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Pediatric upper airway and congenital anomalies

Andrew Infosino, MD

*Department of Anesthesia and Perioperative Care, University of California at San Francisco,
521 Parnassus Ave, Box 0648, San Francisco, CA 94143-0648, USA*

Understanding the differences between the infant upper airway and the adult upper airway is important in properly managing the infant and pediatric airway. Proper history and physical examination and selection of the appropriate endotracheal tubes, LMAs, and laryngoscopes are key to managing the normal infant and pediatric airway. The difficult infant and pediatric airway requires planning, preparation, and teamwork. The LMA, the light wand, and fiberoptic bronchoscope are important tools for managing the difficult pediatric airway. Congenital syndromes associated with difficult airways pose a unique set of challenges. Postoperative problems include postextubation croup and obstructive sleep apnea. Extubating the infant or child with a difficult airway should be orchestrated as carefully as intubating the infant or child with a difficult airway.

Normal anatomy of the pediatric upper airway

There are several important differences between the normal pediatric upper airway and the normal adult upper airway. These differences are most dramatic in the infant upper airway and become less significant as the child grows and matures. Understanding the differences between the normal infant airway and the normal adult airway is the first step toward managing the infant and pediatric airway with skill and confidence [1].

The larynx in the infant is located higher in the neck at the level of C3-4 than in the adult, where the larynx is at C4-5. As a result the tongue is located more superiorly or closer to the palate and more easily apposes the palate, causing airway obstruction in situations such as the inhalational induction of anesthesia. The more superior position of the larynx also creates more acute

E-mail address: infosino@anesthesia.ucsf.edu

angulation during laryngoscopy and can make visualization of the glottic opening more difficult.

The infant tongue is larger in proportion to the size of the mouth than the adult tongue. This relatively large size also contributes to obstruction of the airway during sedation, inhalational induction of anesthesia, or emergence from anesthesia. Anterior pressure on the angle of the mandible to shift the tongue anteriorly often solves this problem during the induction or emergence of anesthesia. An oral airway can also be beneficial in this situation.

The epiglottis in the infant airway is often described as relatively larger and stiffer than the adult epiglottis. More important, the infant epiglottis is typically angled posteriorly during laryngoscopy, making visualization of the vocal cords more difficult as the epiglottis blocks the direct visualization of the vocal cords. In infants and small children, it is often necessary to lift the epiglottis with the tip of the blade of the laryngoscope to visualize the vocal cords and successfully intubate the trachea. This is one reason why a straight laryngoscope blade, which often has a narrower tip, is often more successful than a curved laryngoscope blade, which has a broader tip.

The narrowest portion of the infant airway is the cricoid cartilage, whereas the narrowest portion of the adult airway is the vocal cords. The infant airway is often described as funnel shaped, with a narrow cricoid cartilage and a larger thyroid cartilage above it (Fig. 1). This difference between the pediatric airway and the adult airway are among the reasons uncuffed endotracheal tubes can successfully be used in infants and children to seal and protect the airway at the level of the circular cricoid ring. In adults, the circular endotracheal tube will not form a good seal through the triangular or trapezoidal vocal cords, which are the

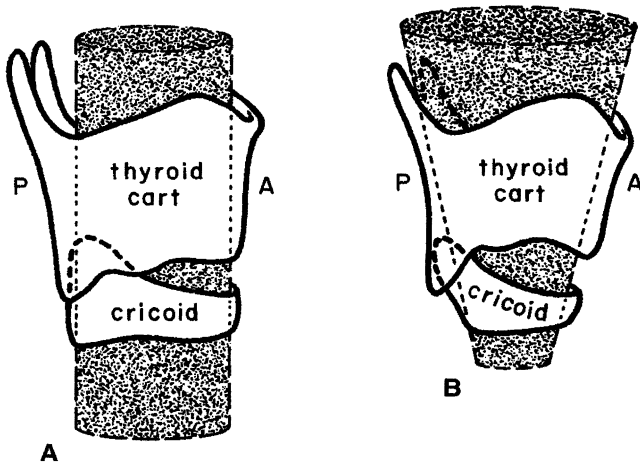


Fig. 1. Configuration of the adult cylindrically shaped larynx (A) and of the infant funnel-shaped larynx (B). (From Wheeler M, Coté CJ, Todres ID. Pediatric airway. In: Cote CJ, Ryan JF, Todres ID, et al, editors. *A Practice of Anesthesia for infants and children*. 3rd edition. Philadelphia: WB Saunders; 2001. p. 85.)

narrowest portion of the adult airway. In infants and small children, the circular endotracheal tube, if it is the appropriate size, can form a good seal with the circular cricoid cartilage, thus providing protection from aspiration. It is also at the level of the cricoid cartilage that subglottic edema most often occurs; when an endotracheal tube that is too large or has too much air in its cuff compresses the tracheal mucosa. This can result in post-extubation croup or stridor in mild cases and tracheal stenosis in severe cases. It is important to remember that the resistance to flow is inversely proportional to the radius of the lumen to the fourth power. Thus, 1-mm edema in an infant airway, which can measure 4 to 5 mm in diameter, is more significant than 1-mm edema in an adult airway, which measures 12 to 15 mm in diameter. This is one reason croup is primarily a problem in infants and small children and not in larger children and adults.

Another major difference is that the head, in particular the occiput, is larger in the infant than in the adult. The proper position for laryngoscopy and intubation in the adult is often described as the sniffing position, with the neck flexed at C6-7 and extended at C1-2, and it is often achieved by elevating the head approximately 2 to 3 inches. On the other hand, a shoulder roll or a neck roll is required to place the infant in optimal position for mask ventilation and direct laryngoscopy.

The last major difference between the infant and the adult upper airway is that the infant's nares are smaller. The nares can offer significant resistance to airflow, especially when they are narrowed by secretions, edema, or bleeding, which can significantly increase the work of breathing. It is important to remember that infants are often obligate nasal breathers in the first 6 months of life, possibly because the tongue—located superiorly because of the superior larynx—more easily apposes the palate, blocking the oral airway. An improperly placed facemask in an infant, for example, can easily compress the external nares and cause significant respiratory obstruction.

All these differences between the infant airway and the adult airway resolve as the child grows. Usually by the time the child is 10 years old, the upper airway has taken on adult-like characteristics.

Managing the normal infant and pediatric airway

General principles

History and physical examination

Complete history and physical examination are the first steps in managing the infant and pediatric airway. If the infant or child has previously had anesthesia, a history of whether there were any problems should be obtained from the parents and, if possible, from reviewing the anesthetic records. An important but often omitted question is whether the child snores. Any report of snoring should prompt in-depth history taking to determine whether the child has obstructive sleep apnea and should alert the practitioner that the child is

prone to respiratory obstruction during the induction and emergence phases of anesthesia and in the postoperative period, especially if postoperative narcotics are given for pain management.

It is often difficult to examine infants and children because they are uncooperative. Usually it is easiest to begin by listening to their heart and lungs. Often the child will voluntarily open his or her mouth and the clinician will be able to assess mouth opening and Mallimpati classification. If the child is uncooperative, external examination of the airway may often reveal enough information to determine whether the infant or child has a normal airway or a potentially difficult airway. A quick method for determining whether the thyromental distance is short and the patient has micrognathia or a hypoplastic mandible is simply to examine the profile of the infant or child. If the chin is posterior to the upper lip, a more difficult airway can be expected. If the chin is neutral to the upper lip, the infant or child probably has a normal airway.

Many children have loose baby teeth, and it is important to ask the parents and the child directly about loose teeth. If any teeth are loose, they should be identified and care should be taken to avoid traumatizing them during laryngoscopy and intubation. If a tooth is very loose, it should be removed after the induction of anesthesia and before direct laryngoscopy to prevent the possibility of the child aspirating it.

Any problems with flexion or extension of the neck should be elicited during history taking, and the child's ability to flex and extend the neck should be examined. If any masses, tumors, or abscesses of the upper airway are present, their effect on the ability to flex and extend the neck and on respiratory function should be evaluated. Any deviation of the airway from midline on physical examination or any degree of respiratory distress, obstruction, or stridor should prompt a more thorough evaluation, which in most cases includes computed tomography.

Premedication

Premedication is sometimes valuable to make the separation of the infant or child from the parents easier and to make the actual induction of anesthesia smoother. Premedication is often not necessary in infants before the age of 6 to 9 months because stranger anxiety has not developed. If the infant or child has an intravenous line, intravenous midazolam can be administered. If the child does not have an intravenous line, then midazolam can be given orally. If the child is uncooperative about taking the oral midazolam and premedication is essential, midazolam can also be given intranasally, intramuscularly, or rectally. One approach to minimizing premedication is to allow the parents to be present for the induction of anesthesia.

Induction of anesthesia: intravenous versus inhalational

If the infant or child has an intravenous line, intravenous induction of anesthesia can be performed. An induction agent such as sodium thiopental or

propofol should be given. Sodium thiopental is relatively inexpensive and is usually not painful when given intravenously. Propofol is more quickly metabolized and eliminated than Pentothal, but it can be painful when given intravenously. After the infant or child loses consciousness and the ability to mask ventilate is demonstrated, a muscle relaxant can be given to facilitate direct laryngoscopy and intubation.

If the infant or child does not have an intravenous line, inhalational induction of anesthesia can be performed. A mixture of nitrous oxide with oxygen (because nitrous oxide is odorless) is given to the child through a facemask. If the child is cooperative, it is best to start the induction with only nitrous oxide and oxygen and then to slowly increase the percentage of inhalational agent such as sevoflurane. If the child is uncooperative, it is often quickest to induce anesthesia with a high concentration of inhalational agent.

When the infant or child reaches a deeper plane of anesthesia, the upper airway muscles may relax and upper airway obstruction may occur. If this happens, nitrous oxide should be turned off and the patient should be placed on oxygen and inhalational agent only. If airway obstruction does develop, it can usually be relieved by opening the child's mouth, extending the neck, and pushing anteriorly on the angle of the jaw. Occasionally, an oral or a nasal airway may need to be inserted at this point. An intravenous line should be placed. Once the ability to mask ventilate the patient has been established, muscle relaxants should be administered to facilitate direct laryngoscopy and intubation. Although it is possible to intubate infants and children without the use of muscle relaxants, muscle relaxants facilitate direct laryngoscopy and intubation and decrease the incidence of laryngospasm. In nonemergency situations in infants and children, the use of nondepolarizing muscle relaxants, such as rocuronium in doses from 0.5 to 1 mg/kg, is recommended. After muscle relaxants have been administered, it is important to remember to begin to assist and then control ventilation.

Laryngoscopy and intubation

When performing direct laryngoscopy and intubation in infants and children, it is important to appropriately position the infant or child with a roll under the neck or shoulders. Ideally, the mouth should be viewed as divided into three compartments with the tongue on the left, the laryngoscope blade in the midline, and the endotracheal tube entering from the right corner of the mouth. Gentle external pressure at the level of the thyroid or cricoid cartilage is sometimes necessary to bring the vocal cords into view.

Once the patient is intubated, the correct tracheal position should be confirmed by capnography, by watching the chest rise and fall, and by auscultation of right and left lung fields as far laterally as possible. Because the trachea in infants and children is short, it is easy to inadvertently intubate a mainstem bronchus rather than the trachea. When using a cuffed endotracheal tube, the correct depth of insertion can be estimated by feeling the endotracheal tube cuff in the suprasternal notch. When using an uncuffed endotracheal tube, the correct depth of

insertion can be estimated by placing the double line of the endotracheal tube at the vocal cords while performing direct laryngoscopy or by deliberately intubating the main stem bronchus and slowly withdrawing the endotracheal tube to a position 1 to 2 cm above the carina or to the point at which bilateral breath sounds can just be auscultated.

Airway equipment

Endotracheal tubes

The appropriate-sized endotracheal tube for infants and children can best be estimated by using the following formula:

$$(\text{Age} + 16)/4 = \text{ETT size}$$

It is important to remember that this formula is for uncuffed endotracheal tubes. Because the cuff is located on the outside of the endotracheal tube, to adapt this formula to cuffed endotracheal tubes it is necessary to subtract half a size from the calculated size. For premature infants, Table 1 can be used for selecting an appropriate endotracheal tube.

Endotracheal tubes half a size larger and half a size smaller than calculated should be available as well. There are risks and benefits to the use of a stylet to stiffen the endotracheal tube and make it easier to manipulate during laryngoscopy and intubation. The risk for perforating the airway must be balanced by the increased ability to intubate successfully and rapidly. A stylet should be used for rapid-sequence intravenous induction and whenever a difficult intubation is anticipated and should always be immediately available.

Laryngoscopes

In general, straight-blade laryngoscopes are easier to use in infants and small children than curved ones. Although it is easier to insert the straight blade in the mouths of infants and small children, its small size prevents it from moving and retracting the tongue as well to the left side of the mouth. The curved blade is larger and bulkier, but it retracts the tongue more easily and may be useful in certain patient populations in whom the tongue is either larger or bulkier than normal. Laryngoscopy with a curved blade may be easier in infants with Beckwith-Weideman syndrome, trisomy 21 and Pierre-Robin syndrome, and a curved blade of the appropriate size should always be available. Generally, a

Table 1

Appropriate endotracheal tube sizes (Internal diameter millimeters) for premature infants according to weight

Weight (g)	Endotracheal tube size
<1500	2.5
1500–2500	3.0
>2500	3.5

Miller 1 straight laryngoscope is useful in infants younger than 1 year of age. In infants older than 1 year of age but younger than 2 or 3 years of age, a size 1.5 straight blade, such as a Wis-Hipple 1.5, is often the most useful. In children older than 3 or 4 years of age, a Miller 2 is often the most useful laryngoscope blade. Children older than 11 or 12 years are often easily intubated with a curved laryngoscope blade such as a Macintosh 3. An assortment of straight and curved laryngoscope blades and various sizes of laryngoscope blades should always be available.

Laryngeal mask airways

The classic laryngeal mask airway (LMA) is a silicone airway device placed in the oropharynx so that its tip sits in the hypopharynx and its bowl-shaped base sits around the epiglottis and forms a seal of the supraglottic area. Its proximal end can then be connected to the anesthesia circuit to deliver oxygen and other anesthesia gases. The LMA is ideally suited for situations in which the patient is breathing spontaneously, but it can also be used to deliver positive pressure ventilation. Care must be taken when using positive pressure ventilation to minimize peak inspiratory pressures by choosing smaller tidal volumes and higher respiratory rates. Patients who have lung disease or any other patient whose peak inspiratory pressures required for ventilation are higher than normal are poor candidates for the LMA because air may leak into the esophagus and may result in distension of the stomach and an increased risk for emesis and aspiration. The LMA does not protect the airway from aspiration and should not be used in patients with full stomachs or in those who are at increased risk for aspiration.

Table 2 is helpful for choosing an LMA of the correct size. An LMA that is too large will be difficult to place. An LMA that is too small will not form a good seal and may be difficult to use if positive pressure ventilation is necessary. A slightly smaller LMA will seat better and have a lower profile than a slightly larger LMA and may be better to use if the surgeons will be working near or around the LMA, as is necessary in eye or ENT patients.

The flexible LMA has a wire-reinforced flexible airway tube that resists kinking and can be positioned to minimize interference with surgical procedures involving the head and neck, such as ophthalmologic procedures. It is slightly

Table 2
Appropriate-sized LMA based on patient weight

Weight (kg)	LMA size
< 5	1.0
5–10	1.5
10–20	2.0
20–35	2.5
35–55	3.0
> 55	4.0

more difficult to insert than the classic LMA, but its lower profile can be a significant advantage. The flexible LMA is available in sizes 2 to 5.

Numerous methods are used for placing the LMA in infants and children. The classic method is with the LMA deflated and placed in its normal position. However, in children the LMA can easily be placed and removed while it is inflated. Placing the LMA already inflated is associated with a higher success rate and less oral trauma than placing it deflated [2,3]. The LMA can be placed while it is rotated 90° in the lateral oropharynx to bypass the base of the tongue and then rotated 90° back to its correct position [4]. It can also be turned backward to facilitate its placement posterior to the base of the tongue and then rotated 180° to its correct position [4]. Both the lateral and the backward approaches can be used with the LMA deflated or inflated. Different approaches to inserting the LMA may be successful in different pediatric patients.

Nasal and oral airways

Nasal airways and oral airways can sometimes be useful in infants and pediatric patients to relieve airway obstruction, especially during mask ventilation at the beginning or the end of a case. The nasal airway is usually made of soft plastic and is carefully placed through the nares after lubricating its exterior. The nasal airway must be long enough to pass through the nasopharynx but short enough that it remains above the glottis. Placing a nasal airway can result in bleeding or in shearing off adenoidal tissue, and it should be done as gently as possible.

Oral airways are also plastic and relieve airway obstruction by displacing the tongue anteriorly. Too large an oral airway will obstruct the glottis or may cause coughing, gagging, or laryngospasm in a patient not deeply anesthetized. Too small an oral airway will push the tongue posteriorly, making the airway obstruction worse. Oral airways should be placed with care to prevent trauma to the oropharynx.

Managing the difficult infant and pediatric airway

General principles

The same general principles outlined above for managing the normal pediatric airway also apply to managing the difficult pediatric airway. Infants and children desaturate quickly with airway obstruction, so additional precautions are necessary when they have difficult airways. Care should be taken with preoperative sedative medications. Ideally, premedications that have minimal respiratory depressant effects, such as midazolam, should be used. Preoperative sedative medication in these infants and children should only be administered if the child can be observed closely and monitored appropriately with at least a pulse oximeter from the time the premedication is given until the initiation of the induction of anesthesia. A surgeon capable of establishing a surgical airway and emergency airway equipment should be in the operating room before the

induction of anesthesia begins. An anesthesia colleague should be available for help to induce anesthesia, insert an intravenous line, and secure the airway.

The most difficult decision in managing the difficult pediatric airway is whether to attempt direct laryngoscopy or to proceed directly with an alternative strategy for managing the airway, such as fiberoptic intubation or surgical airway. Because most infants and children are not as cooperative as adults, most alternative strategies will not be successful in the awake patient. Given that it is necessary to induce anesthesia, it is often reasonable to attempt direct laryngoscopy, even in anticipated difficult airway situations. It is critical to move on to alternative strategies for managing the difficult pediatric airway and not to persevere with direct laryngoscopy, which can result in trauma to the upper airway, edema, and bleeding (Fig. 2). The history and physical examination may indicate situations in which direct laryngoscopy will be unsuccessful, and one should proceed directly to an alternative strategy for managing the airway. An example would be the child who is placed in halo traction and is unable to flex or extend the neck at all.

If an intravenous line is present, after appropriate pre-oxygenation, intravenous induction with Pentothal or propofol can be performed. Once the child is unconscious and the ability to mask ventilate is confirmed, neuromuscular blockade will make direct laryngoscopy and intubation easier. If the infant or child does not have an intravenous line, inhalational induction should be performed with sevoflurane, oxygen, and nitrous oxide. As soon as the child is

Simplified Difficult Airway Algorithm

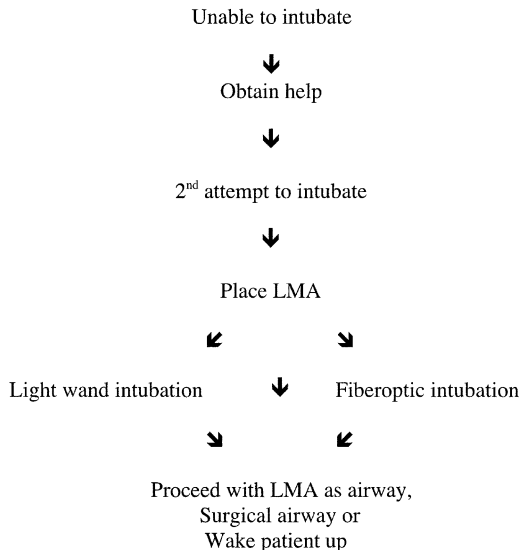


Fig. 2. A suggested simplified algorithm for management of the unexpected difficult airway in pediatric patients.

unconscious, the nitrous oxide should be turned off and an intravenous line should be established. Again, if it is easy to ventilate the infant or child with a mask, neuromuscular blockers may make laryngoscopy and intubation easier. Often a properly placed shoulder roll can facilitate direct laryngoscopy and intubation. An anesthesia colleague may facilitate successful laryngoscopy by applying external pressure on the larynx, which may move the glottis to a position that is more visible. If direct laryngoscopy is unsuccessful after several attempts, an alternative strategy should be chosen.

Reasonable alternative options at this point include using an LMA, light wand intubation, fiberoptic intubation, or surgical airway or waking up the patient. LMA should always be available when attempting to manage the airway of any pediatric patient, particularly one with a difficult airway. LMA may provide a way to successfully ventilate and oxygenate the patient at any time during the attempt to intubate with an endotracheal tube and can provide an excellent channel for fiberoptic intubation. It may also be the only way to maintain an airway until a surgical airway is established or until the patient wakes up [5]. Fiberoptic intubation at this point may be difficult if there is already blood in the airway from multiple attempts at direct laryngoscopy. If blood or edema has made it difficult to intubate the patient and the surgery is elective, it may be better to awaken the patient, reschedule the surgery, and plan for an alternative strategy for intubation from the beginning.

Many other possible options are possible to deal with the difficult pediatric airway, such as the Bullard laryngoscope, transtracheal jet ventilation, retrograde intubation, and transcutaneous cricothyroidotomy. Most of these techniques have been used in the adult population and require specialized equipment that may or may not be the appropriate size for the infant or pediatric patient. These techniques are difficult in the adult population and should only be attempted in the pediatric population by the experienced practitioner.

Light wand

The light wand—a rigid fiberoptic stylet with a light at its tip—can be an effective tool for managing the difficult pediatric airway [6]. Technique depends on the external visualization of the lighted tip in the midline position at the level of the larynx and then in the trachea. Its advantage is that it can lead to success where direct laryngoscopy has failed because it does not depend on good mouth opening or flexion or extension of the neck. The light wand can be simpler and quicker than fiberoptic intubation and is successful even in the presence of secretions or blood, and it may be successful in patients in whom the fiberoptic bronchoscope has failed. The disadvantages of the light wand are that it requires that the room lights be dimmed and that it is more difficult to use when the anatomy of the airway is distorted and the laryngeal structures are not midline.

The endotracheal tube is loaded onto the stylet so that the tip of the light wand is several millimeters proximal to the distal tip of the endotracheal tube. It may have to be cut at its proximal end if it is too long, and if it is too short a rubber or

plastic stopper may have to be loaded onto the stylet first to prevent the endotracheal tube from slipping backward on the stylet. The light wand with the loaded endotracheal tube is bent to an angle generally between 90° to 120° in the same way that an endotracheal tube with a regular stylet is bent. The key to the successful use of the light wand is simply to stay midline and anterior. The light should remain bright red as it passes from the supraglottic area into the trachea. Once the light wand is in the trachea, the endotracheal tube should be advanced off the light wand and the light wand should be carefully removed. An endotracheal tube that is smaller is generally easier to place using the light wand than one that is larger. Many types of light wand are available, but the rigid metal ones are generally easier to use because they allow better manipulation of the tip of the light wand.

Flexible fiberoptic bronchoscope

The fiberoptic bronchoscope is another tool for managing the difficult pediatric airway. It allows the anesthesiologist to see around corners, and, like the light wand, it can be useful for patients with poor mouth opening, limited neck movement, or a congenital syndrome that makes direct laryngoscopy difficult or impossible. The major disadvantage of the fiberoptic bronchoscope is that blood or secretions can make it difficult to use. Fiberoptic bronchoscopes small enough for infants do not have a suction channel and have inferior optics compared with the larger ones for larger children and adults.

Successful use of the fiberoptic bronchoscope as a tool to intubate the trachea in infants and children depends on several factors. Infants and children generally do not cooperate during awake fiberoptic intubation. It is generally easier to keep the infant or child anesthetized but breathing spontaneously on 100% oxygen and an inhalational agent such as sevoflurane. Using an elbow that has a port allowing for insertion of the fiberoptic bronchoscope allows for either continued spontaneous ventilation or assisted positive-pressure ventilation through the facemask. For nasotracheal intubation, the nasopharynx must be topicalized with lidocaine and Neo-Synephrine to prevent bleeding because bleeding can make visualization through the fiberoptic scope difficult. For oral intubation, the LMA can provide an excellent channel while allowing for ventilation and oxygenation during fiberoptic endotracheal intubation. The largest endotracheal tube and fiberoptic bronchoscope that will fit through each LMA are listed in Table 3. When excessive bleeding occurs after an unsuccessful attempt at nasal fiberoptic intubation, using an LMA may allow for successful oral fiberoptic intubation by providing a clean and blood-free channel to visualize the glottic structures.

Congenital syndromes associated with difficult airways

Trisomy 21

Infants and children with trisomy 21, or Down syndrome, can provide challenges in airway management because of their large tongue and relative

Table 3

Largest endotracheal tubes (Internal diameter millimeters) and fiberoptic bronchoscopes that will fit through the different-sized LMAs

LMA size	Largest ETT	Fiberoptic bronchoscope (mm)
1.5	3.5 uncuffed	2.7
1.5	4.0 uncuffed	3.0
2.0	4.5 uncuffed	3.5
2.5	5.0 uncuffed	4.0
3.0	6.0 cuffed	5.0
4.0	6.5 cuffed	5.0

Data from http://www.Imana.com/prod/components/products/Ima_classic.html. Accessed October 23, 2002.

hypotonia. This can make mask ventilation difficult and may necessitate the use of an oral or a nasal airway. Use of a curved MacIntosh-style blade may more effectively hold the large tongue to the left during direct laryngoscopy, allowing for a better view and easier intubation. Usually, hypotonia provides for excellent mouth opening, making it relatively easy to intubate these patients. Care, however, must be taken because a certain percentage of trisomy 21 patients have atlanto-axial instability. Every trisomy 21 patient should be evaluated for the possibility of atlanto-axial instability by history and physical examination. A history of pain on extension or flexion, any physical examination findings of pain on flexion or extension, and any limitation of flexion and extension should alert the practitioner to the possibility of atlanto-axial instability. These patients should be further evaluated with flexion–extension lateral x-ray of the neck. If atlanto-axial instability is evident, care must be taken while securing the airways of these patients. Possibilities include the use of an LMA, intubation with in-line stabilization while limiting extension, or asleep fiberoptic or light wand intubation while the neck is maintained in a neutral position.

Congenital syndromes with mandibular hypoplasia

A series of congenital syndromes have as a common feature mandibular hypoplasia or micrognathia. Mandibular hypoplasia forces the tongue to a relatively posterior position within the oropharynx and hinders visualization of the vocal cords during direct laryngoscopy. Sometimes it is difficult, or impossible to intubate these patients with direct laryngoscopy. Pierre-Robin syndrome consists of micrognathia, cleft palate, and glossoptosis and can result in such severe airway obstruction in the neonatal period that the airway obstructs when the newborn is in the supine position. It may be necessary to perform glossolabiopexy, by which the tongue is sutured to the lower lip to hold it anterior. Fortunately, it becomes easier to intubate most infants with Pierre-Robin syndrome as they become older as the mandible grows. Other congenital syndromes with mandibular hypoplasia or micrognathia include, but are not limited to, Carpenter syndrome, Goldenhar syndrome, Crouzon disease, Freeman-Sheldon syndrome, and Treacher-Collins syndrome. All these infants and

children are It is difficult to intubate infants and children with these conditions through direct laryngoscopy, and the use of LMAs, light wands, or fiberoptic bronchoscopes may be necessary for successful placement of an endotracheal tube. Some patients may even require a surgical airway [7,8].

Congenital syndromes or diseases with limited cervical motion

Klippel-Feil syndrome includes congenital fusion of the cervical vertebrae, severe shortness of the neck, and a low posterior hairline. It can be difficult to intubate infants and children with Klippel-Feil syndrome because of their inability to flex or extend their neck, and it may be necessary to manage their airways with a LMA, a light wand, or a flexible fiberoptic bronchoscope. Juvenile-onset rheumatoid arthritis is a systemic autoimmune disease in which rheumatoid factor is deposited within the joints, resulting in damage to them. Arthritis may involve the temporomandibular joint, limiting mouth opening, and the cervical spine, limiting flexion and extension of the neck. They may also have involvement of the cricoarytenoid joints, narrowing of the glottic opening, and laryngeal deviation from chronic fibrotic changes. It can be difficult or impossible to intubate these children because of their limited mouth opening and limited cervical flexion and extension. LMA or the flexible fiberoptic bronchoscope may be needed to manage the airway of these patients [9].

Extubation of the infant and pediatric airway

Postoperative croup or stridor

Infants and small children are at risk for postextubation croup or stridor. Edema of the upper airway, particularly at the narrowest portion of the infant or pediatric airway—the level of the cricoid ring—can result in increasing resistance to airflow. The edema results from mechanical pressure on the mucosa of the trachea. If the pressure is severe, such as when an endotracheal tube that is too large is used, venous congestion and edema can occur. If the pressure is high enough, arterial blood supply may be compromised. Resultant edema can be symptomatic, especially in the infant airway, which is narrow to begin with. The largest risk factor for postextubation croup is the use of an endotracheal tube that is too large or of a cuff inflated to pressure that is too high. Other risk factors include multiple intubation attempts, unusual positioning of the head during surgery, increasing duration of surgery, and surgery such as rigid bronchoscopy that involves the upper airway.

The patient with postextubation croup or stridor usually has increasing respiratory distress after extubation in the recovery room. Flaring, retraction, increased respiratory rate, audible stridor, and decreased oxygen saturation may constitute the clinical picture. Treatment depends on the degree of respiratory distress. Patients with postextubation croup or stridor must be monitored and treated in the recovery room or ICU. Mild to moderate respiratory distress can be

initially treated with humidified oxygen. Increasing respiratory distress may require aerosolized racemic epinephrine. Patients whose respiratory distress is severe and is not relieved with these measures may have to be reintubated with an endotracheal tube smaller than the one previously used. Intravenous steroids are probably most beneficial when instituted earlier rather than later. In procedures such as rigid bronchoscopy, they should be given before the airway is instrumented.

Obstructive sleep apnea

Infants and children with obstructive sleep apnea or any congenital anomalies that result in obstruction of the upper airway are at particular risk during the postoperative period for airway obstruction, respiratory distress, and respiratory arrest if the patient is not monitored and treated appropriately. Children who undergo surgery to relieve upper airway obstruction, such as tonsillectomy and adenoidectomy or palatoplasty, are at particular risk for two reasons. First, their obstructive sleep apnea is severe enough that it requires surgical intervention. Second, there is sometimes a false assumption that upper airway obstruction is immediately relieved by surgery and that vigilance is no longer necessary. These patients are sometimes in worse condition in the immediate postoperative period because of swelling and bleeding from the surgery. Narcotics used intraoperatively or postoperatively to treat pain from the surgical procedure can depress the ventilatory drive and contribute to postoperative airway obstruction. All infants and children with documented obstructive sleep apnea should be monitored postoperatively with pulse-oximetry and apnea monitoring. High-risk patients should be monitored in an ICU.

Extubation of the difficult infant and pediatric airway

Extubation and intubation of the difficult airway can be extremely challenging. Infants and children must be examined to determine whether they are ready for extubation because reintubation can be more challenging than intubating them the first time. Those with difficult airways should be extubated when they are fully awake and there is no residual neuromuscular blockade. Postoperative factors that may compromise the infant's or child's respiratory function must be considered when extubating the difficult airway. Significant postoperative pain, especially if there is splinting from an abdominal or a thoracic incision, may compromise respiratory function. Pain requiring significant narcotic use will also compromise respiratory function from the respiratory depressant effects of the narcotics. In both situations the infant or child with the difficult airway should remain intubated. The use of regional anesthesia, such as an epidural, may hasten the ability to extubate these infants and children. The presence of any additional factors that compromise respiratory function, such as preexisting restrictive lung disease or neuromuscular weakness, should also be taken into account when deciding when to extubate an infant or a child with a difficult airway.

Edema of the airway can also significantly affect the ability to extubate infants and children with difficult airways. The airway may be edematous from surgical trauma, surgical positioning, or excessive fluid administration. The use of a mouth gag during surgery, such as in cleft palate surgery, can result in post-operative edema of the tongue. Sometimes the endotracheal tube stents open the airway; when the endotracheal tube is removed, the airway swells completely shut. Obviously, the presence of any degree of airway edema can also make it more difficult to reintubate the infant or child should that be necessary. If there is any evidence of edema in the airway, the infant or child should not be extubated until the edema has resolved.

Any evidence on physical examination of edema, especially around the face or eyes, may indicate the presence of edema of the airway. One way to test for the presence of significant edema of the airway is to determine whether there is a leak around the endotracheal tube. If the child is cooperative and there is a cuffed endotracheal tube, air can be let out of the cuff of the endotracheal tube and the end of the endotracheal tube can be occluded. If there is evidence of a leak around the tube when the child inhales or exhales or if the child is able to talk around the endotracheal tube, edema of the airway is usually not significant. If the child is not cooperative and there is an uncuffed endotracheal tube, a positive pressure leak test can be performed. If the leak occurs at a higher pressure than before surgery, airway edema is present and the infant or child should be left intubated.

The infant or child with a difficult airway should only be extubated when personnel capable of reintubating them are available. Extubation itself should be performed in the ICU or in the operating room, where appropriate equipment for reintubating the infant or child is immediately accessible. Generally, if there is doubt or debate as to whether the infant or child with a difficult airway is ready to be extubated, it is usually better to leave them intubated.

Anesthetic management of surgery involving the pediatric upper airway

Many congenital and acquired disorders of the pediatric upper airway require surgical correction. Although it is impossible to describe the anesthetic management of all of these disorders of the pediatric upper airway, a description of the anesthetic management of several representative airway disorders can illustrate many of the basic principles involved in these cases.

Cleft palate repair

Cleft palate deformity can be associated with cleft lip or appear alone. If it is associated with cleft lip, the cleft lip is usually repaired early in the first year of life, and the cleft palate is repaired with a subsequent operation. Cleft palates that are not repaired lead to problems with swallowing, speech and upper respiratory and middle ear infections. The impetus for earlier repair of cleft palates is primarily to obtain more normal speech.

Before surgery it is important to recognize that approximately 20% of children with cleft palates have associated congenital heart disease. Thorough history and physical examination are necessary to rule out associated congenital heart disease. Any murmurs or any other evidence of possible congenital heart disease, such as low room air oxygen saturation, should be properly evaluated by a pediatric cardiologist with echocardiography used before anesthesia and surgery.

During surgery, children with isolated cleft palates are relatively easy to intubate. If they have associated congenital abnormalities such as Pierre Robin syndrome or Treacher Collins syndrome, they may be difficult to intubate. Proper planning and preparation as outlined above are necessary for these patients. Intubation is usually with an oral RAE endotracheal tube secured to the chin in the midline position. When the surgeon places the mouth gag, there may be a change in the position of the endotracheal tube resulting in either extubation or main-stem intubation. The mouth gag may also kink or occlude the endotracheal tube. Any difficulty ventilating or oxygenating the patient, an increase in peak airway pressure, or a change in the shape of the capnogram should prompt immediate investigation.

Before extubation it is important to verify that the surgeon has removed the throat pack if one has been used during surgery. It is also important to visually inspect the oropharynx with a laryngoscope before extubation to verify that there is no ongoing bleeding or significant airway edema. The mouth gag, if it has been improperly placed or if it has been used for an extended period of time, can result in significant airway edema, particularly of the tongue or uvula. If there is significant edema, the patient should be left intubated and sedated until the edema has resolved.

Many surgeons place a tongue stitch through the anterior tongue to have the ability to pull the tongue forward if obstruction occurs after extubation. A combination of several factors can result in postoperative upper airway obstruction—residual anesthesia, narcotics, bleeding in the upper airway, secretions in the airway, difficulty swallowing from the cleft palate repair, and edema of the airway from surgery. What is often not appreciated is that now that the palate is repaired, the tongue must assume a new more anterior position to prevent airway obstruction. The tongue stitch provides a simple way of relieving this upper airway obstruction until the infant or child is awake and aware enough to learn how to reposition his or her tongue. Close observation in an ICU may be necessary after surgery. If reintubation is necessary, it is best performed in a controlled setting in the operating room because significant bleeding or edema may result, making visualization of the vocal cords and intubation more difficult.

Glossolabiopexy

Occasionally infants with Pierre Robin syndrome have such significant airway obstruction caused by the tongue that they have difficulty breathing and feeding. This is often accentuated in the supine position because the tongue tends to

assume a posterior position. Often these infants are managed medically with the use of oral airways placed inside pacifiers and with placement in the prone position. If the airway obstruction is severe enough or if the infant is unable to feed, these infants require glossolabiopexy, by which the tongue is pulled anteriorly and sutured to the lower lip.

If an intravenous line has not been placed in the infant, putting them in the supine position for inhalational induction of anesthesia can accentuate and worsen the airway obstruction. Inhalational induction can be performed in the lateral or prone position, the infant can be turned supine, and an LMA can be placed to provide an airway and an intravenous line can be started. Alternatively, an LMA can be inserted into the awake infant, inhalational induction can be performed through the LMA, and then an intravenous line can be started. If an intravenous line is available, intravenous induction of anesthesia with Pentothal or propofol can be performed.

Once the child has been induced and an intravenous line has been established, an attempt at direct laryngoscopy and intubation should be made. If intubation is unsuccessful on the first attempt, LMA should immediately be inserted because multiple attempts at direct laryngoscopy may result in edema of the oropharynx and tongue and may cause significant airway obstruction. Experienced surgeons are capable of performing glossolabiopexy with an LMA in place.

Laser treatment of papillomatosis of the airway

Papillomatosis of the airway can involve the oropharynx, laryngeal area, and trachea. Left untreated, it can cause upper airway obstruction from progressive upper airway papilloma growth, completely obstructing the upper airway, or from progressive lower airway papilloma growth and spread, causing airway obstruction at the level of the trachea or bronchi. Papillomatosis is treated surgically with laser ablation.

Before surgery it is important to determine the infant's or child's degree of respiratory obstruction. A complete history should be obtained, focusing on any difficulty breathing especially while sleeping or in the supine position. Physical examination findings of stridor, retractions, nasal flaring, respiratory distress at rest, or low oxygen saturation are indications of the potential for complete airway obstruction during the induction of anesthesia as the infant or child loses muscle tone and is placed in the supine position. If there is evidence on history or physical examination of respiratory obstruction from the papillomas, another colleague should be available to assist during the induction of anesthesia. Anesthesia should be induced in the operating room, with a surgeon who is skilled at direct laryngoscopy and emergent tracheostomy present. If there is respiratory obstruction during the induction of anesthesia, direct laryngoscopy and intubation may resolve the problem. Direct laryngoscopy may be difficult because the normal supraglottic anatomy may be distorted by the presence of the papillomas, and the papillomas may actually obscure the vocal cords. It is also possible that a papilloma may become dislodged by the endotracheal tube and

can become lodged in the lumen of the endotracheal tube, preventing ventilation. Suctioning of the endotracheal tube may be necessary.

Decadron should be considered before laser ablation is begun to minimize upper airway edema after surgery. The major intraoperative risk is an airway fire, which usually occurs when the laser ignites the endotracheal tube. The endotracheal tube can be wrapped with metallic tape to minimize the risk for ignition. Special endotracheal tubes designed for laser surgery are generally not useful in infants and children—they are not produced in the appropriate sizes. When the laser is used, the risk for an airway fire should be minimized through use of a mixture of air and oxygen at the lowest concentration of oxygen possible. Nitrous oxide should be avoided. The eyes of all personnel in the room, including the patient, should be appropriately protected from stray laser beams. Alternatively, jet ventilation can be used to minimize the risk for fire and to provide excellent visualization of all of the supraglottic structures. Complications from jet ventilation include barotrauma, pneumothorax, distention of the stomach, and regurgitation with possible aspiration pneumonia. Care should be taken when using jet ventilation to minimize the pressure and duration of the jet. The ideal jet ventilator should have a valve that can be adjusted to minimize the pressure delivered.

The most common postoperative complication is upper airway obstruction because of edema from the thermal injury caused by laser ablation. If postoperative croup develops, it should be treated with humidified oxygen, racemic epinephrine if necessary, and reintubation if necessary. Any patient with respiratory distress after surgery should be monitored in an ICU.

Bronchoscopy for removal of foreign body

Toddlers and small children tend to place small objects in their mouths and occasionally aspirate them into the airway, necessitating bronchoscopy for removal of the foreign body. These children may be asymptomatic and may present weeks after the aspiration with recurrent pneumonia, or they may be in significant respiratory distress and present immediately after the aspiration. In most situations the child is not in an appropriately NPO state, and the decision must be made to proceed with bronchoscopy or to delay the case until the child is appropriately in NPO. If the child is in significant respiratory distress or the respiratory distress is worsening, anesthesia and bronchoscopy should be performed. Physical examination findings indicative of respiratory distress include stridor, retractions, increased respiratory rate, wheezing, decreased breath sounds, and decreased oxygen saturation or evidence of carbon dioxide retention. If there is time, preoperative chest x-ray can often be helpful. In certain cases the foreign body may be visible on chest x-ray findings, and knowledge of its location may make it easier for the bronchoscopist to remove it. Steroids before surgery may decrease airway edema, decrease the incidence of postoperative croup, and increase the likelihood of extubation at the end of the case.

Ideally, an intravenous line should be placed for the induction of anesthesia, especially if the patient is not appropriately NPO. If there is no intravenous line,

then inhalational induction should be performed with oxygen and sevoflurane. Nitrous oxide, if is used during the induction of anesthesia, should be turned off after the child loses consciousness. In most situations, the bronchoscopy and the removal of the foreign body will be smoother and easier if neuromuscular blockers are used. Often using an intravenous anesthetic is easier than continuing with inhalational agents. Anesthetic depth can vary widely because ventilation can be difficult and variable through the sidearm of the rigid bronchoscope. This is one situation in which a propofol and remifentanyl-based intravenous anesthetic can be successful and may even obviate the need for muscle relaxants.

Once induction is complete and the intravenous line is established, the airway can be managed with a facemask until the surgeon inserts the rigid bronchoscope, which has a sidearm for ventilation and oxygenation. If the child is not appropriately NPO, the child should be intubated as rapidly as possible after the induction of anesthesia to protect the airway, and a large-bore orogastric tube should be inserted to evacuate any stomach contents. The child can then be extubated when the surgeon is ready to insert the bronchoscope. Because ventilation and oxygenation are challenging through the rigid bronchoscope and it is often difficult to obtain a reliable capnogram, it is important to monitor ventilation with a precordial stethoscope and to observe the rise and fall of the chest with each breath.

During bronchoscopy it may become difficult or impossible to ventilate the patient properly. Communication with the surgeon is important because the surgeon may have to relocate the bronchoscope above the carina so that both lungs can be ventilated for a period of time before bronchoscopy continues. During rigid bronchoscopy, it is also important to be aware of the potential for airway trauma, which can result in tension pneumothorax. Bronchospasm may be severe enough to impede the ability to oxygenate and ventilate and may have to be treated aggressively with albuterol, steroids, and epinephrine. Another potential catastrophic cause for the sudden loss of the ability to ventilate is that the foreign body, which previously had been located in a bronchus allowing for ventilation of the contralateral lung, is now above the carina, preventing ventilation to both lungs. In this situation, communication with the bronchoscopist is vital—the foreign body should be pushed back into the bronchus to allow oxygenation and ventilation through the contralateral lung. At the conclusion of the bronchoscopy, the most conservative approach is to place an endotracheal tube to protect the airway until the child is awake and alert and any neuromuscular blockade is completely reversed.

Summary

Understanding the differences between the infant upper airway and the adult upper airway is important in properly managing the infant and pediatric airway. Proper history and physical examination and selection of the appropriate endotracheal tubes, LMAs, and laryngoscopes are key to managing the

normal infant and pediatric airway. The difficult infant and pediatric airway requires planning, preparation, and teamwork. The LMA, the light wand, and fiberoptic bronchoscope are important tools for managing the difficult pediatric airway. Congenital syndromes associated with difficult airways pose a unique set of challenges. Postoperative problems include postextubation croup and obstructive sleep apnea. Extubating the infant or child with a difficult airway should be orchestrated as carefully as intubating the infant or child with a difficult airway.

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