Pediatric Anesthesia: A Primer

This primer reviews the basic information necessary for administering anesthesia to children at UMASS Memorial Medical Center safely. It covers key concepts in pediatric anesthesia including fasting guidelines, pertinent airway anatomy, premedication, induction techniques, regional techniques and generally gives helpful information about how pediatric cases may best be performed. Hopefully this information will provide residents the necessary background information when anesthetizing children at our institution.

This primer is NOT meant to be comprehensive in nature. Residents are strongly encouraged to consult Steward's and Leman's Manual of Pediatric Anesthesia or a comprehensive textbook such as Gregory's Pediatric Anesthesia for more detailed information on this broad subspecialty.

Operating Room Equipment

Dedicated pediatric carts are available for using in the operating room and for off-site cases. White pediatric boxes with specialized equipment are also available for use in the anesthesia workroom.

At the Memorial campus, there is a dedicated NICU cart available outside of operating room four for use when caring for NICU patients.

Pediatric Code Carts

There are standard pediatric code carts that are located throughout the operating room and hospital. They are organized differently than the standard adult code carts based on a color-coded system developed by Breselow in the 1970s. Studies have demonstrated that use of these carts reduces delays in gathering specialized equipment needed in emergency situations.

The Breselow system provides a quick estimation of body weight based on body length. Once the corresponding color is determined based on the child's length, a corresponding drawer with size appropriate equipment can be found on the pediatric code cart. Charts are also available on these carts with suggested dosing recommendations of emergency drugs based on corresponding color.

Please take the time to familiarize yourself with the location of these carts and the organization of these carts.

Pediatric Fasting Guidelines

The American Society of Anesthesiologists guideline on preoperative fasting recommend the following for patients of all ages having elective surgery in the absence of co-existing disease or state that may affect gastric emptying: 2 hours for clear liquids, 4 hours for breast milk, 6 hours for formula and 8 hours for solids. The guideline does not distinguish between adult and pediatric patients.

The determination of an appropriate fasting interval is ultimately up to the attending anesthesiologist.

Heat Loss in the Operating Room

Infants, because of their lack of subcutaneous fat insulation and large surface area/body mass ratio, become hypothermic very quickly during induction in a cold operating room. Infants are unable to shiver and are reliant on non-shivering thermogenesis from brown fat in response to the release of norepinephrine, which is the newborn's only mechanism to maintain body heat. Hypothermia may cause pulmonary hypertension, delayed drug metabolism, hypoxia, apnea and impaired reversal of neuromuscular blockade.

Since most of the heat loss occurs by radiation during the first 15 minutes of the anesthetic, the most effective thing that you can do to reduce the risk of hypothermia is to warm the room before induction takes place. Always warm the operating room before induction and emergence, regardless of age.

Infants also have large heads with a high total body surface area of 18% (versus 9% in adults) that can account for more than 60% of total heat loss. For this reason, a cap may help reduce radiative heat loss.

In addition to the standard adult Bair huggers, there are two pediatric Bair huggers that available for children. These are place beneath the patient as opposed to the adult blankets that are usually placed above the patient. One of each size is available in the pediatric cart.

The Pediatric Airway

As can be appreciated from sagittal head profiles of the adult and infant, important anatomical differences exist that make the airway management of an infant more difficult.

1. The infant's tongue is large in relation to the mandible, making airway obstruction more likely.
2. The epiglottis overhangs the vocal cords to a greater extent making visualization of the vocal cords during laryngoscopy more difficult.
3. The anterior commissure is more caudal than the posterior commissure. Endotracheal tubes may "hang up" in the anterior commissure and be more difficult to pass into the trachea for this reason.
4. Up to the age of 8 years, the narrowest part of the infant's trachea is not the region between the vocal cords but rather the cricoid ring, the only complete cartilaginous ring of the trachea. Tracheal mucosal ischemia caused by a large endotracheal tube may cause a reactive hyperemia that can only go centripetally, causing potential upper airway obstruction postoperatively.

Mask Ventilation

Ventilating a child with a mask can be difficult because of the small size of the patient's airway and the relatively large tongue. It is very easy to press under the patient's chin with a finger and push the tongue up against the roof of the mouth and aggravate any pre-existing airway obstruction. There are four different masks available for children. The two larger masks are impregnated with a sweet smelling substance for patient comfort.

Choosing the Appropriate Oral Airway

One should take care to choose the correct size airway because an oral airway that is too small or too large can make any airway obstruction situation worse that it already is.

An oral airway that is too large can push the epiglottis down into the glottic opening. This can precipitate larygospasm during light anesthesia. An overly large oral airway may also protrude from the mouth, making an effective mask fit difficult or even impossible. Conversely, an oral airway that is too small may displace the tongue posteriorly, exacerbating any airway obstruction.

The correct size oral airway can be estimated by holding an airway next to the patient's face. The tip of the airway should lie just beside the angle of the patient's mandible when the flange lies at the level of the patient's lips.

Laryngoscopy in Children

Infants' and toddlers' vocal cords are more easily visualized using a straight laryngoscope rather than a curved Macintosh blade. This is because the epiglottis overhangs the vocal cords more in the smaller child and obscures good visualization. Vallecular traction exerted by the curved blade may not be enough to lift the epiglottis out of the way to expose the cords. Applying direct pressure on the posterior surface of the epiglottis is more reliable.

Choosing an Endotracheal Tube

Pediatric anesthesiologists have traditionally used uncuffed endotracheal tubes in children 8 years of age or younger. Frequently cited reasons for this choice if uncuffed tubes are: adding a cuff necessitates a smaller tube, which increases airway resistance and the work of breathing; cuffs may increase the risk of mucosal injury; and cuffs are not necessary because appropriately sized uncuffed tubes seal well at the cricoid ring when the lumen of the pediatric airway is the narrowest.

If is often difficult to chose the correct size of uncuffed endotracheal tube for infants and children because so much inter-individual variability in tracheal sizes exist for children of the same age. For this reason, if an infant or child is to be intubated with an uncuffed tube, the anesthesiologist should have three sizes of endotracheal tubes immediately available: the size he or she thinks will be appropriate according to the formula below, on half size larger and one half size smaller. The appropriate size of uncuffed should have a slight leak around it at a peak manual inflation pressure of about 20 cm H_20. If no leak is detected at peak manual inflation, the tube should be removed and the next half-size smaller tube inserted. Failure to do so may result in postoperative edema of the trachea at the level of the cricoid ring which may be life threatening. Even edema of 1 mm in an infant's subglottic area may decrease cross sectional area by 75%.

Cole's Formula for an Uncuffed Endotracheal Tube:

Size (Internal diameter) = Age (years)/4 +4

For example, a 4 year old child would have a (4/4 + 4) 5.0 ETT according to this formula.

Work by Kline has shown that using cuffed endotracheal tubes in children 8 years of age or younger has not been associated with an increase incidence of mucosal injury or other airway morbidity and may have advantages. Because of the fit of a cuffed tube can be adjusted it allows for fewer laryngoscopies to replace ill-fitting endotracheal tubes. The reliable presence of a soft cuff has been shown to reduce gas contamination of the operating room and allow the use of low fresh gas flows. It may also reduce the risk of aspiration and may improve the reliability of end-tidal gas monitoring. Should you wish to use a cuffed endotracheal tube in young children, keep in mind that the cuffed tube should be narrower in diameter than an uncuffed tube as per the formula below:

Kline's Formula for Cuffed Endotracheal Tubes:

Size (Internal diameter) = Age (years)/4 +3

If you use a cuffed tube, you must be scrupulous in your inflation of the cuff. After intubation, inflate the cuff with only that amount of air that is needed to seal the leak. Remember that warming of the gas in the cuff to body temperature and nitrous oxide diffusion into the cuff will both expand the cuff and increase mucosal pressure.

These concerns notwithstanding, there are many ENT and other intraoral procedures where the use of a cuffed endotracheal tube may be preferable to an uncuffed tube to minimize contamination of the lungs by blood or secretions.

Avoiding an Endobronchial Intubation

A large uncuffed pediatric endotracheal tube has three sets of black lines marked on its distal end nears its beveled tip while a smaller tube has only two lines. The lines have been placed there by the manufacturer to aid in proper endotracheal placement. While performing a laryngoscopy and advancing the uncuffed endotracheal tube, advance the tube only until the second set of black lines disappears beneath the vocal cords. Taping the tube at this location will ensure that the tip of the tube lies in the mid trachea and not near the carina. Further advancement of the tube beyond the second set of lines may place the tip of the tube in the right main stem bronchus and result in hypoxia.

Why Do Infants Become Cyanotic and Bradycardic so Quickly?

An infant's metabolic rate is twice that of an adult: an infant's oxygen consumption is about 6 ml/kg/min while an adult's is about 3 ml/kg/min. The largest store of oxygen in the human body is the functional residual capacity (FRC). Awake infants have an FRC of about 25 ml/kg while awake adults have an FRC of about 40 ml/kg. Thus an infant's oxygen storage capacity is roughly half as large as an adult's storage capacity. Coupled with increased oxygen demand this leads to rapid oxygen desaturation in the face of hypoxia that may occur during a prolonged laryngoscopy, laryngospasm or breath holding.

While an adult's natural sympathetic response to hypoxemia is tachycardia, the reverse is true for infants. An immature sympathetic nervous system is overcome by the parasympathetic nervous system leading to bradycardia. Infants become rapidly bradycardic when hypoxemic. This can become so severe as to cause hypotension or even cardiac arrest.

While intravenous atropine will transiently reverse any bradycardia caused by hypoxemia, one must quickly correct the underlying reason for the hypoxemia if cardiac arrest is to be averted.

Always assume that bradycardia in a child is due to hypoxemia until you prove otherwise!

Premature and Ex-Pemature Infants

Premature infants have immature respiratory centers that are easily depressed by inhaled anesthetics, opioids, hypothermia, anemia and hypoglycemia. Potentially life threatening apnea or periodic breathing may result. Children who are born prematurely (as defined as born at less than 37 weeks gestation) who are still less than 50 weeks postconception at the time of surgery are still at risk for these apneas. If a premature or ex-premature infant under your care develops serious apneas with hypoxia, the child should be admitted to an observed inpatient bed. Consideration may be given to administration of IV caffeine.

Because of the risk of life threatening apnea, all ex-premature infants (postconceptual age less than or equal to 50 week at the time of surgery) should be admitted to a monitored bed. This holds true even if there is no history of apnea. Under NO circumstances should an ex-premature infant be discharged home on the day of their surgery.

Parental Presence for Induction in the Operating Room

Parents occasionally ask to be present with their child during induction. Officially, the Department of Anesthesiology does not discourage parental presence in the operating room during anesthetic induction of children. But neither does it encourage the practice. The decision to allow a parent to be present for induction is made only by the attending anesthesiologist in charge of the case. When interviewing children and their parents in the Patient Surgical Evaluation Clinic, please do not automatically offer parents the option of being present for their child's induction. During your interview, if parents mention that they wish to be present during induction, they should be told that the decision to allow one parent to be present in the operating room is solely up to the attending anesthesiologist on the day of surgery.

If a parent is allowed to be present for induction, it will be contingent upon the parents agreeing that the parent will leave the operating room immediately upon the child's loss of consciousness or at any other time should the anesthesiologist request it. The parent should also be adequately prepared for what to expect during an inhalation induction, including the expected physiologic changes that occur during stage II of an inhalation induction.

Premature and Ex-Premature Infants

Premature infants have immature respiratory centers that are easily depressed by anesthetics, opioids, hypothermia, anemia and hypoglycemia. Potentially life-threatening apnea or periodic breathing may result. Children who are born prematurely (defined as less than 37 weeks post gestation age) but are still less than 50 weeks postconceptual age at the time of surgery are termed ex-premature infants and are still at risk for apnea.

If a premature or ex-premature infant in your care develops serious apneas with hypoxia in the recovery room, an apnea monitor should be applied, the child should be admitted to the PICU and consideration given to the administration of intravenous caffeine.

Because of the risk of serious life threatening apnea, it is the department's policy that all ex-premature infants (postconceptual age less than or equal to 50 weeks at the time of surgery) be admitted to the PICU with an apnea monitor for the first 24 hours after surgery.

This holds true even if there is no history of apnea prior to surgery. Under no circumstances should ex-premature infants be discharged home early on the day of surgery.

Pediatric Anesthesia Circuits

The circle absorber system with which you are familiar is commonly used in children. However, to be sure to use the small diameter, low compliance pediatric tubing when ventilating children less than 6 years of age. With this type of tubing, less of each of the ventilator-delivered breath is lost to the patient in the distention of the circuit itself. This volume that is lost to the patient is anomalously called the "compression" volume and is more significant in the smaller child.

Anesthesia Induction Techniques

Inhalation Induction

Since children generally have a fear of needles, the most common and humane way of inducing anesthesia is by way of an inhalation induction. During this type of induction, as many of the usual monitors as is practical are first applied to the patient. Then the anesthesiologist allows the child to breath a mixture of oxygen and nitrous oxide before turning on the sevoflurane.

Succinylcholine should always be immediately available with a 20g IM needle should an airway event occur before intravenous access is established.

Intravenous Induction

If a child already has an intravenous line in place, one can perform an IV induction in the usual manner.

Pharmacologic Considerations

Estimating a Child's Weight From Age

All children should have a recent documented weight in kilograms on their preoperative evaluations.

1. For the first year of life, assign the child a weight of 10 kg.
2. For every year beyond the age of one, add 2 kg/year.

Premedication

Whereas infants less than six month of age separate from their parents quite readily in the holding area, toddlers and small children generally do not. If a child already has intravenous access, consider administering midazolam by this route prior to going into the operating room. If the children do not have an IV, some form of premedication may be a useful separation aid. Whenever possible, avoid intramuscular injections although this may be a useful technique at times.

Oral Midazolam

Oral midazolam is the most commonly used premedication in the perioperative period. Two formulations are available in the Surgical Admissions Care Unit (SACU) Pyxis. A commercially prepared midazolam syrup is available. The intravenous preparation may also be given orally in a sweet vehicle like cherry syrup or apple juice.

The bioavailability of the intravenous form of midazolam is affected by the vehicle it is mixed with creating unpredictable absorption characteristics. This has led to the use of higher per kilogram doses in the range of 0.5 mg/kg to 1 mg/kg. Doses as low as 0.25 mg/kg of the commercially prepared midazolam syrup have been shown to produce sedation and anxiolysis with minimal side effects on respiration and oxygen saturation.

Nasal Midazolam

A dose of 0.2 mg/kg sprayed into a nostril will give adequate sedation in about 5 minutes but can be very irritating.

Anticholinergic Agents

When halothane was commonly used for inhalation inductions, it was common to give children less than one year of age a dose of atropine to prevent bradycardia. Halothane is no longer commercially available in the United States so this practice is no longer common.

Consideration may be given to a dose of 0.02 mg/kg IV to maintain an adequate heart rate during the administration of succinylcholine, the vagal stimulation cause by laryngoscopy or during traction of the eye. Glycopyrolate at a dose of 0.01 mg/kg is a better antisialogogoue than atropine but is a less reliable vagolytic.

Intravenous Fluid Administration

Children less than 6 years of age should always have a Buretrol attached in-line to their IV solution sets. This reduces the possibility of accidental volume overload. Please note that the standard Buretrol set does not include stop cocks. Great care should be taken to purge the intravenous tubing of air that often gets trapped at injection ports during setup. Consideration should be given to the addition of an air filter in children with congenital heart disease to reduce the possibility of systemic air embolization. You cannot administer blood though an air embolism filter though.

The type of intravenous solution preferred will depend on your attending and the nature of the surgery. As a general rule, it is safe to say that isotonic solutions like lactated Ringer's or normal saline are preferred over hypotonic solutions like half-normal saline.

The decision to add glucose to an intravenous solution depends on the attending's preferences and the nature of the surgery. Generally, one should not use glucose-containing solutions for healthy infants and children since these children generally exhibit a vigorous stress response and have sufficient glycogen stores in the liver to prevent hypoglycemia.

Children who may need dextrose include:

1. Infants of diabetic mothers
2. Small-for-gestational age infants
3. Infants on beta-blockers
4. Premature infants
5. Infants with TPN discontinued in the operating room

A D5 solution may be made by adding 10 ml of 50% dextrose with 90 ml of LR or NS. These patients should have their glucose measured regularly while in the operating room and the content of their solutions adjusted accordingly.

Maintenance Fluid Needs in the Operating Room

Patient weight (kg)	Ml/kg/hour
For the first 10 kg of weight	4
For the next 10 kg of weight	2
For each kg beyond 20 kg	1

A child's fluid deficit is estimated by multiplying his/her hourly maintenance fluid requirement by the number he/she has been NPO. During surgery, one should administer one-half of the estimated deficit + the maintenance requirement in the first hour, one-quarter of the deficit + maintenance during the second hour, and the remaining quarter + maintenance during the third hour. If large fluid shifts or blood losses occur during this time, you should replace those losses according to the same principles you apply to adults.

Charting Fluids on the Anesthesia Record

Many pediatric hospitals record volumes of the fluid/blood administered in a serial fashion, i.e. not as a running total. On the anesthesia record, record the volume you put in the Buretrol with a bracket on the left side only while that volume is currently being administered and close the bracket on the ride side once that Buretrol volume is completely administered. Any anesthesia care provider who relieves you can then see at a glance what fluid volumes you have administered.

For example, the following shows that your patient completely received 150 ml of LR and that the last Buretrol volume of 50 ml is currently being administered:

←--------------100----------→←--------50-----------→←-----50------

Blood Administration

The only accurate way of delivering blood intravenously to an infant or small child is to syringe it in using a stopcock system. In order to warm the blood you may need to prime the blood set with undiluted packed RBCs. One should always take care to flush all the air out of the system to inadvertently avoid injecting air into the patient.

Estimating A Child's Blood Volume

Age	Estimated Blood Volume (ml/kg)
Premature	90

Newborn	80-85
6 Weeks to 2 years	75
2 years to puberty	72

Caudal Epidural Block

The most common regional block performed in children is the caudal epidural block. It is simple, applicable to many pediatric surgical procedures and has a long duration of action. In children, it is technically an easy block to perform with a very high success rate.

The other regional techniques that are used in children including the lumbar epidural block and the subarachnoid block are not covered in this primer. The technical details of the epidural block do not differ in children save that the distance from the skin to the epidural space is much shorter.

Caudal epidural blocks are usually performed in children who have already been anesthetized. Small children who are often distressed by parental separation will not lie still for any length of time in the operating room, despite having adequate regional anesthesia for their operation.

There are several advantages to placing the caudal block after the induction of general anesthesia but still prior to the onset of surgery. Administration of a caudal epidural block before surgery allows the anesthesiologist to administer less anesthetic agent during the procedure. The few extra minutes it takes to perform the block are recouped at the end of the case with a faster emergence and turnover. In children having perineal procedures, the caudal block reduces the risk of reflex laryngeal spasm. If a single-shot caudal appears unsuccessful, the anesthesiologist can always repeat the block at the end of the surgery ensuring adequate postoperative analgesia for virtually all patients. Finally, caudal blocks used in conjunction with general anesthesia decrease postoperative opioids requirements and result in suppression of the endocrine responses to surgery.

Technique

Following induction of general anesthesia, the child is turned to the lateral position. The location of the sacral hiatus is determined by palpation keeping in mind the following aspects of sacral surface anatomy.

A line joining the two posterior superior iliac spines forms the base of an inverted equilateral triangle on the skin. The apex of this triangle determines the location of the sacral hiatus which provides access to the epidural space.

The anesthesiologist prepares the puncture site in a sterile fashion. Puncture of the sacrococcygeal ligament occurs at an initial angle of about 30 degrees relative to the skin. A distinct loss of resistance is often felt as the needle enters the epidural space via the sacral hiatus. A short-bevel needle or Angiocath may be used to access the space.

Following a negative aspiration of for blood or CSF, the local anesthetic is slowly injected into the caudal epidural space. If an Angiocath is use, easy advancement of the catheter is indicative of correct tip placement in the epidural space. The resistance to injection for a caudal should be the same as that perceived during a lumbar epidural and there should be no be no subcutaneous swelling with injection. If a blunt needle is selected, some anesthesiologists recommend that while the needle is advanced through the sacrococcygeal ligament, the bevel face anteriorly to reduce the chance of piercing the anterior sacral wall. Inadvertent puncture of the anterior sacral wall may lead to an intraosseous injection of the local anesthetic with high blood levels.

The most cephalad extent of analgesia is dependent upon the volume of local anesthetic injected through the sacrococcygeal membrane and not the concentration of the local anesthetic used. The concentration determines the quality of the block. Many dosage formulas have been used to determine the optimal volume of local anesthetic for a single shot caudal but one should appreciate that the final upper limit of sensory blockade can vary widely from one patient to another, especially in older children. Mo mathematical formula can predict the rostral limit of analgesia in any individual case with a high degree of accuracy.

When compared to adult doses, pediatric doses for the same segmental level of blockade are much higher. This is due to the differences in the composition and anatomy of the pediatric epidural space. The epidural space in children contains no fat and extends laterally out the intervertebral foramina so that a larger volume of local is required to achieve the same level of sensory blockade.

Regardless of the formula used to determine the volume of bupivicaine used, the recommended maximum dose of bupivicaine with epinephrine is 3 mg/kg. Plasma levels with this dose stay well below the generally accepted toxic limit of 4 micrograms/ml.

Antibiotics Administration in the Perioperative Period

Prophylactic antibiotics may be requested by the surgeon. Below is a list of common antibiotics administered in the perioperative period with weight adjusted dosing guidelines. The chart below assumes that patient receiving antibiotics is at term with no preexisting conditions that may alter drug metabolism, drug absorption or drug elimination. Therefore the chart below should only be used to ensure that the ordered dose is within accepted guidelines. Consultation with a pharmacist is recommended should requested dose fall outside of these guidelines.

Antibiotic	**Commonly used dose**
Cefazolin	25 mg/kg IV q 4 hours for the duration of the procedure(Maximum 1 gram IV)
Ampicillin	50 mg/kg
Gentamycin	2 mg/kg IV (single dose)
Vancomycin	15 mg/kg IV q 6 hours for duration of procedure
Clindamycin	10 mg/kg IV q 6 hours for the duration of the procedure
Cefoxitin	40 mg/kg IV q 4 hours of the duration of the procedure

The above information is also available online through OurNet under "UMMHC Surgical Antibiotics Prophylaxis Guidelines."

Patients with preexisting cardiac lesions or disease may require prophylactic antibiotics even if they aren't indicated or requested by the surgeon for surgical prophylaxis for the prevention of infective bacterial endocarditis. The American Heart Association recently updated the guidelines and the information can be accessed on its website. The guidelines are based on the specific cardiac lesion and the type of surgery.

This Pediatric Primer is revised by Spiro G. Spanakis DO from the original written by John Pullerits, MD.