most men and 20-22 cm in most women. For children, simply multiply the size of the ETT by 3 to determine how deep to place the tube. Always listen to breath sounds to confirm placement. If breath sounds are only heard on one side, the tube is likely in a bronchus and will need to be repositioned.

<u>Double Lumen Endotracheal Tubes</u>

Double lumen ETTs are used during thoracic surgery to ventilate one lung while the operative lung collapses, thus optimizing surgical conditions. Correct placement of these large tubes can be challenging, and one-lung ventilation often proves problematic in patients with preexisting lung pathology. Visit the CVOR to learn more.

Part 5. Regional Anesthesia

Regional anesthesia is the process of anesthetizing only part of the body. It is often combined with sedation for patient comfort. Regional blocks may be used for surgical anesthesia or postoperative pain management. Blocks can be classified as follows:

- Neuraxial (spinal and epidural blocks)
- Peripheral nerve/plexus blocks (upper and lower extremities)
- Compartment or field blocks

<u>Subarachnoid blocks</u>

Subarachnoid blocks (also called spinal blocks) involve inserting a needle through the dura mater and injecting anesthetic into the CSF. The spread of local depends on the dose given and the density of the solution compared to CSF. For a typical spinal block, hyperbaric local anesthetic is used. When the patient is laid supine, the anesthetic settles into the thoracic curvature. Because all distal sensation travels through this point, the patient develops a block from the midthoracic dermatomes all the way down.

In addition to sensory nerves, motor and autonomic fibers are also blocked. Motor fibers are more resistant, so the distribution is a few dermatomes below the sensory block. Autonomic fibers are more sensitive, so they are blocked a few dermatomes higher than the sensory block. This autonomic block of the sympathetic chain, which causes vasodilation and slowing of the heart, can lead to hypotension. This can be attenuated somewhat by volume loading the patient prior to the block. Patients with severe or critical stenotic valvular heart disease do not tolerate a drop in systemic vascular resistance, as it is crucial for diastolic coronary filling. Therefore, spinal anesthesia is usually avoided in these patients.

Neuraxial blocks are avoided in anticoagulated patients, as paraspinous bleeding from epidural veins can proceed unopposed, possibly leading to nerve compression (and permanent injury) from a hematoma. The procedure must be performed with a sterile technique to reduce the risk of meningitis. Thus, the procedure would be contraindicated if a patient has signs of infection at the injection site. Previous hardware in the spine may make placement difficult (if not impossible), but patients with back pain, disc disease, stenosis, or scoliosis are not precluded from having spinal blocks.

Subarachnoid blocks are performed below L2 to minimize risk of injuring the spinal cord. A small leak of CSF from the needle stick may predispose the patient to developing a postdural puncture headache that can manifest 1-2 days later. This risk can be minimized by using small gauge needles and needles without a cutting edge. These “pencil point needles” theoretically spread the dural fibers apart, then let them close up again on withdrawal, instead of cutting a hole in the fibers. With these needles the risk of headache is less than 1%.

Common scenarios for subarachnoid blocks:

- Knee and hip replacement surgery
- Cesarean section
- Cerclage placement during pregnancy

Epidural Blocks

For an epidural injection, needle placement is similar to a subarachnoid block but is stopped prior to entering the dura. The space between the dura mater and the ligamentum flavum is the epidural space, which is a potential space containing adipose tissue, connective tissue, and blood vessels. Medication can be injected through the needle, or a small catheter can be threaded into the space through a large bore (Tuohy) needle and left in place for an infusion of medication. This is especially helpful when the required duration of anesthesia is unknown (ie. a laboring patient) or for postoperative pain relief.

Unlike a spinal injection, an epidural can be performed anywhere along the spine. Because the needle does not penetrate the dura, there is (theoretically) minimal risk of damaging the spinal cord. The distribution of anesthesia is also different than a spinal injection. As the epidural space fills with local anesthetic, only nerve roots passing through the space will become anesthetized. Increasing the volume of local anesthetic will add to the number of dermatomes covered. However, nerves that exit below the level of anesthetic will not be anesthetized. Therefore, the location of anesthesia can be more precisely targeted than that of a spinal block. For example, a patient undergoing thoracotomy may have an epidural catheter placed at T7, then an infusion run to target dermatomes T4-T8 for postoperative pain relief. This patient will likely still have use of their legs to get up and walk with assistance. Labor epidurals are generally placed in the lumbar spine and dosed to get coverage of at least T10-L1 for the first stage of labor. The second stage of labor requires sacral coverage which can sometimes be difficult to achieve with an epidural. For postoperative pain relief, an epidural catheter can be maintained for several days, as long as the dressing is clean and intact.

Common scenarios for epidural placement:

- Laboring patients
- Postoperative pain relief for large laparotomies
- Postoperative pain relief for thoracotomies
- Pain relief for patients with multiple rib fractures

Peripheral Nerve Blocks

For peripheral nerve blocks, large volumes (30-40mL) of local anesthetic are injected along nerves or nerve plexuses to provide several hours of analgesia (typically 16-24 hours depending on dose). Nerve stimulators can be used to guide needle placement (a motor response is seen as the needle gets close to the nerve), but ultrasound visualization is more common.

Anesthesia of the upper extremity is typically accomplished with brachial plexus blocks. There are four sites to block the brachial plexus, chosen based on the location of the surgery:

1. Interscalene block: The most proximal brachial plexus block provides anesthesia to the shoulder and upper arm. There are several common and temporary side effects from this block:
    - Phrenic nerve block, causes ipsilateral diaphragmatic paresis that manifests as mild shortness of breath with deep inspiration or while coughing. May cause pulmonary distress in patients with poor lung function, so it may not be appropriate for patients with preexisting pulmonary disease.
    - Horner's Syndrome from blocking the nearby Stellate ganglion
    - Vocal cord paresis from blocking the recurrent laryngeal nerve, may result in hoarseness or voice changes

2. Supraclavicular block: This block covers just above the elbow to the fingers. The plexus is located close to the dome of the lung, so a pneumothorax is possible if the needle is not visualized during the block. The ulnar nerve is often spared during this block.
3. Infraclavicular block: This block covers the elbow to the fingers. It is performed lateral to the lung, so pneumothorax is rare.
4. Axillary block: This block provides anesthesia to the hand and part of the forearm. The musculocutaneous nerve is spared and must be blocked separately.

Anesthesia for the lower extremity can be accomplished with the following blocks:

- Femoral nerve block - Performed near the inguinal crease, this block covers the anterior thigh down to the knee. It causes a significant motor block, so patients cannot bear weight until the block resolves.
- Saphenous nerve block - The saphenous nerve is a branch of the femoral nerve that supplies sensory innervation to the knee. Blocking it helps with analgesia while sparing motor nerves. It is a popular block for patients having knee replacement surgery because they can bear weight and participate in rehabilitation shortly after surgery. The nerve itself often cannot be seen on ultrasound, but the location is known to be within the adductor canal (another name for this block is an adductor canal block). Ultrasound is used to guide a needle through the sartorius muscle into the adductor canal, which is then filled with local anesthetic.
- Sciatic nerve block - This block results in anesthesia to the lower leg and foot, except for the saphenous nerve, which innervates the medial malleolus. The sciatic nerve can be blocked below the gluteus muscles, or in the popliteal fossa before it branches into the posterior tibial and common peroneal branches.
- Ankle block - This is a superficial block performed around the ankle that blocks a total of five nerves: Tibial, Sural, Saphenous, Deep peroneal, and Superficial peroneal. It is commonly used by podiatrists for their procedures.

<u>Compartment Blocks</u>

Smaller sensory nerves often travel throughout the body between layers of muscle fascia. Many of these can be anesthetized by injecting local anesthetic into fascial planes using ultrasound. These blocks aren't particularly dense, but can help dramatically with postoperative pain control, especially if performed prior to the surgery for preemptive analgesia.

- PECS block - Useful in breast surgery, ultrasound is used to inject anesthetic in the fascial plane between Pecs Major and Pecs Minor, then more between Pecs Minor and Serratus Anterior.
- TAP block - Useful in laparotomy incisions below the umbilicus, ultrasound is used to inject local anesthetic in the fascial plane between the Internal Oblique and Transversus Abdominis muscles.
- Fascia Iliaca Compartment Block - Useful in hip surgery, anesthetic is injected just below the superficial fascial layer of the iliopsoas muscle. A large volume (40-50mL) of dilute local is injected with the hope of it spreading proximally to the lumbar plexus.

Part 6. Intraoperative Care

Routine Care

Intraoperatively, patients are monitored closely for changes in anesthetic depth, changes in physiology, and issues with any medical problems. Anesthesiologists need to be ready to address all general medical issues, from the common (asthma/COPD, diabetes, hypertension), to the rare and complex (carcinoid crisis, thyroid storm, pheochromocytoma, ketoacidosis). Fluid balance is closely monitored, and pain is managed through careful dosing of analgesics. Vital signs can change suddenly, each with its own differential to work through. Common aberrations include hypoxia, hypotension, hypertension, bradycardia, tachycardia, hyperthermia, hypothermia, and changes in end-tidal CO2.

Monitoring Equipment

The American Society of Anesthesiologists sets standards for monitoring. All cases require the following:

- EKG (typically 5-lead)
- Blood pressure readings at least every 5 minutes, typically via noninvasive oscillometric cuff
- Pulse oximetry
- Gas monitoring system (Monitors O2 level from machine and patient's exhaled gases)
- Temperature probe (for general anesthetics)

Additional monitors may be added at the discretion of the anesthesiologist. Selection may be based on patient comorbidities or in anticipation of their needs based on the type of surgery.

- Train-of-Four neuromonitor: Should be used during any case in which a patient receives a muscle relaxant (see Part 3).
- Arterial line: Gives beat-to-beat blood pressure readings for closer monitoring. Can draw frequent samples to measure ABGs, hemoglobin, and electrolytes. Consider for patients with poor cardiac function, severe pulmonary issues (to help with ventilator settings), or for cases with the potential for major blood loss or fluid shifts.
- Central line: Can monitor CVP which may help with fluid management. More commonly central lines are placed for better venous access in patients who may need large amounts of fluid or blood transfusions.
- Pulmonary artery catheter: Placed during certain heart surgeries. Can give PAP (pulmonary artery pressure),PCWP (pulmonary capillary wedge pressure), SvO2 (mixed venous oxygen saturation), and CO/CI (cardiac output/index). Used infrequently since the advent of intraoperative TEE.
- Transesophageal echocardiogram: Relatively easy to place and much less invasive than a PA catheter, TEE can readily provide real time information on myocardial contractility, wall motion abnormalities, and fluid status. Proper interpretation can immediately diagnose myocardial ischemia, causes of hypotension, and catastrophic events such as pulmonary embolism and cardiac tamponade. Overall it is probably the best indicator of myocardial ischemia. TEE is useful in cardiac and trauma patients, or any patient with unexplained or difficult to diagnose hypotension.
- Processed EEG: These are "depth of anesthesia" monitors (Entropy, BIS, SedLine). A sensor is placed on the patient's head to pick up EEG waves and interpreted by the machine. A number from 0-100 is displayed based on each company's proprietary algorithm that is supposed to reflect the patient's consciousness level. Zero represents an isoelectric EEG while 100 represents full consciousness. Adequate anesthesia is supposedly in the 40-60 range. These may be helpful

in patients who may not be able to tolerate adequate anesthesia (sick, elderly, poor cardiac status) during high risk procedures (cardiac, trauma), or in patients with a history of intraoperative awareness.

Fluid Management

Historically, four types of fluid losses are accounted for and replaced during anesthesia:

1. Maintenance fluid: 4mL/kg for the first 10kg + 2mL/kg for the next 10kg + 1mL/kg for each additional kg, replaced hourly.
2. NPO deficit: (Maintenance rate) x (# hours NPO) replaced over the first 3 hours.
3. Insensible losses: Fluid lost through the breathing circuit and open body surfaces. May be low in noninvasive procedures (1-2mL/kg/hour) to very high in large laparotomies where the bowel is exposed (8-10mL/kg/hour).
4. Blood loss: If replaced with crystalloid, replace with 3mL for every mL of blood loss because only 1/3rd of crystalloid solution stays intravascular. If replacing with PRBCs, replace 1:1.

Trying to calculate and preemptively give fluids is an outdated method of fluid management, but gives an idea of why fluid management is important and often difficult to achieve perfectly. Insensible losses and blood loss are usually impossible to accurately calculate. Significant debate still exists on crystalloid vs. colloids, restrictive vs. liberal fluid replacement, and when to give blood transfusions. Thus, intraoperative fluid management remains challenging and should be tailored to each patient’s individual needs.

Part 7. Anesthetic Complications

Postoperative Nausea and Vomiting (PONV)

Postoperative nausea and vomiting is common in patients receiving volatile anesthetics. Additional risk factors for PONV include:

- Female sex
- Nonsmoker
- History of motion sickness or previous PONV
- Perioperative opioids

Patients with all four risk factors who receive volatile anesthesia have an 80% risk of PONV. The type of surgery may also play a role. Strabismus and inner ear surgery are known risk factors, but laparoscopic and gynecologic surgeries tend to have higher rates as well. Patients with multiple risk factors sedated with propofol by itself tend not to have PONV.

Many drugs exist for prophylaxis and treatment of PONV:

- Dexamethasone: Given for prophylaxis near the start of anesthesia, the exact mechanism of action in preventing PONV is unknown.
- Ondansetron: Given at the conclusion of surgery or as rescue therapy in the PACU.
- Aprepitant: An NK-1 receptor antagonist, it is given orally prior to surgery for prophylaxis.
- Scopolamine: An anticholinergic that is given as a sustained-release transdermal patch. May take several hours to begin working, thus us used for prophylaxis.
- Promethazine/prochlorperazine: Effective for rescue therapy but are very sedating, so their use is limited in outpatient surgery. Also can cause extrapyramidal side effects.
- Diphenhydramine: An antihistamine that can be effective for some patients, but is also quite sedating.
- Metoclopramide: A weak antiemetic that is rarely used. Can effectively increase gastric emptying. May cause abdominal cramping and extrapyramidal side effects.
- Droperidol: Blocks dopamine stimulation of the chemoreceptor trigger zone. An effective antiemetic that is rarely used due to a black box warning for QT prolongation and Torsade de Pointe issued by the FDA.
- Propofol: Small subanesthetic doses (10-20mg) can be given in PACU.

There are also several nonpharmacologic approaches to treating and preventing PONV:

- Avoidance of triggers: Regional anesthesia may allow patients to avoid volatile anesthetics and opioids altogether. If general anesthesia is necessary, total intravenous anesthesia (TIVA) is usually effective in preventing PONV
- IV hydration: Like treating a hangover, adequate rehydration tends to make patients feel better.
- Aromatherapy: certain aromas, including isopropyl alcohol, can temporarily be effective at reducing nausea
- Acupuncture: Stimulation of the 6-P acupuncture point may be effective for some patients.

Dental Injury

There are certainly far worse things that can happen to patients having surgery, but when a patient comes in for an elective procedure and leaves with a chipped or broken tooth, they tend not to be very happy about it. Dental injury, although mostly benign, is one of the leading causes of payouts to “injured” patients by anesthesia providers. All patients are counselled on the risks of dental injury whenever airway management is needed. Endotracheal intubation puts patients at risk of having a dental injury (particularly upper incisors) from the laryngoscope, although teeth can be damaged by LMAs and oral airways as well. Other risk factors include poor dentition, overbite, poor mouth opening, and other causes of a difficult airway. Patients are routinely asked to remove dentures and other oral appliances to prevent damage (and to prevent airway obstruction if they become loose intraoperatively).

<u>Aspiration</u>

Aspiration is a feared event during anesthesia and can sometimes happen even when all appropriate precautions are taken. The risk of developing pneumonitis after an aspiration event correlates directly with volume of aspiration and the amount of particulate matter in the stomach contents, and varies inversely with pH of the material. If a patient aspirates prior to intubation, they are placed in the Trendelenburg position while the oropharynx is thoroughly suctioned. They are then intubated and suctioned via the endotracheal tube. A fiberoptic scope may be passed to assess the airways, but pulmonary lavage is not recommended. Patients are more prone to developing a chemical pneumonitis than in infection. Routine antibiotics and steroids are not recommended. After the surgery, positive pressure ventilation is only needed if hypoxia is present. Chest physiotherapy and pulmonary toilet may be indicated.

<u>Nerve Injury</u>

Nerves may be injured under anesthesia whenever undue stress (pressure or stretching) is applied to them. Patients obviously are not able to reposition themselves from an uncomfortable position while under anesthesia. Although it’s up to the entire surgical team to ensure safe patient positioning, it often falls under the purview of the anesthesiologist to assess the final position prior to the start of surgery. However, nerves aren’t only damage from malpositioning. An appropriately positioned patient can still suffer from postoperative neuropathy. Risk factors include body habitus, pre-existing neuropathy, diabetes, length of surgery, fluid administration, and specific position. Nerve injury manifests as numbness or tingling that is present upon emergence from anesthesia. Most cases resolve within 48 hours, although some injuries can be permanent.

- Ulnar: The most common nerve injury. Can be from elbow flexion stretching the nerve, or from laying the arms out to the side with compression from the arm board. May also happen from frequent compression by a blood pressure cuff during a prolonged surgery.
- Brachial plexus: Can be injured when arms are abducted greater than 90 degrees, such as during thoracic and hip surgeries. Can also be compressed when the arms are tucked close to the sides (especially in morbidly obese patients) such as for robotic surgeries.
- Peroneal nerve: Can be injured when legs are placed in stirrups that compress the head of the fibula.
- Obturator nerve: Relatively rare, but can be injured with prolonged lithotomy position
- Optic nerve: A rare but extremely significant complication of surgery in the prone position that can cause permanent blindness. May be caused by external pressure on the globe, or from excessive fluid administration causing increased pressure behind the eye. Sometimes no external cause is identified at all.

Malignant Hyperthermia

Malignant hyperthermia is a rare (1:100,000 general anesthetics) hypermetabolic crisis that occurs when a genetically susceptible individual is exposed to a triggering agent. Volatile anesthetics and succinylcholine are the only known triggering agents. A defect in either the ryanodine or dihydropyridine receptor leads to unregulated efflux of calcium from the sarcoplasmic reticulum to the intracellular space. Sustained muscle contraction leads to oxygen depletion and anaerobic metabolism. Eventually rhabdomyolysis and acidosis can lead to DIC, multiorgan failure, and death.

Early signs of the syndrome include:

- Elevated end-tidal CO_2
- Muscle rigidity and/or trismus

Later signs include

- EKG changes associated with hyperkalemia
- Hyperthermia
- Myogobinuria

The diagnosis is presumptive, as no confirmatory tests exist during an acute episode. Treatment involves stopping triggering agents and administering Dantrolene, which inhibits further opening of the ryanodine receptor. Communicate with the surgeon about stopping the procedure or finishing as soon as possible. Further treatment is supportive (treat hyperthermia, metabolic acidosis, hyperkalemia, and rhabdomyolysis).

Definitive diagnosis is expensive and cumbersome, as it requires a muscle biopsy performed at one of only a few sites in the US. Genetic testing can be suggestive of susceptibility if a family member has tested positive, but is not considered definitive.