Chapter 13: Pediatric Airway

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INTRODUCTION

FOCUS POINTS

1. To better understand pathologies, malformations, and difficulties of pediatric airways, it is helpful to know their embryogenesis and anatomy.
2. Children are not small adults, and it is important to remind to all anesthesiology providers. The differences are related to functional anatomic structures in the pediatric patient, different availability of equipment adaptable to pediatric airways, and the extremely dynamic nature of pediatric airway problems.
3. The high oxygen consumption combined with a lower functional residual capacity (FRC) and high closing capacity predispose children to hypoxia. Respiratory pathologies highly contribute to airway narrowing.
4. Preparation to induction in children is crucial. The experience of being separated from the caretaker could become a stressful experience. The induction is a critical time when difficulties and cardiorespiratory problems may occur. The pediatric anesthesia provider must be flexible and consider all these factors while planning the anesthetic.
5. Video laryngoscopy provides better views of the glottis compared to direct laryngoscopy, although intubation times may be prolonged. Skill acquisition in elective cases before use in complex difficult airway situations is recommended. Corrective maneuvers in the “Can see, can’t intubate” situation must be learned.

EMBRYOLOGY AND ANATOMY OF THE PEDIATRIC AIRWAY

The respiratory apparatus begins to form at the third gestational week when the laryngotracheal diverticulum (LTD) originates from the ventral wall of anterior primitive intestine. These structures are in communication until esophagotracheal septum separates the airways from the esophagus. The glottis region of larynx develops from the cranial portion of the LTD, while the caudal part forms the tracheal tube and the major bronchi. The supraglottis region will form the larynx and pharynx.

The LTD grows and extends caudally toward the future thoracic cavities, then splits into the two buds of the future main bronchi. The right will create the three bronchial lobes and the left the two lobes. The lobar bronchi form by dichotomous division during the sixth month of gestation and then expand to 23 bronchi by birth.

The respiratory tissue and vascular scaffolding derive from the mesoderm layer. The alveoli expand and form by breathing action, reaching full maturation by 5 to 8 years of age. During this very delicate developing embryologic phase, any pathogenic events may result in severe consequences with airway malformations as well as defects of the esophagus, duodenum, and gastric sac. Anomalies of the esophagotracheal septum may cause esophageal atresia, with or without tracheoesophageal fistula (TEF). Tracheal vascularity abnormalities may result in agenesis or complex tracheal stenosis.

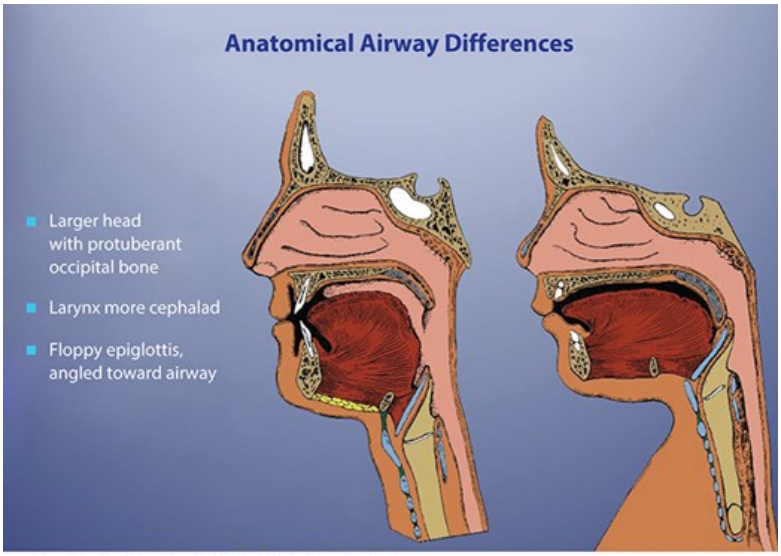
AIRWAY MANAGEMENT IN CHILDREN

Children are not small adults, and it is important to remind to all anesthesia providers that only a few adult airway considerations are transferable to

the pediatrics. For instance, the definition of difficult airways, ventilation, and some criteria of intubation may be like the adult difficult airway principles. The differences are related to functional anatomic structures in the pediatric patient, different availability of equipment adaptable to pediatric airways, and the extremely dynamic nature of pediatric airway problems because of patient size, weight, dimension, anatomy, as well as maturity and functions of organs and cardiorespiratory systems (Figure 13-1).

Figure 13-1

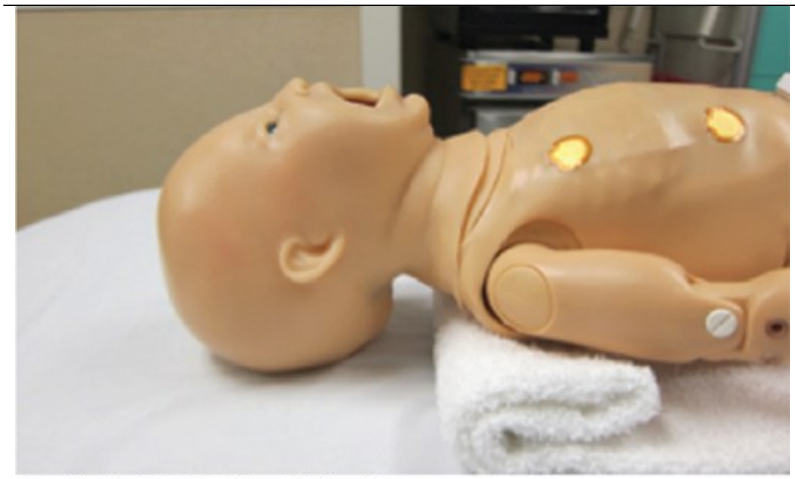
Anatomical airway differences in adult and child. (Reproduced with permission, from Sasaki CT, Isaacson GC. Functional anatomy of the larynx. *Otolaryngol Clin North Am.* 1988;21: 595-611. https://www.oto.theclinics.com.)



Understanding the important anatomical, physiological, and pathological features related to the pediatric airway as well as knowledge of the various tools and methods available are essential in airway management. The head of a pediatric patient is larger relative to body size, with a prominent occiput, large tongue, and short neck. These anatomic features predispose to airway obstruction in anesthetized children, because the neck is flexed when they lie on a flat surface. A folded towel or a gel pad is often required as a shoulder roll to achieve a neutral position of the neck and opening of the airway, as demonstrated in Figure 13-2.

Figure 13-2

Correct position of a toddler head, chin, and shoulder roll during inhalation induction. (Reproduced with permission, from Tintinalli JE, Ma O, Yealy DM, et al., eds. *Tintinalli's Emergency Medicine: A Comprehensive Study Guide*, 9th ed. 2020. https://accessmedicine.mhmedical.com. Copyright © McGraw Hill LLC. All rights reserved.)



The larger occiput combined with a shorter neck makes laryngoscopy relatively more difficult by providing obstacles to the alignment of the oral, laryngeal, and tracheal axes. The hypopharynx of the pediatric patient is relatively shorter in height and narrower in width. On cross section, the airway of an adult is more elliptical than that of the child, which has implications for supraglottic airway placement.[1]

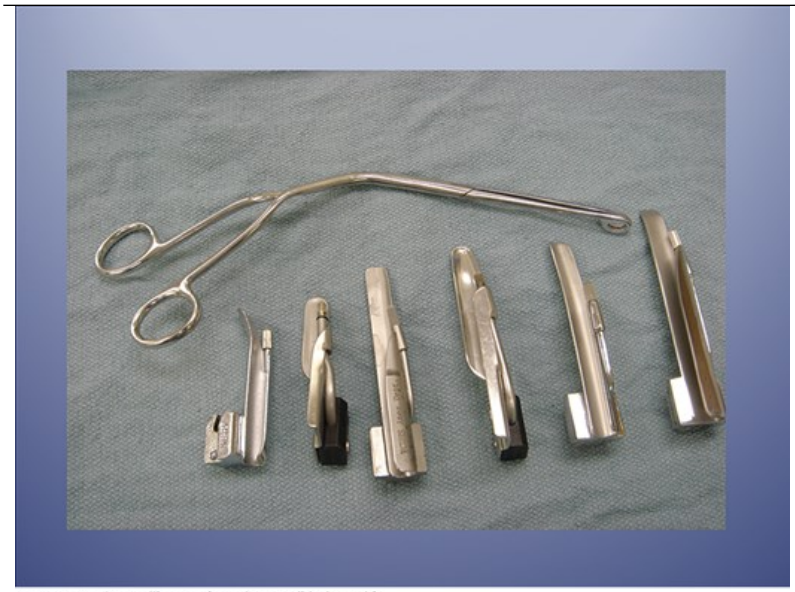
The larynx is relatively higher in the neck in children. In some positions, the mandible may lie in line with the upper glottis structures. The cricoid ring is located approximately at the level of the C4 vertebrae at birth, C5 at age 6, and C6 as adult.[2]

The vocal cords are not typically found at a right angle (90°) to the tracheal rings. Instead, they are angled in an anterior-inferior to posterior-superior fashion, making insertion of an endotracheal tube challenging and sometime traumatic. If a suboptimal view is present the endotracheal tube will have a higher tendency to collide with or become obstructed on the anterior commissure of the vocal cords.[3]

Given the large tongue and “U” shape rigid epiglottis in children, many anesthesiologists prefer semi-straight laryngoscope blades such as a Miller, Wis-Hipple, and Phillips sizes 1 or 2, which are designed to directly lift the epiglottis and move the tongue at the left, out of view compared to a curved Macintosh blade which are designed to go into the vallecula (Figure 13-3).

Figure 13-3

Series of pediatric blades, from left to right: Miller 0, 1, 1.5, and a Magill forceps. (Photo courtesy of Dr. Iolanda Russo Menna.)



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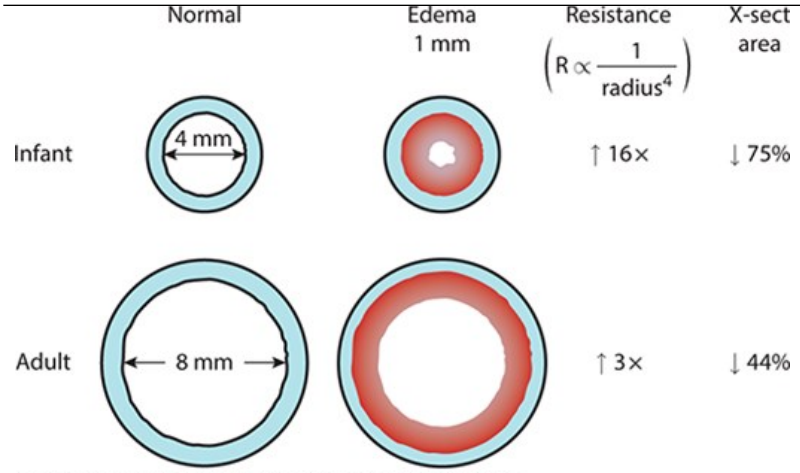
Physiological Differences

The physiological challenges predisposing children to hypoxemia are high oxygen consumption, the rate of 6 mL/kg/min in children vs 3 mL/kg/min in adults, combined with a lower functional residual capacity (FRC) and high closing capacity (CC). Oxygen desaturation occurs quickly during apnea, long laryngoscopy, or a rapid sequence induction, despite best efforts at preoxygenation time.[4] CO_2 production is increased as well, on the order of 100 to 150 mL/kg/min compared to the 60 mL/kg/min in an adult. Since the tidal volume (per kg body weight) is relatively consistent with that of an adult, the respiratory rate increases in order to meet the higher oxygen consumption and need for rapid CO_2 elimination.[5]

The resistance to air flow in the airway is governed by Poiseulle's law: $R=8\eta L/\pi r^4$. It is important to note that the inverse relationship to the radius of the airway raised to the fourth power, so a small amount of narrowing (due to edema, inflammation, etc.) in the already small pediatric airway may have severe consequences on respiratory function (Figure 13-4).

Figure 13-4

Airway diameter relationship between infant and adult in normal status vs edema governed by Poiseulle's law: $R=8\eta L/\pi r^4$. (Reproduced with permission, from Cote CJ, Lerman J, Todres ID. *A Practice of Anesthesia for Infants and Children*. 2009. Copyright © Saunders Elsevier. All rights reserved.)



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There are numerous causes of airway narrowing. Some pathological etiologies include hemangiomas, papillomas, thoracic masses, tracheomalacia, laryngomalacia, laryngeal clefts. Iatrogenic causes include vocal cord paralysis, subglottic stenosis from prolonged intubation[6] or the placement of an inappropriate endotracheal tube size.

Preparation to Induction and Intubation

The induction of general anesthesia in children is a critical time when difficulties and cardiorespiratory problems may occur. The experience of being separated from the parents is a crucial moment. In the past, a child was often forcefully detached from the caretaker and moved to the operating room, which could become a stressful experience not easily forgotten, especially when returning for repeated anesthesia and surgery.[7] The pediatric anesthesiologist must empathize and understand the young patient's and caregivers' psychological status and support their emotional needs. Parental presence in operating room may be desirable, as parents might be the best "premedication."[8,9]

Anxiety reduction may be approached not only by pharmacological strategies such as midazolam PO, ketamine IM, or dexmedetomidine intranasal, but also by the increasingly popular use of videos and television programs.[10] Familiarization with the mask and bringing along a favorite blanket or toy are also useful. These psychological approaches are effective to establish trust and reassurance between the patient and anesthesiology provider. This is especially important given the short duration of interaction prior to surgery.

Prior to the initiation of induction, the operating room must be ready to receive the patient, the machine should be checked, vaporizers filled, suction available, and all equipment available. This includes blades, endotracheal tubes, stylets, oral and nasal airways, nasal gastric tube, and IV catheters. Additionally, emergency medications such as succinylcholine, atropine, and epinephrine and also appropriate IV fluids should be available, and tubing should be cleared of air bubbles. The room should be warm, and anesthetic machine should be checked and prepared as should all the necessary monitors. Placement of monitors prior to induction may be challenging. Some providers choose to place monitors immediately after inhalational induction, while others induce with only pulse oximeter on. On the other hand, in a small and sick infant it is imperative to place all the monitors before induction and review their baseline values, which are sometimes unexpectedly abnormal.

Induction techniques vary and can be performed via inhalational, intravenous, or intramuscular route. The most commonly used is inhalational, commonly called "mask induction," or "gas induction." This technique is often less objectionable in babies and toddlers, if they do not have already an IV catheter in place. The anesthesia provider must be flexible and consider the preexisting comorbidities and needs of each child, when choosing the method of induction.

Once in operating room, ambient noise should be minimized while the appropriate monitors placed. The child can be induced in the supine or sitting position. Adding a pleasant smell to the mask usually facilitates mask induction. It is often helpful to prime the machine with 70% nitrous oxide and 30% oxygen, and creating a closed circuit by blocking the outflow of the corrugate expiratory tube allows the breathing system to be saturated in 1 or 2 minutes. It is best to avoid an abrupt mask placement on the patient's face without warning. Engaging the child's imagination by singing a song or telling a story will decrease anxiety and allows a smoother induction. The appropriately sized mask is placed gently over the patient's face, and a few

minutes of breathing will be enough to calm the child. It is imperative that the anesthesia provider carefully observes breathing and chest movements as the child passed through the hypnosis stage into deeper anesthesia. At the first sign of anesthetic induction (nystagmus maybe noted) sevoflurane is added gradually or quickly up to 7% to 8%. The transition through the excitation phase can result in laryngospasm that may be avoided by assisting the patient ventilation and deepening the anesthetic.[7,8] As soon as the patient is in adequate plane of anesthetic, monitors are immediately placed.

With a low blood-gas partition coefficient of 0.5, and nonirritable smell, sevoflurane is well tolerated by infants and children for inhalation induction. Rapid induction and emergence as well as relative safety make sevoflurane the most popular volatile agent for mask induction. Potential problems are degradation in soda lime, and biodegradation to the inorganic fluoride ion.[11] A problem that may be encountered during inhalation induction is an airway obstruction due to relaxation of the genioglossus and upper airway muscles. Oral and nasal airways may help to relieve the obstruction. Appropriate size, length, and lubricant usage may facilitate placement as well as prevent mucosal injury and epistaxis. The oral airway must be of correct size to prevent obstruction secondary to impacting the airway opening or pushing the tongue posteriorly into the pharynx.

If the insertion of an oropharyngeal or nasopharyngeal airway does not relieve the obstruction, the anesthesia provider should consider laryngospasm as a potential source of obstruction. Often, continuous positive pressure is enough to release vocal cords tightening. If this does not resolve vocal cords spasm, a muscle relaxant such as succinylcholine may be required. Succinylcholine may be given by intravenous (IV) injection of 2 mg/kg, or 4 mg/kg intramuscularly. This often quickly resolves the obstruction. Sublingual injection is not encouraged, as it may create swelling and complicate tracheal intubation. If recognized and managed appropriately, the effects of laryngospasm are transient and reversible. Prolonged obstruction could create negative pressure pulmonary edema, a severe respiratory complication.

Intravenous induction can be carried out with various agents including propofol, usually at a dose of 2 to 3 mg/kg followed by a small amount of fentanyl and muscle relaxant if indicated. Many providers also utilize a combination of IV induction in addition to 4% to 5% of sevoflurane, if the hemodynamics allow.

Emergency drugs including atropine (10 mcg/mL), succinylcholine, and epinephrine (10 mcg/mL) should be readily available. Older children may prefer intravenous to mask induction, others will fear the placement of an intravenous catheter and will require the “mask induction” approach. Pre-oxygenation should be started just before IV induction commences. Choosing an IV induction vs inhalation induction is highly dependent on the age of the patient and coexisting pathologies they present, such as dehydration, hypotension, type of surgical procedure, presence of full stomach, and how the patient will tolerate the needle stick.

PROCEDURES IN PEDIATRIC ANESTHESIA: ADVANCED AIRWAY TECHNIQUES

Initial airway assessment begins with a good history. Questions are directed toward indications of a potentially difficult airway, including complications of birth or delivery, history of prior trauma or surgery to the airway or adjacent structures, or prior difficult intubation. Additionally, one should inquire about current or recent symptoms suggesting upper respiratory infection (URI): speech, breathing, or feeding difficulty, hoarseness, snoring, and noisy breathing.

A history of snoring, day time drowsiness, or cessation of respiration during sleep may help identify children with obstructive sleep apnea which is very common and not well diagnosed. Many syndromes are associated with potentially difficult airway management (Table 13-1).

Table 13-1

Comorbidities Associated to Difficult Airway

Medical Conditions Associated with Difficult Airways	
Microstomia	C-spine instability
Choanal Atresia	Mass Effect
Defective Malocclusion	Subglottic Stenosis
Macroglossia	Airway Trauma
Mandibular Retrognathia	Obesity

Numerous physical exam findings typically discussed in the adult difficult airway literature also apply to children. For example, limited head extension, reduced mandibular space, and increased tongue thickness have been shown to be reliable predictors of difficult intubation.[12] Case series have demonstrated a relationship between mandible length and lip to chin distance as associated with Cormack-Lehane view classification.[13] Micrognathia has been highly associated with a 42% incidence of difficult laryngoscopy.[14] However, even if no specific diagnosis is known, severity of disease or certain types of surgery as palate and craniofacial malformations are associated with increased risk for airway management complications.[6]

The fundamental maneuver in airway management is properly performed mask ventilation. As in adults, there are one- and two-hand techniques.

Upper airway obstruction, which may be encountered during simple mask ventilation, is often relieved by head tilt, chin lift, more than jaw thrust in children, and the application of continuous positive airway pressure.[15,16]

Additionally, the lateral position may also improve airway patency. This has been demonstrated in children undergoing surgery for adenotonsillary hypertrophy, a group that is more prone to upper airway obstruction.[17,18]

It is important to note that face mask ventilation increases dead space compared to ventilation via an endotracheal tube. In smaller children, this increase in volume becomes more significant due to the low absolute volumes of ventilation.[5] The use of an oral airway during spontaneous or positive pressure ventilation with a face mask helps relieve the obstruction that may be caused by posterior displacement of the tongue in the anesthetized child.[19,20]

The appropriate size of airway is important for an effective obstruction release. Nasopharyngeal airways may also be used to relieve upper airway obstruction during mask ventilation and are very useful in providing anesthetic gas, oxygen, and end tidal CO_2 monitoring while performing fiber-optic tracheal intubation in the child with a difficult airway.[21]

There are many tools to facilitate tracheal intubation. The standard is still direct laryngoscopy with various laryngoscope blade styles and sizes to choose from. Many anesthesiologists prefer the Macintosh blade, adapted from adult sizes, for older children. This blade is designed to be utilized with an indirect elevation of the epiglottis by placing the tip of the blade in the vallecula.

As mentioned earlier, in younger children the orientation of the epiglottis is in a more anterior-posterior plane, making this indirect method of elevating the epiglottis potentially less effective. Therefore, many pediatric anesthesiologists prefer the use of a straight or semi-curved blade designed to directly elevate the epiglottis in patients under the age of 4 years.[1,2]

In the past, uncuffed endotracheal tubes were used in this population to minimize resistance of the endotracheal tube while also minimizing pressure trauma to the subglottis, but it is now believed that cuffed tubes can provide better sealing and ventilating conditions while minimizing operating room gas pollution, and trauma to the delicate airway of pediatric patients. Therefore, it is increasingly common to use cuffed endotracheal tubes in children

of all ages.

Checking for an air leak at an airway pressure of less than 20 cm H_2O is important. However, the utility of using an audible air leak has been called into question as being inadequate to prevent overinflation of endotracheal tube cuffs.

There are multiple options for induction of anesthesia in the anticipated difficult intubation. The use of inhalational induction tends not only to maintain spontaneous respirations but also depresses upper airway musculature and may worsen upper airway obstruction.[17,22]

Remifentanil has the advantage of being a short-acting opioid which can produce reasonable intubating conditions. Dexmedetomidine may help as an adjuvant while gas induction is obtained, reducing the gag reflex and allowing easier airway manipulation by fiber optics. Muscle relaxant use is discouraged unless the child's age allows the use of sugammadex; however, it has the limitation of not reversing anesthetic agents, and may not be sufficient for a patient to regain upper airway muscular tone in a failed airway attempt.[22]

In adults, awake fiberoptic intubation is often considered the gold standard method for the known or predicted difficult airway. It allows for the maintenance of spontaneous respirations until the trachea is intubated.[23]

However in the pediatric population, this option is more complex due to the need for significant cooperation on the part of the patient, which is usually impossible. Other approaches include fiber-optic intubation after induction. This can be done through a laryngeal mask airway (LMA), supraglottic device, or face mask.[24]

Another method involves placement of a supraglottic airway, followed by introduction of the fiberoptic bronchoscope into the trachea through the supraglottic airway. Once the fiberscope is in the trachea, a J-wire can be placed through the operating port of the scope.[25] The scope can then be removed and an airway exchange catheter advanced over the wire. Following the removal of the wire and supraglottic device, an endotracheal tube can be advanced over the exchange catheter.[26,27]

Newer devices designed to aid laryngoscopy include video laryngoscopes with pediatric blade sizes (Glidescope, Karl-Storz). Newer devices and ones with an endotracheal tube track to guide it into the trachea.[28,29] There is evidence that the video laryngoscopes provide better glottic views when compared to traditional direct laryngoscopy, especially when direct laryngoscopy is predicted to be challenging.[30]

The variety of airway devices are extremely useful in improving laryngeal views, higher likelihood of successful intubation, and a faster learning curve (Figures 13-3 and 13-4). They are important when difficult airways need to be secured, and have become an integral part of operating room equipment. The difficulty of airway management in children is usually related to either inadequate mask ventilation or difficulty in achieving tracheal intubation.

Anticipated difficult airways should be planned carefully with the appropriate equipment and staff. It may be prudent to have an ENT or pediatric surgeon in the operating room during airway management in the event the provider encounters a "cannot ventilate, cannot intubate" situation. The surgical colleagues can assist in cricothyroidotomy or tracheostomy. Even then it has been suggested that risk of complications from needle cricothyroidotomy is too high in children under the age of 5 or 6 years. In these situations, it is recommended to consider a tracheostomy.[31–33]

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