Airway management is one of the most important aspects of pediatric anesthesia because of its inextricable relationship to the most important complication—the development of hypoxemia. This importance is further exemplified by the inherent differences in pediatric airway management when compared with adults. This chapter reviews the basics of pediatric airway management, with an emphasis on the differences between children and adults. The anatomy of the pediatric airway is reviewed, followed by a discussion of pediatric airway management techniques. Pediatric airway complications are discussed, including laryngospasm, pulmonary aspiration, and negative-pressure (postobstructive) pulmonary edema.

**PEDIATRIC UPPER AIRWAY ANATOMY**

The approach to airway management of infants and young children is influenced by developmental differences in head and neck anatomy. These differences include:

1. A larger occiput, which influences head and neck positioning during airway management, such that neck flexion is not required to attain the “sniffing” position.
2. The presence of hypertrophied tonsil and adenoid tissue, which causes rapid development of upper-airway obstruction after administration of general anesthesia.
3. A more cephalad larynx (C2–C3) than in the adult (C4–C5), which renders it more easily visualized using a straight, rather than a curved laryngoscope (Fig. 17-1).
4. A narrower and shorter epiglottis which is angled into the lumen of the airway, making it difficult to displace anteriorly during laryngoscopy.

In paralyzed children, the cricoid cartilage is the narrowest portion of the upper airway because of its inability to distend in a similar manner as the vocal cords. Therefore, an endotracheal tube that easily passes through the vocal cords may compress tracheal mucosa at the level of the cricoid cartilage and predispose to inflammation, edema, and subsequent scarring and stenosis. Although the infant tongue is relatively larger in proportion to the oral cavity when compared with the adult, MRI studies of the upper airway during general anesthesia have demonstrated that, as in adults, upper-airway obstruction occurs primarily at the levels of the soft palate and epiglottis, and rarely by the tongue.
Overall, the most important difference between young children and adults is merely the smaller size. Small nasal passages are more likely to become obstructed with blood or secretions, and tracheal edema is more likely to increase airway resistance in smaller diameter airways since the resistance to flow through a tube is related to the fifth power of the radius of the tube (since this flow is largely turbulent). Of interest, the upper airway of a normal infant is smaller in both inspiration and expiration at 6 weeks of age compared to the neonatal period. This relative narrowing may be caused by postnatal growth of adenoid tissue, or thickening of the mucous membrane lining in response to infection or second-hand smoke exposure.

Dental Development

The 20 primary teeth are identified by a lettering system (Fig. 17-2). They begin to erupt during the first year of life, and are shed at between 6 and 12 years of age. The preoperative physical exam of children in this age group should include a search for loose teeth, which may be dislodged during airway management and accidentally lost within the respiratory tract. Loose or chipped teeth should be documented on the anesthetic record. Significantly loose teeth should be removed by the anesthesiologist (or dentist if one is present) prior to airway instrumentation. This is easily accomplished by grasping the tooth with gauze and rocking the tooth back and forth.
forth while simultaneously pulling. Minor bleeding in the tooth socket will abate with gentle pressure applied for several minutes.

The 32 permanent teeth begin to appear at the same time as the primary teeth are shed and are identified by a numbering system (Fig. 17-3). Orthodontic hardware can be placed at any time after the eruption of the primary teeth. If feasible, rubber bands should be removed prior to anesthetic management. During the preoperative physical exam, permanent orthodontic devices should be examined for loose or damaged pieces, and this should be clearly documented on the anesthetic record. If a permanent orthodontic device is in danger of being dislodged during airway management, dental or orthodontic consultation is required before proceeding with the general anesthetic.

**Pediatric Airway Assessment**

In adults, there are several validated physical characteristics that are associated with the inability to perform mask ventilation or tracheal intubation. No such physical characteristics exist for the pediatric population. Unless syndromic facial anomalies exist (e.g., midface hypoplasia, micrognathia), it is extremely rare that tracheal intubation cannot be accomplished in the prepubertal child. On the other hand, mask ventilation may be difficult for a variety of reasons, including the distorted facial anatomy of the neonate, the relatively large tongue of the child with trisomy 21, and the presence of hypertrophied tonsil and adenoid tissue in toddlers.

**PEDIATRIC AIRWAY MANAGEMENT TECHNIQUES**

**Mask Ventilation**

In children aged 4 years and above, mask ventilation is usually uncomplicated and easy to perform. Younger patients may present a challenge to mask ventilation because of the relatively smaller face, larger tongue, and ease with which the anesthesiologist’s fingers may compress the soft tissues of the neck and impinge on the upper airway. In the newborns, unintentional jaw pressure from neck flexion, submental pressure, or mandibular pressure during facemask application is associated with upper-airway obstruction. Furthermore, many infants have some degree of laryngomalacia, which renders the supraglottic structures prone to collapse during inspiration.

The most effective mask ventilation technique for infants and young children is for the anesthesiologist to hold the mask over the mouth and nose with the thumb and forefinger, while the middle finger is placed on the bony portion of the mandible (Fig. 17-4). With this...
technique, the chin can be lifted to provide head extension without compressing the soft tissues of the neck. The upper part of the mask should rest on the bridge of the nose. The most common error of inexperienced practitioners is to hold the mask too low over the nose and compress the nasal passages.

**Manual Airway Opening Maneuvers**

If mask ventilation becomes difficult owing to upper-airway obstruction, there are a series of manual maneuvers that may improve airflow prior to airway instrumentation. These include chin lift, jaw thrust, and application of continuous positive airway pressure (CPAP). Chin lift will extend the head at the atlantooccipital joint, thus stretching and straightening the airway to decrease the severity of soft tissue obstruction. Jaw thrust will displace the genioglossus in an anterior direction and alleviate obstruction at the levels of the soft palate and epiglottis (via ligaments that connect the genioglossus with supraglottic structures). CPAP distends the soft tissues of the pharynx and larynx, thus counteracting the effects of laryngomalacia and the decrease in pharyngeal dilator tone that is normally seen with loss of consciousness. The use of CPAP, however, often causes unintentional inflation of the stomach. To avoid gastric distention, peak inspiratory pressures should not exceed 15 cmH₂O, when possible.

**Oral Airway Insertion**

When manual techniques have failed to improve upper-airway patency, insertion of an oral airway will establish airflow in almost all cases of children with normal airway anatomy. This is primarily because the oral airway device bypasses the obstruction, which is usually caused by enlarged tonsils and/or adenoids.

The most commonly used airway device in pediatric anesthesia is the Guedel airway, which contains a central lumen for the passage of airflow and for suctioning the posterior pharynx. The insertion technique is similar to that for adults. It can be inserted with the aid of a tongue depressor, or initially inserted with the distal tip oriented cephalad, and then turned 180 degrees when the tip has reached the posterior aspect of the palate.

Oral airways are sized depending on the total length of the device (50–80 mm for most children) or based on an arbitrary scale designated by the manufacturer. The appropriate size is determined by placing the airway adjacent to the child’s face to approximate its position in the oral cavity (Fig. 17-5). When appropriately placed, its distal end should snugly curve around the back of the tongue, without the proximal end protruding out of the mouth. Too small an oral airway will push the posterior portion of the tongue against the posterior pharyngeal wall, and too large an oral airway may itself cause upper-airway obstruction at the laryngeal inlet by compressing or distorting the epiglottis (Fig. 17-6).

Complications of
A “custom” nasal airway can be fashioned by cutting off the appropriate length of an endotracheal tube.

Prior to insertion, the nasal cavities should be inspected to assure the absence of significant septal deviation, or other causes of narrowing (e.g., polyp) that will obstruct passage of the nasal airway. To avoid trauma and bleeding of the delicate nasal mucosa, the nasal airway should be lubricated and inserted in a posterocaudal direction along the floor of the nasal cavity. In addition, a topical vasoconstrictor, such as 0.05% oxymetazoline, can be sprayed on the nasal mucosa prior to nasal airway insertion. The proper diameter is determined by approximating the circular diameter of the nasal opening.

The proper length of the nasal airway is estimated by measuring the distance from the nares to the tragus of the ear. When appropriately placed, its distal tip should lie at the level of the angle of the mandible, between the posterior aspect of the tongue and above the tip of the epiglottis. Some red rubber nasal airways are supplied with a movable ring at the proximal end, with which to adjust the proper length at the tip of the nasal opening.

The most common complication from nasal airway insertion is trauma to the nasal or pharyngeal mucosa that results in minor bleeding. Adenoidal tissue may be disrupted and may bleed into the oropharynx. Occasionally, a friable vessel is encountered in the nasal mucosa and bleeding is brisk. A lesser known, though not rare, complication is the insertion of the nasal airway device into a false passage beneath the posterior wall mucosa of the nasal and oral pharynx. This is not usually accompanied by bleeding, so it may be caused by a patent Thornwaldt bursa. Nasal airways should not be inserted in children with a coagulopathy, neutropenia, or suspicion of a traumatic basilar skull fracture.

### Laryngeal Mask Airway

The laryngeal mask airway (LMA) is used in pediatric anesthesia as a routine airflow conduit during general anesthesia and as a component of the difficult airway algorithm (see Chapter 18). A variety of sizes are available for pediatric patients (Table 17-1). When the LMA

<table>
<thead>
<tr>
<th>LMA Size</th>
<th>Approximate Weight (kg)</th>
<th>Cuff Volume (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;5</td>
<td>2-5</td>
</tr>
<tr>
<td>1.5</td>
<td>5-10</td>
<td>3-8</td>
</tr>
<tr>
<td>2</td>
<td>10-20</td>
<td>5-10</td>
</tr>
<tr>
<td>2.5</td>
<td>20-30</td>
<td>10-15</td>
</tr>
<tr>
<td>3</td>
<td>30-50</td>
<td>15-20</td>
</tr>
<tr>
<td>4</td>
<td>50-70</td>
<td>25-50</td>
</tr>
</tbody>
</table>
was first introduced it was considered to be useful only during situations that were amenable to facemask anesthesia; however, as practitioners have become more comfortable with its use, the LMA has become a substitute for an endotracheal tube in certain cases, such as tonsillectomy or strabismus repair. An LMA that is specially designed with a wire-reinforced shaft is available for use during tonsillectomy or other procedures that would otherwise require an oral RAE endotracheal tube (see below). When compared with an endotracheal tube, the LMA is associated with less laryngeal stimulation and a decreased incidence of airway complications in children with upper respiratory tract infections. In most normal children, positive-pressure ventilation is easily accomplished via an LMA, but peak inspiratory pressure should not exceed 20 cmH₂O to prevent gastric insufflation. Because of its inability to seal off the trachea adequately, the LMA is not indicated for use in children at risk for pulmonary aspiration of gastric contents.

The relatively cephalad location of the pediatric larynx does not lend itself to ideal LMA placement. Thus, the smaller the patient, the more difficult it is to achieve ideal LMA positioning in the larynx. Fiberoptic and magnetic resonance imaging (MRI) studies on LMA placement in children do not lend itself to ideal LMA placement. Thus, the LMA is not indicated for use in children at risk for pulmonary aspiration of gastric contents.

The relatively cephalad location of the pediatric larynx does not lend itself to ideal LMA placement. Thus, the smaller the patient, the more difficult it is to achieve ideal LMA positioning in the larynx. Fiberoptic and magnetic resonance imaging (MRI) studies on LMA placement in children have shown a high incidence of malpositioning with the epiglottis situated within the aperture of the LMA, despite seemingly adequate ventilation. In children the LMA is likely to become displaced with patient movement or twisting from its proximal end, and is more likely to result in the deterioration of ventilation after placement when compared with adults.

A variety of methods of LMA placement in children are possible. Besides the direct method of pushing the flattened LMA cuff posterior by applying pressure against the hard palate, the LMA can be inserted with the cuff partially or fully inflated, or inserted with the aperture facing posterior and then turned 180 degrees once in the larynx. There are no advantages to one particular insertion method. A water-based lubricant smeared on the posterior surface of the LMA may decrease the resistance to insertion. Nevertheless, in many children the insertion is difficult and is associated with pharyngeal bleeding. Postoperative sore throat is observed after LMA use, though it is not as common as seen after endotracheal intubation.

During emergence from general anesthesia, the LMA can be removed at any time. Removal with the cuff inflated will facilitate removal of blood or secretions that have collected above the cuff. If one chooses to wait until the child is strong and awake before removing the LMA, a bite block should be inserted between the patient’s teeth to prevent compression of the lumen of the LMA, which can result in negative-pressure pulmonary edema (see below). Removal of the LMA during the excitement phase of emergence is associated with a lower incidence of airway complications when compared with removal of an endotracheal tube. Nevertheless, airway complications during emergence are least when the LMA is removed prior to the child regaining airway reflexes and full consciousness. Rapid removal of the LMA may cause displacement of loose teeth.

**Endotracheal Intubation**

Techniques of endotracheal intubation differ between children and adults. This section will review differences in laryngoscopy, choice of the appropriate type and diameter of the endotracheal tube, confirming proper tracheal placement of the tube, and determining the correct endotracheal tube length.

**Laryngoscopy**

In most children, laryngoscopy is technically easier than in adults. An unexpectedly difficult view of the glottis is unusual. However, in neonates and small infants, laryngoscopy is often challenging because of the smaller and more cephalad location of the larynx, and the narrower view through the oropharynx. The optimal position for laryngoscopy is attained differently than for adults. The relatively large occiput provides flexion of the head, while the shoulders lie flat on the table. The anesthesiologist’s line of sight should be nearly directly over the child’s airway, and the laryngoscope blade is inserted almost perpendicular to the OR table to obtain the easiest view of the glottis. This is in contrast to adults, in whom the best glottic view is usually obtained with the laryngoscope blade almost parallel to the OR table.

A variety of pediatric-sized laryngoscope blades are available (Table 17-2). A straight blade is most often used to obtain the best glottic view. In infants and small children, the straight blade is usually inserted into the vallecula to tilt the epiglottis anteriorly to view the glottic opening. The infant’s small size and anteriorly placed larynx afford the anesthesiologist the opportunity to use the fifth finger of the nondominant hand to push the larynx in a posterior direction to improve the glottic view (Fig. 17-7).

**Endotracheal Tubes**

A variety of formulas have been developed by which to determine the most appropriate size of endotracheal tube for children, based on age, weight, or height. All of these formulas have reasonable reliability. The most popular to use with uncuffed oral endotracheal tubes is Cole’s formula:

\[
\text{Internal tube diameter (mm)} = \left[ \frac{16 + \text{age (years)}}{4} \right]
\]

Another moderately reliable method is to approximate the diameter of the trachea with the diameter of
the child’s fifth finger. Once one gains enough experience with pediatric patients, formulas are abandoned in favor of a “mental” chart (Table 17-3). When using a cuffed endotracheal tube (see below) the choice of its size is less important because the cuff can compensate for the selection of too small a tube.

A RAE (Ring–Adair–Elwyn) endotracheal tube is preformed for oral or nasal use (Fig. 17-8). The proximal end of the oral RAE tube curves onto the chin and is used for oral or ophthalmologic procedures when the surgeon is situated behind the head of the patient. The proximal end of the nasal RAE tube is preformed to rest on the forehead during procedures in the oral cavity or neck. Because an RAE tube is preformed, its length cannot be adjusted once it is properly placed.

### Cuffed versus Uncuffed Tubes

Pediatric anesthesiologists have traditionally preferred to use only uncuffed endotracheal tubes in children up to the prepubertal age group. This practice is based on the notion that the unyielding cricoid ring is functionally the narrowest portion of the upper airway, so a cuff is not necessary to seal off the upper portion of the trachea to provide adequate ventilation and prevent pulmonary aspiration. At some uncertain age between 6 and 10 years, the larynx changes shape from conical to cylindrical, and the glottis becomes the narrowest portion; a cuff is then needed to seal off the trachea since the portion of the endotracheal tube that passes the cricoid ring is no longer snug. These hypotheses are

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Table 17-2  Laryngoscope Blade Types and Sizes

<table>
<thead>
<tr>
<th>Age</th>
<th>Miller</th>
<th>Wis–Hippel</th>
<th>Macintosh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Premature neonate</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Term neonate</td>
<td>0–1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1-12 months</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1-2 years</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
</tr>
<tr>
<td>2-6 years</td>
<td>2</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>6-12 years</td>
<td>2</td>
<td>-</td>
<td>3</td>
</tr>
</tbody>
</table>


Table 17-3  Approximate Endotracheal Tube Sizes for Children

<table>
<thead>
<tr>
<th>Age</th>
<th>Size (mm) and Cuff Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–3 months</td>
<td>3.0–3.5 uncuffed</td>
</tr>
<tr>
<td>3–10 months</td>
<td>3.5–4.0 uncuffed</td>
</tr>
<tr>
<td>10–12 months</td>
<td>4.0 cuffed or uncuffed</td>
</tr>
<tr>
<td>2 years</td>
<td>4.5 cuffed or uncuffed</td>
</tr>
<tr>
<td>3 years*</td>
<td>4.5–5.0 cuffed</td>
</tr>
</tbody>
</table>

* For children 4 years of age and older, use Cole’s formula. If the value falls in between tube sizes, round down and use a cuffed tube.

---

**Figure 17-7** The infant’s small size and anteriorly placed larynx afford the anesthesiologist the opportunity to use the fifth finger of the free hand to push the larynx in a posterior direction to improve the glottic view.

**Figure 17-8** The oral RAE tube is preformed for easy attachment to the chin when the surgeon is positioned behind the patient. The nasal RAE tube is preformed to sit on the forehead for procedures in the oral cavity or neck.
based on data obtained from pediatric cadaver specimens, and the consistent clinical observation is that an endotracheal tube will often pass easily through the vocal cords, only to meet resistance at the level of the cricoid ring. Furthermore, an uncuffed endotracheal tube will have a relatively smaller external diameter compared with a cuffed endotracheal tube of the same internal diameter. Therefore, a relatively larger sized internal diameter tube can be inserted comfortably. This will provide relatively less resistance to airflow, and will facilitate suctioning of secretions.

In recent years, a growing number of pediatric anesthesiologists have begun using cuffed endotracheal tubes in smaller children. This trend is a result of the gradual recognition that cuffed tubes are not associated with an increased incidence of airway complications. Furthermore, since spontaneous ventilation in intubated children is not usually performed, the increased resistance of the slightly smaller internal diameter tube will not increase work of breathing. Use of a cuffed endotracheal tube will prevent the need to change the tube if it is incorrectly sized, thus sparing the child from an extra laryngoscopic attempt. The very act of changing endotracheal tubes while the child is anesthetized increases the risk of aspiration. A modified Cole’s formula can be used to estimate the most appropriate size of cuffed endotracheal tube. As long as the cuff is able to be advanced through the vocal cords without much resistance, it is then adjusted to provide a leak between 15 and 25 cmH₂O.

**Confirming Tracheal Location**

Once the endotracheal tube has been inserted, it must immediately be determined to be in the trachea and not in the esophagus. Methods for confirming tracheal placement are similar to those for adults and include the characteristic rise of the chest wall and absence of gastric inflation, the presence of breath sounds in the left axilla and absence of breath sounds over the epigastrium, and the characteristic capnographic tracing. These are all confirmed simultaneously in the first several seconds following endotracheal intubation. When the endotracheal tube is placed properly in the trachea, mist should be observed in the proximal end of the tube during exhalation. In small infants, breath sounds are easily transmitted across the epigastrium and chest wall, so auscultation may be less reliable for confirming tracheal placement.

**Confirming Tube Dimensions**

**Tube Diameter**

Following insertion of an uncuffed endotracheal tube, the anesthesiologist should determine whether or not it is the appropriate size for the child’s trachea. Although standard formulas or guidelines are often used, it is not infrequent that the chosen size is too small or too large. If it is too small, ventilation may be inadequate, and anesthetic vapors will pollute the OR environment. If the endotracheal tube is too large, there may be undue pressure on the tracheal mucosa, resulting in inflammation, injury, and edema, which manifests clinically as postintubation croup. Therefore, it is common practice to determine the fit of the endotracheal tube by performing a “leak test” shortly after the tracheal position is confirmed. This test is performed by auscultating over the mouth or anterior neck while the pop-off valve on the anesthesia machine is progressively closed. The rising airway pressure will reach a point at which it will begin to escape around the wall of the tube, and this can be heard as a characteristic squeak. In children, the pressure at which tracheal damage begins is unknown. However, a leak pressure between 15 and 25 cmH₂O will ensure adequacy of ventilation while minimizing injury to the tracheal wall. When the pressure is above 40 cmH₂O, consideration should be given to changing the endotracheal tube to a smaller size; however, for relatively short surgical procedures, it is unknown whether this tight fit is associated with tracheal injury. Unfortunately, the leak test has been shown to be unreliable and inconsistent between pediatric anesthesiologists on the same child.

Furthermore, there are several factors that change the leak, including neck position and degree of neuromuscular blockade. A modified Cole’s formula can be used to estimate the most appropriate size of cuffed endotracheal tube. As long as the cuff is able to be advanced through the vocal cords without much resistance, it is then adjusted to provide a leak between 15 and 25 cmH₂O.

**Tube Length**

There are several fairly reliable methods for determining the proper length of insertion of the endotracheal tube in children. Four of these are described below.

First, during direct laryngoscopy and insertion of the endotracheal tube through the glottis, the length is noted at which the endotracheal tube has passed 2–3 cm past the vocal cords. Some endotracheal tube manufacturers place black line markings at the distal end of the tube that are designed to rest at the level of the vocal cords.

Second, for most children with normal airway anatomy, the proper length in centimeters at which to secure the endotracheal tube at the teeth (or gums for infants) is three times the internal diameter of the tube used (in millimeters), assuming that the proper size of endotracheal tube has been placed.

The two methods noted above will accurately place the endotracheal tube between the vocal cords and the carina in the majority of children with normal tracheal anatomy. However, there are many children in whom the
trachea is abnormally short, and the use of these methods may place the endotracheal tube in a main bronchus. Therefore, a third, more precise, method of localizing the distal end of the endotracheal tube is warranted. Once it is confirmed that the endotracheal tube is correctly inserted in the trachea, and maximal oxygenation is assured, an assistant manually ventilates the child while the anesthesiologist slowly advances the endotracheal tube and simultaneously listens to breath sounds in the left axilla. At the moment when breath sounds are lost, it can be assumed that the endotracheal tube has passed the carina and has entered the right main bronchus. In rare cases the endotracheal tube will advance into the left main bronchus. If breath sounds are not lost in the left axilla within a reasonable amount of advancing distance, it should be withdrawn and the process should be repeated. If the endotracheal tube still does not appear to enter the right main bronchus, the child’s head can be turned to the left, as this maneuver will help guide the tube into the contralateral bronchus. The length of the endotracheal tube at the carina is noted, and it is then pulled back several centimeters so that the optimal location is midway between the vocal cords and the carina. In normal full-term newborns the distance between the vocal cords and the carina is usually 4–5 cm.

Finally, when using a cuffed endotracheal tube, palpation of the cuff in the suprasternal notch usually confirms an adequate position between the glottis and carina.

**Effect of Neck Movement on Tube Position**

It is very common for head and neck position to change during pediatric surgical procedures. A number of studies have determined the effect of different neck movements on the position of the endotracheal tube in the trachea in children. These studies consistently

---

**Table 17-4**

<table>
<thead>
<tr>
<th></th>
<th>Cuffed Tube</th>
<th>Uncuffed Tube</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total patients</td>
<td>251</td>
<td>237</td>
<td></td>
</tr>
<tr>
<td>Patients needing tube changes</td>
<td>3 (1.2%)</td>
<td>54 (23%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Patients needing &gt;2 L/min fresh gas flow</td>
<td>3 (1.2%)</td>
<td>26 (11%)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

demonstrate that: (1) neck flexion causes the tip of the endotracheal tube to move toward the carina; (2) neck extension causes the tip to move away from the carina; and (3) lateral rotation causes the tip to move away from the carina, although to a lesser extent than occurs during neck extension. These findings are similar with both orotracheal and nasotracheal tube placement.

**Nasotracheal Intubation**

Nasotracheal intubation is primarily used for procedures in the oral cavity, and can be safely performed in children of all ages. The tube size chosen is the same as for oral endotracheal tubes. There are various methods that facilitate ease of nasotracheal intubation and decrease the incidence of tissue damage and bleeding. These include softening the nasal tube by soaking it for several minutes in warmed saline, preinsertion of a lubricated soft red rubber catheter through the nasal passage, and administration of a topical vasoconstrictor agent such as cocaine 4% or oxymetazoline 0.05%. The nasal endotracheal tube should be well lubricated, and inserted through the most patent nasal canal.

The technique for insertion of a nasotracheal tube in children is similar to adults and is partially described in the previous section on insertion of nasal airways. In supine, paralyzed children, a Magill forceps is almost always required to direct the tip of the endotracheal tube into the glottic opening. Since nasal endotracheal intubation causes transient bacteremia, endocarditis prophylaxis is indicated in susceptible children.

**RAPID SEQUENCE INDUCTION**

The key components of a rapid sequence induction (RSI) of general anesthesia include preoxygenation, apneic oxygenation after administration of a hypnotic agent and muscle relaxant, and application of cricoid pressure to prevent passive regurgitation of gastric contents into the pharynx. Each of these components will be reviewed as they pertain to their usefulness in pediatric patients.

**Preoxygenation**

Preoxygenation, with the goal of removing nitrogen from the lungs, is performed prior to RSI to lengthen the duration of apnea prior to laryngoscopy. In adults, preoxygenation is easily attained by breathing 100% oxygen for several minutes or asking the patient to take several vital capacity breaths. These maneuvers are not always possible in young uncooperative children who may struggle with facemask application. On the other hand, the relatively smaller ratio of functional residual capacity (FRC) to tidal volume will facilitate a more rapid denitrogenation in children compared with adults. Nevertheless, the optimal length of time for denitrogenation of the pediatric lung has not been determined, although longer preoxygenation times are associated with longer times to desaturation during apnea in children over 2 years of age. Most pediatric anesthesiologists will administer 100% oxygen for at least 1 minute prior to rapid sequence induction, or longer until the oxygen saturation reaches 100% by pulse oximetry.

**Apneic Oxygenation**

Apneic oxygenation is the process by which the lungs continue to take up oxygen in the absence of spontaneous or controlled breathing movements. It occurs by bulk flow of oxygen from an oxygen source (i.e., anesthesia breathing circuit) through a patent upper airway, trachea, and lower respiratory system. Oxygen will continue to flow into the lungs as it is taken up by the blood passing through the pulmonary vascular bed.

Apneic oxygenation occurs during the phase of rapid sequence induction that follows preoxygenation and administration of a hypnotic agent plus a neuromuscular blocker. This period is required for the neuromuscular blocker to take effect prior to performing laryngoscopy. In healthy, nonobese children, oxyhemoglobin desaturation during apnea may not occur for several minutes. In infants and small children, rapid oxyhemoglobin desaturation during apnea will occur rapidly, despite seemingly adequate preoxygenation and denitrogenation. During apneic oxygenation, a neonate may become hypoxic within several seconds! This phenomenon is commonly attributed to the infant’s relatively lower FRC while anesthetized, combined with a relatively larger oxygen consumption. It is for this reason that, during RSI in infants and small children, positive-pressure ventilation is usually required prior to endotracheal intubation. When this is performed while cricoid pressure continues, it is termed a ‘modified’ rapid sequence induction.

**Cricoid Pressure**

Cricoid pressure reliably occludes the esophagus in infants and children, even in the presence of a nasogastric tube. In addition, it prevents the entry of gas into the esophagus during mask ventilation. However, in very small infants, cricoid pressure may compress the trachea and prevent adequate air entry into the lungs. The performance of cricoid pressure has not been shown to be associated with a decreased risk of pulmonary aspiration in susceptible patients, but it remains the standard of care for rapid sequence induction in many centers.
the passage of anesthetic gases to deepen the level of many cases, prevent or treat hypoxemia, and allow administration of positive-pressure ventilation. This will, in a small amount of air entry is possible with the admin­istration of positive-pressure ventilation. This will, in the presence of high-pitched inspiratory stridor, be given without hesitation. Hypoxemia is a potent stimulus for the alleviation of laryngospasm, but it should never be relied upon in lieu of pharmacologic treatment. 

As a result of the laryngospasm, the glottis may become partially or completely obstructed, thereby limiting the airflow and causing hypoxemia. Laryngospasm can be caused by a variety of factors, including respiratory irritation, mechanical stimulation, or direct laryngeal stimulation. In the presence of laryngospasm, the airway is narrowed, resulting in increased airway resistance and decreased tidal volume. 

Laryngospasm is a self-sustaining condition that can be difficult to manage. It is important to recognize the early signs of laryngospasm and take appropriate action to prevent its progression. 

**MANAGEMENT**

Laryngospasm is a medical emergency that requires immediate attention. The first step in managing laryngospasm is to establish a patent airway. This can be achieved by providing oxygen therapy or intubation. Oxygen therapy is the preferred method of establishing a patent airway in the presence of laryngospasm. Oxygen therapy helps to alleviate hypoxemia and prevent bradycardia. Intubation is used when oxygen therapy is ineffective or when there is a need to maintain a patent airway for prolonged periods of time.

In the presence of laryngospasm, the administration of a nondepolarizing neuromuscular relaxant is often necessary. Succinylcholine is the most commonly used relaxant for this purpose. Succinylcholine is effective in relieving the laryngospasm by temporarily paralyzing the adductor muscles of the glottis. However, the administration of succinylcholine should be limited to cases where the patient’s condition warrants it, as it can cause severe hypotension and bradycardia. 

Other measures that can be used to manage laryngospasm include the use of sedatives, analgesics, and antitussives. These medications can help to alleviate the symptoms associated with laryngospasm, such as coughing and stridor. In cases where the laryngospasm is severe, the use of a tracheotomy may be necessary to establish a patent airway. 

In conclusion, laryngospasm is a serious medical condition that requires prompt and effective management. The primary goal of management is to establish a patent airway and prevent hypoxemia. This can be achieved through the use of oxygen therapy, intubation, and the administration of a nondepolarizing neuromuscular relaxant. Other measures that can be used to manage laryngospasm include the use of sedatives, analgesics, and antitussives. In cases where the laryngospasm is severe, the use of a tracheotomy may be necessary. 

**References**


therapy because hypoxemia is associated with the development of negative-pressure pulmonary edema (see below) and/or cardiac arrest.

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**Pulmonary Aspiration**

Pulmonary aspiration of gastric contents is usually diagnosed when a child demonstrates unexplained hypoxemia and respiratory symptoms along with: (1) the direct observation of gastric contents in the pharynx or larynx; or (2) characteristic findings on chest radiography. It is a rare perioperative complication in children, with an estimated incidence ≤0.1% in retrospective studies. Most cases of perioperative pulmonary aspiration in children occur at the time of intubation and, when clinically significant, will cause symptoms within 2 hours. Risk factors for its occurrence include emergency surgery for bowel obstruction or ileus, and lack of sufficient paralysis at the time of laryngoscopy.

In two large retrospective series, the majority of children with directly observed pulmonary aspiration of gastric contents were asymptomatic. Symptomatic children developed cough, wheeze, or unexplained hypoxemia with radiologic changes, and some required postoperative mechanical ventilation, but all eventually recovered.

There are no data to indicate the proper preparative pharmacologic regimen for children suspected of being at risk for pulmonary aspiration. A variety of agents theoretically decrease this risk. Metoclopramide is a prokinetic agent, but most studies in children do not show convincing efficacy for its ability to decrease gastric volume or increase gastric pH at the time of induction of general anesthesia. In addition, metoclopramide should not be administered to children with bowel obstruction or ileus. H₂ antagonists, such as ranitidine and cimetidine, reduce gastric volume and increase gastric pH in children; however, for optimal efficacy, these agents should be administered at least 2 hours prior to surgery. The use of these agents by pediatric anesthesiologists is theoretically acceptable. Asymptomatic children who do not cough or wheeze should be hospitalized and monitored appropriately. Asymptomatic children who do not require supplemental oxygen after a witnessed intraoperative aspiration may receive routine postoperative care including discharge home, if appropriate. Chest radiography is indicated only in the presence of respiratory distress or unexplained persistent hypoxemia.

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**Negative-pressure (Postobstructive) Pulmonary Edema**

Acute pulmonary edema may develop after brief episodes of severe upper-airway obstruction in children of all ages, and is known as negative-pressure (or postobstructive) pulmonary edema. It most often occurs shortly after alleviation of severe laryngospasm, but it can also be observed after upper-airway obstruction of any cause. Since many cases of negative-pressure pulmonary edema are caused by the child biting on the endotracheal tube or LMA during emergence, a bite block should be inserted prior to emergence.

The exact mechanism of the development of pulmonary edema after upper-airway obstruction is unknown; however, the concomitant development of transient hypoxia appears to be an important contributing factor. Most authors speculate that the substantial negative intrathoracic pressure that results when a child attempts to breathe against an obstruction results in a dramatic increase in venous return to the right side of the heart. Hypoxemia that accompanies the obstruction leads to massive sympathetic discharge that promotes systemic vasoconstriction. These two aforementioned processes result in the rapid transudation of fluid and lymph into the alveoli.

The clinical manifestations of negative-pressure pulmonary edema include the rapid development of rales, the appearance of a frothy pink fluid in the endotracheal tube, and a variable degree of hypoxemia. Treatment includes administration of supplemental oxygen, CPAP or PEEP (if mechanically ventilated), and furosemide. An echocardiogram may be indicated to rule out a cardiogenic cause. In healthy children symptoms usually resolve within 12–24 hours.

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**ADDITIONAL ARTICLES TO KNOW**


