INTRODUCTION

Differences in anatomy and physiology make administering anesthesia to children unique. However, these differences can also make the anesthesia induction challenging and unpredictable. Thus, it is important to carefully evaluate patients, understand the history of their problem(s), evaluate their laboratory tests, and do a thorough physical examination before taking them to the operating room (See Chapter 1).^1

Providing anesthesia for children in any part of the world requires an understanding of the advantages and disadvantages of the local healthcare system. In many areas of the world children are faced with natural calamities, famine, war, social unrest, and communicable diseases.^2 Malaria, human immunodeficiency virus (HIV) and tuberculosis are common in many of the world's poorest countries. The World Federation of Societies of Anesthesiologists published standards for safe anesthesia in 1992, but anesthetists in some countries cannot comply with these guidelines for lack of equipment, drugs, and training. In most of these countries, there are few trained anesthesiologists. Nurse anesthetists or Clinical Officers, not physicians, provide most anesthetics in these countries, often under difficult conditions.

EVALUATION AND SELECTION OF PATIENTS

Children in some of the poorest countries on earth are frequently free of congenital anomalies because those with congenital syndromes and genetic diseases do not survive early life.^2 However, those who do survive often experience anemia, malnutrition, and parasitic or other infectious diseases. When possible anemia and infections should be treated prior to surgery. However, this is usually not possible when emergency surgery is required. While it may sometimes be difficult to obtain an appropriate history of the child’s health, it is usually possible to do a thorough physical examination. Anomalies of the airway (congenital or acquired), heart (rheumatic heart disease), hepatosplenomegaly (malnutrition, malaria, sickle cell disease) are a few examples of problems that can be detected by a thorough physical examination. Pulse oximetry (SpO2) and knowledge of the patient’s hemoglobin concentration are important. If
bleeding is anticipated, it is probably safest for the patient if her/his hemoglobin concentration is \( \geq 10 \text{gm/dl} \) at the start of surgery.

**PREPARATION OF OPERATING ROOM**

Functional and properly serviced anesthesia equipment is important for delivery of safe anesthesia.\(^3\,4\) All equipment needed to deliver anesthesia should be available and tested before anesthesia is induced to assure that the equipment functions normally. A continuous supply of electricity is needed to power electrical equipment, including monitors and ventilators. Whenever possible there should be a backup generator that quickly and effectively provides electricity to the operating rooms when the local electricity source fails. If no backup generator is available, the anesthetist, surgeon, and nurses must have backup plans for how they will monitor the patient’s vital signs, suction secretions and blood, and provide enough light for the surgeon to operate and control bleeding. If intravenous (IV) cannulas, tracheal tubes (TT), and laryngoscopes must be reused, they should be sterilized between patients to prevent inadvertent infections and deaths. Before inducing anesthesia, the anesthetist and surgeon must determine the type and quantity of IV fluids available and the availability of blood or blood products for transfusion should they be required.

**Oxygen Supply**

When cylinders provided oxygen, it is important to have an alarm system that alerts the anesthetist to the fact that the oxygen cylinder is running out of oxygen. E-cylinders only contain 625 liters of oxygen when full.\(^5\) If the inspiratory gas flow is 10 liters/minute, the tank will empty in about one hour. Pressure in the oxygen tank is proportional to the amount of oxygen left in the tank. Full G-cylinders contain 5,300 liters and H cylinders contain 6,900 liters of oxygen respectively. Thus, it takes much longer for the tank to empty. Oxygen from the wall commonly comes from G and H cylinders, and the tanks must be changed frequently. It is good practice to have an E-cylinder and its pressure-reducing valve immediately available in the operating room for times when larger tanks unexpectedly run out of oxygen during surgery. Having a self-filling Ambu™ type bag immediately available will allow the anesthetist to ventilate the patient’s lungs with room air in case of a sudden loss of oxygen or electricity. If nothing else is available, the anesthetist can provide mouth-to-mouth breathing. This is more effective if oxygen is available and a tube from the oxygen source is placed in the anesthetist’s mouth to increase the inspired oxygen concentration.

Oxygen concentrators are used to extract oxygen from air when compressed oxygen is unavailable (Figure 7-1).\(^6\) The Zeolite in these devices adsorbs nitrogen from the air, leaving 85-90% oxygen in gas breathed by the patient. Concentrators provide a cheap, reliable source of oxygen and are unlikely to cause fires. Oxygen cylinders are usually painted white to comply with World Health Association (WHO) standards.\(^5\) Pressure regulators and gas flow meters, integral
parts of oxygen delivery systems, must be serviced often to assure they are functioning correctly and accurately.

**Fig 7-1: Oxygen Concentrator Connected to Vaporizer with Jackson-Rees Circuit**

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**Anesthesia Delivery Systems**

Anesthesia delivery systems should be inexpensive, safe, and easy to assemble (Figure 7-2). They should also work when compressed gas is unavailable. Two of these systems, EMO (Epstein Macintosh Oxford) and OMV (Oxford Miniature Vaporizer), are widely used for inhalational anesthesia when there is no secure source of compressed gas. These draw-over vaporizers work well with oxygen concentrators. The negative pressure created by the patient’s inspiratory efforts draws air from the atmosphere, which is used as the carrier gas for the anesthetic.
**Mode A** – provides basic inhalation anesthesia with air, spontaneous ventilation, or self-inflating bags

**Mode B** – provides oxygen enrichment but requires an oxygen source (concentrator or cylinder)

**Mode C** – requires electricity to power the oxygen concentrator, air compressor and/or ventilator

**Mode D** – requires a Boyle machine and nitrous oxide cylinders

*T-piece with reservoir tube and face mask*

*Ambo™ pediatric valve*

*Self inflating bag*

*Oxford inflating bellows*

*Oxford miniature vaporizer with halothane*

*OMV with trichloroethylene*

*Epstein Macintosh Oxford vaporizer with ether*

*Farmer’s entrained with an oxygen cylinder*

*Oxygen cylinder*

*Electrical power source*

*Oxygen concentrator*

*Air compressor*

*Manley ventilator*

*Nitrous oxide*

*Boyle’s apparatus*
Oxygen cylinders or oxygen concentrators can be connected to the supplementary inlet of the vaporizer to increase the oxygen concentration of the delivered gas. When EMO and OMV systems are used for pediatric anesthesia, the recommendation is to use them with Jackson-Reese system for greater patient safety.

Copper Kettle or Vernitrol devices are nonspecific vaporizers that can be used with most inhaled anesthetic agents. The concentration of anesthetic delivered to the patient depends on the vapor pressure of the anesthetic liquid, gas flow through the device, and total gas flow in the system. When providing anesthesia with draw over vaporizers at high altitude, it is often necessary to supplement the air with some oxygen to prevent hypoxemia.

The Ohmeda 885A machine has a universal, non-agent specific vaporizer that allows safe delivery of different inhaled agents and has been used for wartime medical care as well as medical missions. This machine conveniently and safely provides anesthesia in remote locations (Figure 7-3). It consists of a simple circle system and a carbon dioxide (CO₂) absorber. It is lightweight, compact, and can be used with either compressed oxygen or medical air. Because nitrous oxide (N₂O) cannot be used with this machine, it is difficult to deliver a hypoxic mixture of gas. Standard halothane, isoflurane and sevoflurane vaporizers work with this machine. The vaporizers are temperature and pressure compensated, making their output relatively constant, assuming the vaporizers are serviced at least once a year.
Figure 7-3: The OBAMED Portable Anesthesia Machine

This photograph shows an OBAMED portable anesthesia machine with a sevoflurane vaporizer, anesthesia circuit and bag, anesthesia, flow meters for oxygen and nitrous oxide, and a CO₂ absorber.

The Kambatta anesthesia system is another simple, low technology way to deliver anesthesia and oxygen (Figure 7-4).¹⁰ It includes a pressurized oxygen supply, a flow meter connected to a freestanding vaporizer, a portable disposable sealed carbon dioxide absorber, and a breathing circuit. This system can be assembled in a few minutes.
Inhaled anesthetics can be interchanged in non pin-indexed standard vaporizers. A pin-indexed vaporizer is one that has pins that only allow a drug-specific vaporizer to be connected to the anesthesia machine and to deliver one inhaled anesthetic at a time. When the pin indexing system is bypassed, the anesthetist must pay close attention to the output of the anesthetic vaporizers and the patient’s condition, because it is possible to administer too much or too little anesthetic to the patient. Halothane and isoflurane have roughly the same vapor pressures. Consequently, they can be used with either a halothane or isoflurane vaporizer without significantly affecting the vaporizer’s accuracy and output. It is advisable to empty all residual volatile anesthetic from the vaporizer before filling it with fresh liquid anesthetic to avoid mixing anesthetics and delivering a mixture of anesthetics to the patient. Monitoring end-tidal anesthetic concentrations is the best way to detect the presence of anesthetic mixtures.

It is advisable to scavenge anesthetic gases from the operating room to prevent their inhalation by surgeons, nurses, and anesthetists. This can be done with portable anesthesia machines by running corrugated tubing from the exhaust valve of the breathing system to an outside window or a suction device.

Old exhausted soda lime may not change color when exposed to CO₂. Consequently, when exhausted soda lime is used, patients develop hypercarbia and respiratory acidosis. When soda lime is unavailable or in limited supply, a non-rebreathing circuit (e.g., Mapleson or Bain circuit) is a good option because the patient’s PaCO₂ will not rise if the gas flow in the system is at least 189
twice the patient’s minute ventilation [tidal volume (7m/kg in all patients) X respiratory rate]. The disadvantage of these systems is that they require a high total gas flow to prevent CO₂ rebreathing and this wastes precious oxygen and anesthetic.

Monitors

Intraoperative monitoring of oxygen saturation (SaO₂), arterial blood pressure (BP), body temperature, and the electrocardiogram (ECG) provides early warning of impending cardiopulmonary problems (See Chapter 2). Monitoring of end-tidal CO₂ is also very helpful. If CO₂ is present in the expired gases, the tracheal tube is in the trachea (not the esophagus) and ventilation is occurring.

A precordial stethoscope allows the anesthetist to determine the presence of breath sounds and the quality of the heart tones. Breath sounds indicate that the patient’s airway is patent and he/she is breathing. Heart tones, on the other hand, are an indication of cardiac function. Crisp, normal heart tones suggest normal myocardial function. Diminished and less crisp heart tones suggest decreased myocardial function. Changes in heart tones during anesthesia indicate improving or worsening myocardial function.

INDUCTION OF ANESTHESIA

NPO Guidelines and Preoperative Sedation

It is important to determine preoperatively if a patient has drunk or eaten anything recently. The standard Society of Anesthesia (ASA) guidelines for when to stop eating and drinking before elective surgery [Nothing By Mouth (NPO)] (See Table 1), reduces the incidence of vomiting and aspiration of gastric contents in the perioperative period, a common cause of death in many patients.

<table>
<thead>
<tr>
<th>Type of food/liquid</th>
<th>Hours before inductions of anesthesia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear liquids</td>
<td>2 hrs.</td>
</tr>
<tr>
<td>Light meal</td>
<td>6 hrs.</td>
</tr>
<tr>
<td>Full meal</td>
<td>8 hrs.</td>
</tr>
</tbody>
</table>

Clear liquids are fluids one can see through (water, apple juice without pulp, etc.); a light meal consists of toast and liquid (e.g., coffee). NPO – nothing by mouth.
Infants and young children who live in warm climates and have fasted for many hours are at risk for developing hypovolemia and becoming hypotensive during anesthesia induction. Hence every patient without a reason not to drink should be encouraged to take in clear liquids up to 2-3 hours prior to surgery. They should be allowed to drink as much as they want before being made NPO because large volumes of fluid empty from the stomach faster than small volumes of fluid.

Oral premedication is often used to sedate children before surgery. This often allows the anesthetist to place an IV catheter preoperatively, which he/she can use to induce anesthesia. The amnesia and sedation provided by preoperative medication often reduces the child’s anxiety and agitation when he/she is taken from her/his parents.

Midazolam (Versed) syrup (0.5 – 0.75mg/kg; maximum dose 10mg), when given 15-20 minutes before the induction of anesthesia, usually produces a calm child during the induction. Midazolam sedates most children and produces amnesia for preoperative events. If midazolam syrup is unavailable, the intravenous form of this drug can be given orally. However, midazolam, which has a high pH, taste awful. The taste can usually be hidden in a sweet, acid solution (e.g., 30ml of Coca Cola or clear fruit juice). If an elixir of acetaminophen is available, midazolam can be mixed with the elixir to hide midazolam’s bitter taste. To get the desired effects of oral midazolam, the drug must be given 15-20 minutes before entering the operating room. Midazolam is sometimes given intra-nasally 0.2-0.3mg/kg to uncooperative children, but this produces a bitter taste and stings when the drug comes in contact with the nasal mucosa. The intravenous dose of midazolam is 0.05mg-0.1mg/kg. Half of each dose of oral midazolam is metabolized when venous blood from the stomach passes through the liver (first pass effect). Thus, half of an oral dose never reaches the central circulation and brain. If the surgery is short, premedication with midazolam may delay discharge from the recovery room, but not by more than a few minutes.

Ketamine (Ketalar) is another drug that is often used for premedication because it produces a dissociative state that allows smooth transfer of combative children to the operating room. The oral dose of ketamine is 5-10mg/kg (maximum dose 10mg/kg). It too has a bitter taste that must be hidden in something sweet (see above). Ketamine can also be given intramuscularly 2-5mg/kg (max dose 6mg/kg), but ketamine produces significant pain and burning on injection. Despite this, intramuscular ketamine is often the preferred route for sedating combative children or those who will not drink midazolam or ketamine. Delayed awakening from anesthesia and euphoria during recovery from anesthesia are the chief side effects of oral ketamine. Combining oral ketamine with oral benzodiazepines (ketamine 3mg/kg + midazolam 0.5mg/kg) provides effective preoperative sedation and significantly reduces the incidence of postoperative hallucinations. Rectal ketamine 4-6mg/kg can be given once or one dose of intranasal ketamine 0.75mg/kg provides good sedation. The long half-lives of diazepam and lorazepam make them less attractive as premedication drugs.
ANESTHETIC TECHNIQUES

The method by which anesthesia is induced depends on the age and health of the child and on the type and urgency of the surgery. **Inhalation induction** is the most common method used in children in most countries because children seldom like being stuck with needles to start an IV. Inhalation induction of anesthesia occurs quickly due to the fact that the uptake and distribution of inhaled agents occurs more rapidly in children than in adults. This happens because children have increased minute ventilation and a decreased functional residual capacity (MV:FRC). They also have lower blood-gas partition coefficients for inhaled anesthetics than older patients. All of these factors work together to increase the rate at which the anesthetic concentration rises in the lungs. This makes more anesthetic available to pulmonary blood. The larger cardiac output/kg of body mass and the relatively higher blood flow to vessel rich tissue groups provides more anesthetic to the brain and central nervous system in a shorter period of time.

Halothane and sevoflurane are commonly used for inhaled induction of anesthesia because they cause less airway irritation than other drugs; however, in higher concentrations halothane and sevoflurane can also produce coughing, breath holding, and laryngospasm, especially when the anesthetic concentration is increased rapidly. Children frequently have respiratory infections and are seldom free of a cough and congested airways. These infections increase the risk for coughing if anesthetic concentrations are rapidly increased. For these reasons it is usually best to gradually increase the anesthetic concentration (halothane 0.5–1% every four breaths; sevoflurane 2% every 2–4 breaths) to reduce the incidence of coughing and breath holding. Nitrous oxide is a good analgesic and amnestic; its administration shortens induction times when administered with sevoforane or halothane. If proper safety mechanisms are not in place, it is possible to inadvertently deliver a hypoxic mixture of gases when using nitrous oxide.

When a child is combative and crying uncontrollably, anesthesia induction can be rapidly accomplished with a high concentration of anesthetic (**single-breath induction**). The anesthesia circuit is first filled with high concentrations of the gas (halothane 5%; sevoflurane 8%) and the gas flows through the circuit increased to 8-10L/min. The y-connector on the anesthesia circuit is occluded and the gases are allowed to circulate and equilibrate in the anesthesia system for 2-3 minutes. The mask is then placed on the child’s face and he/she is allowed to breathe the gas mixture. The Adjustable Pressure Limiting (APL) valve is kept wide open to make it easier for the child to exhale. A good seal between the mask and face is necessary to prevent dilution of the anesthetic gases and ensure rapid induction of anesthesia. As the child cries, he/she will take several deep breaths of the anesthetic/oxygen mixture and quickly become unconscious. At this point, it is important to reduce the anesthetic concentration and gas flow to normal. Sometimes it is necessary to assist the child’s breathing. Failure to decrease the anesthetic concentration sufficiently rapidly will cause rapid depression of respiratory and cardiac function.
Children can be placed in one of several positions for induction of anesthesia. They can sit on the operating room table (Figure 7-5) while the anesthetist holds the child close to her/his chest. This often works well for children who refuse to lie down.

**Figure 7-5 Mask Induction of Anesthesia**

This photograph shows the author holding a young child while he is sitting on an operating table and leaning backwards against the anesthetist during the induction of anesthesia. This is easy to do, calming for the child, and gives the anesthetist better control of the situation.

The child can also sit in the mother’s or the anesthetist’s lap (Figure 7-6). Singing to the child or telling her/him a story often distracts the child and makes the induction smoother. The inside of the facemask can be smeared with different flavors (orange, bananas, strawberry, bubble gum) to hide the pungent odor of the anesthetic vapor. It is important not to get this food flavoring on the rim of the mask, as it may stain the child’s face for days.
The child is held in the anesthetists lap. It is important not to apply excessive pressure on the abdomen because this will obstruct breathing.

Halothane has long been successfully used to anesthetize children and is still available in many countries. It depresses airway reflexes, causes bronchial dilatation, and provides good depth of anesthesia for tracheal intubation without the need for muscle relaxants. It causes some peripheral vasodilatation and myocardia depression. Therefore, its concentration should not be increased too rapidly.

Sevoflurane is less pungent than other inhaled agents and usually allows for a rapid, smooth induction of anesthesia, even when high doses (8%) are used. Because loss of consciousness occurs more quickly, children struggle less with sevoflurane than they do with halothane. Sevoflurane is associated with less cardiac depression and fewer cardiac arrhythmias than halothane. It is also less likely to sensitize the myocardium to epinephrine. Rapid recovery from sevoflurane reduces the child’s length of stay in the PACU, unless he/she develops emergence delirium, which occurs more frequently in younger children.

Intravenous induction of anesthesia is usually preferred for older children. If necessary, the child can be given oral premedication to help her/him tolerate insertion of an IV. Breathing a 50/50 percent mixture of nitrous oxide (if available) and oxygen provides sufficient sedation and pain relief to allow insertion of an IV. For emergency surgery intravenous induction of anesthesia is usually preferred, as it is for the child who is predisposed to aspirate her/his gastric contents. The
most common drugs used for intravenous induction of anesthesia are propofol and ketamine. Pentothal (Thiopental Sodium) can also be used if available.

If the child’s sympathetic nervous system is not maximally stimulated, ketamine preserves airway reflexes and breathing. It also maintains hemodynamic stability in moderately hypovolemic patients. Ketamine does not, however, prevent hypotension in severely hypovolemic patients. Ketamine is also a good analgesic and an effective drug for supplementing inhaled anesthetics during maintenance anesthesia. One problem with ketamine is that it often causes excessive airway secretions. Combining atropine (10-30mcg/kg – maximum dose 1mg) or glycopyrolate (8-16mcg/kg – maximum dose 200mcg/dose) with ketamine prevents the excessive secretions. When intravenous access is difficult and an inhalation induction of anesthesia is not a good choice (bleeding after tonsillectomy or full stomach), ketamine 5-8mg/kg can be administered into the deltoid or triceps muscles. Drugs are absorbed twice as rapidly from these muscles as they are from the legs or buttocks. Ketamine injection can be followed by intramuscular succinylcholine 4mg/kg – maximum dose 100mg. A better solution is to combine ketamine with atropine or glycopyrolate and succinylcholine in the same syringe. Doing this usually results in an anesthetized patient and good intubating conditions in about 45 seconds. Oxygen should be given for two minutes before injecting this drug mixture to avoid causing hypoxemia. Ketamine 100mg/ml is used for IM injections (when available) because its used reduces the total volume of fluid injected and injection-induced pain.

**Propofol** 2-3mg/kg IV is widely used as an induction agent for pediatric anesthesia. However, IV propofol causes burning and pain in the vein unless lidocaine 1mg/kg and/or fentanyl 1mcg/kg is injected before giving the ketamine. When lidocaine is injected into the vein, the arm circulation should be occluded for a couple of minutes before injecting the propofol. Propofol should not be given to patients who are allergic to eggs, as this may induce an allergic reaction.

**Thiopental** 4-5mg/kg IV is an ultra short-acting barbiturate that is also used for IV induction of anesthesia. However, its use may delay emergence from anesthesia if the surgical procedure is short.

**Methohexital** 30mg/kg, **Ketamine** 4-6mg/kg, **Thiopental** 5-8mg/kg and **midazolam** 0.75mg/kg can be given rectally for induction of anesthesia, but this is seldom done due to poor and erratic drug absorption from the rectum.

Once the child is unconsciousness, IV access is obtained. This can be challenging in children who have been fasting for many hours in a hot environment. Fortunately, most inhaled anesthetics dilate peripheral veins, which makes starting an IV easier. At times it is necessary to insert an IV while simultaneously assuring a good mask fit and adequate ventilation of the patient’s lungs (**Figure 7-7**). If a second person (surgeon, nurse) is available who is skilled at starting IVs, he/she can start the IV while the anesthetist maintains the airway.
Chapter 7: INDUCTION AND MAINTAINENCE OF ANESTHESIA

Figure 7-7. An Anesthetist Starting an IV While Maintaining a Good Mask Fit and an Open Airway

Note that the anesthetist is holding a mask and providing a jaw thrust at the same time she is starting an IV. A nurse placed a tourniquet on the arm and is holding the hand in position for the anesthetist. After the needle is in the vein, the nurse connects the IV to the intravenous catheter and secures the IV with tape.

The tracheas of most children are usually intubated under deep inhalation anesthesia. Administering a dose of IV lidocaine 1mg/kg, propofol 2-3mg/kg or fentanyl 1mcg/kg just before laryngoscopy and inserting the tracheal tube reduces coughing and breath holding that can occur when the anesthesia level is too light. A single dose of succinylcholine 1mg/kg often makes tracheal intubation easier, but it may also lead to malignant hyperthermia in susceptible patients, especially when administered with halothane. Cardiac arrest and death can also occur when succinylcholine is administered to patients who have known or unknown muscle disease. Despite this, a syringe of succinylcholine should be immediately available for injection into an upper extremity if laryngospasm and upper airway obstruction occur and the patient has no IV. If the patient has severe hypoxia and bradycardia, it may not be possible to relieve the laryngospasm by I.M. injection of succinylcholine because both conditions severely reduce blood flow to peripheral muscles. Consequently, the amount of time required to absorb the drug may be very long. Under these circumstances, it is often better to inject succinylcholine into the base of the tongue through a 25 or 30-gauge needle, because blood flow to the head is better maintained during hypoxemia and acidosis than it is to peripheral muscles. After an intra-lingual injection, the vocal cords usually relax sufficiently in about 10 seconds to permit ventilation of the lungs with oxygen. Using larger needles for intra-lingual injection of drugs (unless absolutely necessary to prevent death) may cause bleeding into the tongue and worsen airway obstruction.
Left – Standard tracheal tubes. Right - RAE tubes. They have a preformed bend that allows the proximal end of the oral tube to be directed downward to allow the surgeon better access to the mouth and face. The nasal RAE tube has a preformed bend that allows the proximal end of the tube to be directed towards the top of the head, which potentially reduces injury to the nose during nasal intubation. Care must be taken to assure there is no upward tension on a nasal tracheal tube to prevent ischemia of the nares.

Whether to use a tracheal tube (TT – Figure 7-8) or a laryngeal mask airway (LMA) to secure the airway depends on the type and duration of surgery. Tracheal tubes are either cuffed or uncuffed. Cuffed TTs are ideal for abdominal and airway surgery, for preventing aspiration of gastric contents and oral secretions, and for providing more effective mechanical ventilation for patients with poorly compliant lungs. However, non-cuffed tracheal tubes are commonly used for children less than six months of age because cuffed tubes can interfere with blood flow to their tracheal mucosa and cause airway damage. When either type of tube is used, gas should be heard to leak from between the tube and the trachea when 20cmH₂O inspiratory pressure is applied to the airway. This reduces the chance of tracheal injury. Tracheal intubation is the preferred method for securing an airway for complex and/or prolonged procedures. Oral RAE tubes (Figure 7-8 - Right) are used for surgery on the face, mouth, throat, and neck, including repair of cleft palates and cleft lips. These tubes reduce the likelihood of the tube kinking during surgery. They also move the tracheal tube out of the surgeon’s way, making it easier for her/him to see and operate. Age appropriate RAE tubes might be too long for the airways of children whose necks are shorter than average, or they might be too short for children who necks are longer than average. If the tube is too long for a given patient, the tip may enter the right mainstem bronchus or it might stimulate the carina and induce coughing. If the tube is too short, it may come out of the trachea during surgery, especially when the head is extended.
Laryngeal Mask Airways (LMAs) are often used for hernia repair, orchidopexy, and orthopedic procedures on extremities (Figure 7-9). However, it must be remembered that LMAs can become malpositioned or dislodged easily, especially in infants, and that when this occurs it can obstruct the airway. They add a considerable amount of dead-space to the child’s airway (about 100% in neonates), and this elevates her/his PaCO₂ and causes respiratory acidosis. It is inappropriate to use an LMA in patients who have or may have increased intracranial pressure (e.g., head trauma).

LMAs have a cuffed opening that fits over the glottis of a patient through which the patient breathes. The mask is connected to a wide-bore tube that has a 15mm connector that allows connection to an anesthesia circuit or ventilator. It is seldom possible to generate more than 20cmH₂O inspired pressure without causing gas to leak around the mask.

Complications During Induction of Anesthesia

Several things can go wrong during the induction of anesthesia. If coughing and breath holding occur, they can quickly lead to oxygen desaturation. Low levels of inhaled anesthetics block tone in the genioglossis and hyoglossis muscles, muscles that normally keep the tongue forward and
away from the posterior pharyngeal wall to maintain a patent airway. Loss of tone in these muscles often causes upper airway obstruction, especially in young children. Enlarged tonsils and adenoids can also interfere with breathing (See Chapter 17). Airway secretions and regurgitation of stomach contents are frequent causes of laryngospasm. Respiratory infections, oral secretions or blood in the oral cavity, attempts at tracheal intubation during light levels of anesthesia, or painful stimuli during the second stage of anesthesia also cause laryngospasm. It is best not to examine children while anesthesia is being induced.

**Figure 7-10: Sniffing Position During induction of Anesthesia and Tracheal Intubation**

![Image](image_url)

*Note that the anesthetist’s fingers are on the bone of the mandible, not in the soft parts of the chin. Placing the fingers in the soft parts of the chin pushes the tongue posteriorly and obstructs the airway. The child’s face is looking forward and the head is not flexed or extended. This gives the best conditions for intubation of the trachea and for ventilation of the lungs of a baby with a bag-and-mask.*

Properly positioning patients during induction of anesthesia is important for the prevention of upper airway obstruction and for improving conditions for tracheal intubation. Placing a small roll under the shoulders of small children and having their heads rest on a small pillow keeps their head in a neutral position and reduces airway obstruction. *(Figure 7-10)* This improves conditions for mask ventilation and tracheal intubation. A proper fitting facemask is necessary for good mask ventilation, especially in patients who have abnormalities of their head, face, and neck. A combination of chin lift, jaw thrust, and the application of 10 cm of H₂O continuous positive airway pressure (CPAP) helps overcome upper airway obstruction in spontaneously breathing children. Once an appropriate level of anesthesia has been reached, it is possible to insert an oral
airway, if needed. The heads of small children should not be hyperextend, as this narrows the tracheas and decrease air movement. The anesthetist’s fingers should be placed on the mandible, not in the soft tissue of the submental triangle of the chin. The latter pushes the tongue into the pharynx and obstructs the airway.

*Laryngospasm*, while a frequent occurrence in children, only occurs during light levels of anesthesia or when the patient is awakening. It does not occur in deeply anesthetized patients. Failure to recognize laryngospasm and intervene immediately can result in hypoxemia, central nervous system (CNS) injury, and death. During severe laryngospasm, the true and false vocal cords reflexly close, causing complete closure of the glottic opening and absence of air movement. Milder laryngospasm causes inspiratory noise (stridor) when the child attempts to breath through a partially closed glottis. With worsening laryngospasm, the initial suprasternal and infra-sternal retractions progress to rocking chest movements. Once the glottis is fully closed, attempts at breathing cease, and severe hypoxia and bradycardia occur. Without rapid, appropriate treatment, cardiac arrest follows. Initial treatment includes applying a tight-fitting mask to the face and creating a end-expiratory pressure of 15-20cm of H2O plus applying jaw thrust and gentle positive pressure ventilation. This often breaks the laryngospasm. If ventilation of the lungs is successful, the depth of anesthesia is deepened. If this does not break the laryngospasm and the anesthetist has IV access, propofol 1-2mg/kg can also be administered. Succinylcholine 1-2mg/kg IV or 2-4mg/kg IM or intralingual can be used to facilitate tracheal intubation if the laryngospasm persists (see above). Gentle compression of the chest has been known to occasionally break laryngospasm, but this is not routinely recommended.

**Hypotension** (a >30% decrease in preoperative systolic blood pressure) is common during the induction of anesthesia in children. Both volatile anesthetics and propofol produce hypotension because they depress cardiac function and induce vasodilation. Induction-induced hypotension is more pronounced in children who have fasted for many hours or who have had vomiting or chronic diarrhea. Administering boluses (10-20ml/kg) of a balanced salt solution [e.g., lactated Ringer’s solution (LR) or normal saline (NS)] often restores blood pressure to normal. It must be remembered, however, that only 20% of each bolus of fluid given remains in the intravascular space; the remainder is lost into the intra- and extra-cellular spaces. Thus, more than one bolus of LR or NS may be required to treat hypovolemia. Hemorrhage and/or sepsis are frequent causes of hypovolemia and hypotension. Ketamine is a good choice for induction of anesthesia in moderately hypovolemic patients because it causes the release of catecholamines, and this raises the arterial blood pressure.

**Bradycardia** has many causes, including hypoxemia, succinylcholine, and halothane. Since young children mostly depend on heart rate for cardiac output, it is important to quickly restore their heart rate to normal when it is low. Reducing the anesthetic concentration is one way of increasing the heart rate, but this usually takes a few minutes. Atropine 20-30mcg/kg or
glycopyrolate 4-10mcg/kg, on the other hand, rapidly increases the heart rate to normal. To prevent succinylcholine-induced bradycardia, atropine is often given just before or along with the injection of succinylcholine.

A difficult airway is defined as the inability to ventilate the patient’s lungs with a bag and mask or the inability to intubate the patient’s trachea by direct laryngoscopy (See Chapter 6). Anatomic abnormalities of the face and/or neck (short mandible, large tongue, small mouth) or the presence of a congenital syndrome or of an intraoral or pharyngeal mass should alert the anesthetist to the fact that it may be difficult to maintain a patent airway. It may be possible to determine how difficult it will be to ventilate the patient’s lungs by giving a breath by bag-and-mask each time the patient inspires. Using an airway adjunct, such as a lighted wand or bougie (when available), is very helpful (See Chapter 6). A video laryngoscope or glidescope are other options, but these are very expensive and seldom available. If one suspects the patient has a difficult airway, spontaneous ventilation should be maintained while inducing anesthesia and securing the airway. If the lungs cannot be ventilated and oxygen desaturation occurs, an 18-gauge IV catheter can be inserted into the trachea through the cricothyroid membrane to provide an emergency airway. Doing so may be life saving. (Figure 7-11)

**Figure 7-11. Insertion of an IV catheter for Ventilation of the Lung in a Patient with a Totally Obstructed Airway.**

The figure on the left shows the equipment needed to provide ventilation and/or oxygenation through a catheter inserted into the cricothyroid membrane. The flow meter adjusts the flow of gas through the catheter. Because the resistance of the catheter is so high the gas flow through the catheter is low. By inserting a 3.0 tracheal tube 15mm connector into the proximal end of the tracheal catheter, it is possible to connect a Jackson-Reese breathing circuit to the tracheal catheter and slowly ventilate the lungs. Ventilation must be done slowly because the resistance of the catheter. Gas usually escapes from the lungs during exhalation, but if there is no gas escapes during exhalation, the lungs will become over inflated, which may interfere with pulmonary blood flow or cause a pneumothorax. While the lungs are being oxygenated, every effort to relieve the airway obstruction must be undertaken. The figure on the right shows a catheter through the neck and cricoid membrane of a child with airway obstruction.
MAINTENANCE OF ANESTHESIA\textsuperscript{11,12}

Inhalational agents (isoflurane, sevoflurane, halothane) are commonly used to maintain anesthesia during surgery. Halothane is still commonly available and used in many hospitals throughout the world. An important problem with halothane is its ability to sensitize the myocardium to exogenous epinephrine, which results in dysrhythmias. No more than 10-15mcg/kg of epinephrine should be injected when infiltrating tissues, and the dose of epinephrine should not be repeated more often than every 20 minutes. Prolonged recovery from anesthesia is another drawback to using halothane for maintenance of anesthesia, especially if rapid turn over of cases is anticipated.

Inhaled anesthetics can be supplemented with intravenous analgesics (fentanyl 1mcg/kg, morphine 100mcg/kg) to reduce the amount of inhaled anesthetic administered. Narcotics are inexpensive and provide good intra- and postoperative analgesia. Large doses of intraoperative narcotics may delay emergence from anesthesia. Ketorolac 0.5 mg/kg – maximum dose 30mg - given intraoperatively provides good analgesia, but fear of platelet dysfunction and of postoperative bleeding deters some surgeons from using it. Either rectal 40mg/kg or intravenous or oral acetaminophen 15mg/kg can also effectively relieve postoperative pain.

Use of neuromuscular blockade to facilitate surgery requires a means of artificially ventilating the lungs, either a mechanical ventilator or an AMBU™ type bag during surgery. Ventilating the patient’s lungs by hand often distracts the anesthetist and ties up her/his hands, making it difficult to perform and/or concentrate on other tasks. However, when the lungs must be ventilated by hand, it is important to occasionally give a breath that is twice the patient’s normal tidal volume to prevent atelectasis from developing.

Regional anesthesia (See Chapter 21) and neuraxial blockade are great adjuncts to general anesthesia. They can also provide adequate anesthesia for surgery if general anesthesia is unavailable or cannot be performed for some reason. Sedating children with small amounts of narcotics or benzodiazepines helps calm them while the blocks are being performed. It is important that someone other than the person doing the block monitor the child’s heart rate, respiratory rate, and blood pressure while the block is being performed. Regional and neuraxial blocks are cost effective and provide good postoperative pain relief as well. However, learning to successfully provide these blocks requires time and training. Infra-orbital and nasal nerve blocks provide effective pain relief for repair of a cleft lip and reduce the need for opioids, especially in babies.\textsuperscript{15} Caudal epidural blocks are usually adequate for lower abdominal and urological surgeries. Extremity blocks effectively reduce postoperative pain for patients undergoing orthopedic and burn procedures.

Total intravenous anesthesia (TIVA) using propofol, narcotics, benzodiazepines and ketamine is more difficult to use without an infusion pump because it is difficult to control the rate of
Infusion. Muscle relaxants are often used during TIVA. Before adding muscle relaxants, it is important to assure that the patient is adequately anesthetized to prevent her/him from being awake, paralyzed, and in pain during surgery. Propofol lacks analgesic properties, but it reduces postoperative nausea and vomiting. After the initial bolus dose, lower infusion rates of propofol are used for maintenance of anesthesia in babies because they clear the drug more slowly than older patients. Prolonged infusion of propofol may not be a good idea, because prolonged infusion of propofol has caused the propofol infusion syndrome (lactic acidosis and death) after several days of use in intensive care units.

Ketamine based general anesthesia is popular and effective in countries where the availability of tracheal tubes, masks, anesthesia machines, and inhaled anesthetics is limited. This drug provides dissociative anesthesia and can be administered by one of several routes (IV, IM, rectally); in most patients ketamine use preserves cardiovascular stability and airway reflexes. When using this technique, it is still necessary to assure that the airway is patent and that the patient is breathing adequately. It may also be helpful to add midazolam 0.1-0.2mg/kg IV to the initial dose of ketamine to prevent the unpleasant hallucinations experienced by some patients during recovery from ketamine anesthesia. Because ketamine increases the production of airway secretions, it is helpful to give a single dose of glycopyrrolate (8-16mcg/kg or atropine 10-30mcg/kg) with the initial dose of ketamine to block the production of secretions.

Normal saline and lactated Ringer’s solutions are commonly used as maintenance IV fluids during surgery. However, giving large volumes of normal saline may lead to hyperchloremic acidosis. Albumin or plasmalyte are frequently used for rapid expansion of the intravascular volume. The anesthetist should be sure that blood products are immediately available if significant blood loss is expected during surgery.

Maintaining the patient’s body temperature near normal is important. Covering exposed body surfaces with plastic sheets, clothing, and surgical drapes is a simple, inexpensive ways to do this. If possible, the surgeon should use warm, sterile irrigation solutions during surgery to help conserve the patient’s body heat.

Standard ASA monitoring (arterial blood pressure, ECG, heart rate, body temperature, and SaO2) should be used when available. (https://www.asahq.org/For-Members/Standards-Guidelines-andStatements.aspx). These monitors provide early warning of impending problems and save lives. (See Chapter 2)

**EMERGENCE FROM ANESTHESIA**

Awakening from anesthesia requires the anesthetist to anticipate the conclusion of surgery, reduce the anesthetic concentration being used, and allow the child to breathe spontaneously. If muscle relaxants were used, their effects should be reversed. The concentration of more soluble
anesthetics (e.g., halothane) should be reduced earlier to allow the patient to awaken from anesthesia at the end of surgery. Once spontaneous respiration, tidal volume, and respiratory rates are adequate, secretions are suctioned from the oral cavity and throat and the tracheal tube is removed while the lungs are fully expanded (deep breath). Otherwise any secretions present in the mouth may be sucked onto the vocal cords with the next inspiration and cause laryngospasm. The dose of narcotics or other analgesics should be given in sufficient quantities to block pain but not to such an extent that they interfere with breathing.

Tracheal extubation can be done when the patient is fully “awake” and has return of her/his airway reflexes or while he/she is still anesthetized. A fully awake child is one who is breathing adequately, opens her/his eye on request, grimaces, and makes purposeful movements. Anything less than this means the child is still partially anesthetized. This degree of awakening usually occurs at end-tidal halothane concentrations below 0.15% or sevoflurane concentrations below 0.6%. It is probably safer to extubate the tracheas of most patients when they are awake. Awake extubation is necessary for patients with delayed gastric emptying (due to drugs, trauma, or systemic illness), a difficult tracheal intubation, or respiratory problems.

Deep tracheal extubation occurs when the TT or LMA is removed from a spontaneously breathing patient who is still anesthetized. This method is recommended for children with asthma and those with elevated intraocular pressures. A surgical level of anesthesia is maintained with a volatile anesthetic (e.g., sevoflurane 1.64%). After suctioning the mouth and pharynx to remove any secretions, a large breath is given and the tracheal tube is removed while the lungs are fully expanded. This causes the patient to exhale before Inspiring, which reduces the likelihood of pulling secretions onto the vocal cords or into the lungs with the next inspiration. This maneuver often induces a cough, which also helps expel any secretions. The volatile anesthetic agent is then turned off and the patient allowed to breathe 100% oxygen through a facemask while awakening from anesthesia. It is sometimes helpful to insert an oral airway for a few minutes to prevent upper airway obstruction during awakening. The child can then be taken to the recovery area (See Chapter 22).

The choice of deep or light tracheal extubation depends on the preference and training of the anesthetist, as well as on surgical needs. Oxygen saturations are higher during the first five minutes after deep tracheal extubation, but there is no difference in the incidence of airway complications or oxygen requirements after that. One advantage of deep tracheal extubation is that turnover of the room between cases is quicker than it is following awake extubation.

When to remove an LMA after surgery has been studied extensively. The usual practice is to remove it during deep anesthesia because this reduces the incidence of laryngospasm and oxygen desaturation.
Emergence from anesthesia can be delayed for one of several reasons, including the patient having received large doses of narcotics or being more sensitive to anesthetic vapors. Hypothermia and acidosis prolong the effects of muscle relaxant, which can also delay recovery. When the child is ready to be transferred from the operating room to the recovery area, he/she can be transferred breathing room air if the SaO₂ is normal or while breathing 100% oxygen if it is not. The SaO₂ of about 15% of children is below 95% when they breathe room air during transport. At high altitude (where the oxygen concentration of air is reduced) it is often helpful to moderately hyperventilate the patient with 100 percent oxygen for 3-4 minutes before rapidly transferring the patient to the recovery room where he/she should again breath oxygen if possible. The hyperventilation reduces breathing during transport of the patient and maintains a more normal oxygen saturation.

Complications During Recovery

Postoperative nausea and vomiting are common complications during recovery from anesthesia. Prophylactic anti-emetics, such as ondansetron (Zofran- 0.1mg/Kg) and dexamethasone (4-8mg), reduce these symptoms when these drugs are given near the end of surgery. Nausea and vomiting are more common after tonsillectomy or bowel or eye surgery. Pain and dehydration also increase the incidence of nausea and vomiting. When patients are adequately hydrated and free of pain, their recovery from anesthesia is smoother.

Emergence delirium is common in 2-6 year old children, mostly after they have been anesthetized with sevoforane or desflurane. Many times the symptoms are self-limited but pharmacological intervention may be needed if the symptoms persist. Small intravenous doses of propofol 0.5-1mg/Kg, midazolam 0.02-0.1mg/Kg, dexmedetomidine 0.5mg/Kg, or fentanyl 1-2mcg/Kg can be given.

Post extubation stridor is common if tracheal, laryngeal, or vocal cord edema develops during surgery and narrows the airway. Gas flow through the constricted area is turbulent and this causes the stridor (a harsh, high-pitched inspiratory sound). Stridor is more common in smaller infants and children due to the fact that their airways are smaller and that a small amount of edema significantly narrows these small airways. The amount of respiratory distress caused by this obstruction may be severe. Treatment of the edema includes humidified oxygen, dexamethasone, and nebulized racemic epinephrine (0.25ml of racemic epinephrine diluted in 2.5ml of normal saline). When racemic epinephrine is unavailable, epinephrine 0.5 ml per kg (maximal dose: 5 ml) of L-epinephrine 1:1,000 can be mixed with saline and given via a nebulizer.

Negative pressure pulmonary edema (NPPE) is a rare but potentially lethal problem. It occurs when the patient generates large negative pressures to overcome a totally or partially obstructed upper airway. Pink frothy fluid is often seen coming from the mouth. Administration of 100% oxygen and application of 5-10cmH₂O positive end-expiratory pressure (PEEP) may be required to
treat the edema. A potent diuretic, such as Lasix (1mg/kg in patients <1 year of age – max dose 2mg/kg/dose, 6mg/kg/24hrs. IV; 0.5-1mg/kg IV for older patients – max dose 6 mg/kg/24hrs.) may hasten fluid removal from the lung and improve oxygenation.

**CONCLUSION**

Safe induction and maintenance of anesthesia requires a thorough understanding of the patient’s medical problems and past medical history. All drugs and equipment needed to meet likely emergencies should be available before the induction of anesthesia. If blood or blood products will be required during surgery, they should be available before surgery begins. Preparation should be made to care for the child after surgery (PACU, ICU, home) and for her/his pain relief.

**REFERENCES:**

1. Khambatta HJ, Schechter WS, Navedo AT. Good outcome and volunteer medical services in developing countries are compatible. Anesthesiology 2002; 97:755-56
13. Online ISSN 1471-6771 - Print ISSN 0007-0912 Copyright © 2014 the British Journal of Anaesthesia Oxford Journals Oxford University Press; Relationship of inspiratory and expiratory times to upper airway resistance during pulsatile needle cricothyrotomy ventilation with generic delivery circuit.


