Assessment and Management of the Pediatric Airway

Derek S. Wheeler, James P. Spaeth, Renuka Mehta, Suriyanarayana P. Hariprakash, and Peter N. Cox

Introduction

Respiratory failure is a common cause of cardiopulmonary arrest in children, both within and outside the hospital [1–5]. Acute airway obstruction (AAO) can cause rapidly progressive respiratory compromise and prevent progression to respiratory failure and cardiopulmonary arrest, as once respiratory arrest progresses to asystolic cardiac arrest, the outcome is quite poor [6,7]. The goal of airway management is to anticipate and recognize respiratory compromise and to provide support and stabilization of the airway in a timely manner. Anatomic differences between pediatric and adult patients render children more susceptible to acute airway compromise; it is therefore important to recognize and understand these differences, as they may have an impact on the success of airway management.

Developmental Anatomy and Physiology of the Pediatric Airway

The upper airway is a vital part of the respiratory tract and consists of the nose, paranasal sinuses, pharynx, larynx, and extrathoracic trachea. The structural complexity of the upper airway reflects its diverse functions, which include phonation, olfaction, humidification and warming of inspired air, digestion, preservation of airway patency, and protection of the airways [8,9]. The pediatric airway is markedly different from the adult airway [10–13]. For example, the larynx is located relatively cephalad in the neck, with the inferior margin of the cricoid cartilage residing at approximately the level of C2–C3 in infants compared with C4–C5 in adults. This elevated position brings the epiglottis and palate in close proximity, thus making the infant an obligate nose breather in the first few weeks to months of life, which has potential clinical significance for various congenital abnormalities of the nasal airway. Infants are at greater risk of upper airway obstruction as nasal breathing doubles the resistance to air flow [13]. In addition, anatomic features that differ between children and adults include (1) a proportionally larger head and occiput (relative to body size), causing neck flexion and leading to potential airway obstruction when lying supine; (2) a relatively larger tongue, decreasing the size of the oral cavity; (3) decreased muscle tone, resulting in passive obstruction of the airway by the tongue; (4) a shorter, narrower, horizontally positioned, softer epiglottis; (5) cephalad and anterior position of the larynx; (6) shorter, smaller, narrower trachea; and (7) funnel-shaped versus cylindrical airway, such that the narrowest portion of the airway is located at the level of the cricoid cartilage (Figure 24.1).

The first and perhaps most obvious difference is that the pediatric airway is much smaller in diameter and shorter in length than the adult’s. For example, the length of the trachea changes from approximately 4 cm in neonates to approximately 12 cm in adults, and the tracheal diameter varies from approximately 3 mm in the premature infant to approximately 25 mm in the adult [11,13]. According to Hagen-Poiseuille’s law, the change in air flow resulting from a reduction in airway diameter is directly proportional to the airway radius elevated to the fourth power:

$$Q = \frac{\Delta P \pi r^4}{8 \eta L},$$

where $Q$ is flow, $\Delta P$ is the pressure gradient from one end of the airway to the other end, $r$ is the radius of the airway, $\eta$ is the viscosity of the air, and $L$ is the length of the airway. Therefore, increasing the length of the airway ($L$), increasing the viscosity of the air ($\eta$), or decreasing the radius of the airway will reduce laminar air flow. Changing the airway radius, however, has the greatest effect on flow. Small amounts of edema will therefore have a greater effect on the caliber of the pediatric airway compared with the adult airway, resulting in a greater increase in airway resistance (Figure 24.2).
The tongue, which is large relative to the size of the oral cavity, more easily apposes the palate and represents one of the more common causes of upper airway obstruction in unconscious infants and children. A jaw-thrust maneuver or placement of either an oral or nasal airway will lift the tongue and relieve the obstruction in this situation (see later).

Tracheal intubation requires the alignment of three axes: the oral axis, the pharyngeal axis, and the laryngeal axis (Figure 24.3). Normally, the oral axis is perpendicular to the laryngeal axis, and the pharyngeal axis is positioned at an angle of 45° to the laryngeal axis. Placement of a folded towel beneath the occiput will flex the neck onto the chest, thereby aligning the pharyngeal and laryngeal axes. With proper extension of the atlanto-occipital joint, that is, head extension and neck flexion (sniff position), these three axes are superimposed to establish the necessary line of visualization for optimal tracheal intubation. The cephalad position of the infant's larynx effectively shortens the length over which these three axes are superimposed, thereby creating more of an acute angle between the base of the tongue and the glottic opening. The glottic opening appears anterior such that adequate visualization may be difficult during direct laryngoscopy. The occiput is much larger in children than in adults, leading to hyperflexion of the neck on the chest. A neck or shoulder roll will facilitate adequate visualization of the glottic opening during laryngoscopy. In addition, straight laryngoscope blades are often used in infants and young children to better visualize the airway during tracheal intubation.

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caudal position (the anterior attachments are more inferior than the posterior attachments). The tracheal tube can therefore become caught on the anterior commissure during passage through the glottic opening. Simple rotation of the tracheal tube will usually allow the tube to pass in this situation.

The narrowest portion of the pediatric airway is located below the level of the vocal cords at the cricoid cartilage, whereas the narrowest portion of the adult airway is at the level of the vocal cords (Figure 24.4). The pediatric airway is funnel shaped as a result compared with the cylindrical shape of the adult airway (Figure 24.5). This anatomic configuration is one reason why uncuffed tracheal tubes can be used effectively in infants and children in that an effective seal will often form between the tracheal tube and the ringlike cricoid cartilage. Conversely, in adults, the circular tracheal tube will not form a good seal through the trapezoid-shaped glottic opening, and cuffed tracheal tubes are essential to provide for adequate ventilation and protection from aspiration. The subglottic airway is completely encircled by the cricoid cartilage and is restricted in its ability to freely expand in diameter. In addition, the subglottic airway contains loosely attached connective tissue that can rapidly expand with inflammation and edema, leading to dramatic reductions in airway caliber (see Figure 24.2). Children are at significant risk for viral laryngotracheobronchitis (croup) or postextubation stridor, especially
Intraluminal pressures are slightly positive in relation to atmospheric pressure, so air is negative intraluminal pressure in relation to atmospheric pressure. Of the extrathoracic trachea because of the increased compliance of the trachea and the increased negative intrathoracic pressure relative to intraluminal and atmospheric pressure. The net result is a longitudinal stretching of the larynx and trachea, dilation of the intrathoracic airways, and leading to dynamic compression of the intrathoracic airways. The larger gradient between atmospheric pressure and the airway pressure leads to dynamic collapse of the extrathoracic trachea just beyond the level of obstruction. Conversely, lower airway or intrathoracic airway obstruction (e.g., aspirated foreign body, asthma, bronchiolitis) results in a ball-valve effect and subsequent air trapping. Increased respiratory effort during exhalation is required, generating an increase in intrapleural pressures and leading to dynamic compression of the intrathoracic airways.

Acute Airway Obstruction

Children are at particular risk for AAO because of the anatomic differences between the pediatric and adult airway, as discussed earlier [13,14]. Children may appear surprisingly well despite being on the verge of cardiorespiratory collapse. Infants have a high oxygen demand because of a higher metabolic rate relative to body size and weight. Consequently, in the presence of apnea or inadequate ventilation, hypoxemia develops more rapidly in the child than in the adult, and acute decompensation of cardiorespiratory status may be swift and often difficult to reverse [14–16]. Upper airway obstruction often leads to acute respiratory failure and is an important cause of out-of-hospital cardiopulmonary arrest, in stark contrast to adults in whom primary cardiac disease commonly precipitates cardiopulmonary arrest. Once respiratory arrest progresses to cardiac arrest, outcome is dismal [17,18], and prompt recognition of AAO and appropriate, timely intervention are crucial to ensure the best possible outcome.

The pediatric airway is highly compliant and the cartilaginous support less well-developed than the adult airway and is therefore more susceptible to dynamic airway collapse in the presence of airway obstruction. The normal respiratory dynamics change significantly in the presence of upper airway or lower airway obstructions (Figure 24.6). A forced inhalation that is required to generate air flow in the presence of a partial upper airway obstruction requires a stronger contraction of the diaphragm and respiratory muscles, generating a greater decrease (i.e., more negative relative to atmospheric pressure) in intrapleural and intraluminal airway pressures. The movement of a gas (i.e., air) through a partially closed, collapsible tube (i.e., airway) obeys the laws of physics. According to

![Figure 24.6](https://via.placeholder.com/150)

**Figure 24.6.** (A) Normal Inspiration. At end expiration, intrapleural pressure is less than atmospheric pressure, so it should maintain airway patency. In infants the highly compliant chest wall does not provide the support required. Thus airway closure occurs with each breath. Descent of the diaphragm and contraction of the intercostal muscles develop a greater negative intrathoracic pressure relative to intraluminal and atmospheric pressure. The net result is a longitudinal stretching of the larynx and trachea, dilation of the intrathoracic trachea and bronchi, movement of air into the lungs, and some dynamic collapse of the extrathoracic trachea because of the increased compliance of the trachea and the negative intraluminal pressure in relation to atmospheric pressure. (B) Normal expiration. Intraluminal pressures are slightly positive in relation to atmospheric pressure, so air is forced out of the lungs. (C) Extrathoracic obstruction (obstructed inspiration). Respiratory dynamics occurring with upper airway obstruction; note the severe dynamic collapse of the extrathoracic trachea below the level of obstruction. This collapse is greatest at the thoracic inlet, where the largest pressure gradient exists between negative intratracheal pressure and atmospheric pressure. (D) Intrathoracic obstruction (obstructed expiration). Respiratory dynamics occurring with lower airway obstruction. Breathing through a partially obstructed lower airway (such as occurs in bronchiolitis or asthma) results in greater positive intrathoracic pressures, with dynamic collapse of the intrathoracic airways (prolonged expiration or wheezing). (Reprinted from Coté et al. [11]. Copyright 1993 with permission of Elsevier.)
24. Management of the Pediatric Airway

Table 24.1. Common causes of upper airway obstruction in children.

<table>
<thead>
<tr>
<th>Category</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anatomic</td>
<td>Altered level of consciousness (airway muscle laxity)</td>
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<tr>
<td></td>
<td>Postextubation airway obstruction</td>
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<tr>
<td></td>
<td>Subglottic stenosis (acquired or congenital)</td>
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<td></td>
<td>Macroglottis</td>
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<td></td>
<td>Vocal cord paralysis</td>
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<td>External or internal compression</td>
<td>Tumor</td>
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<td></td>
<td>Hemangioma</td>
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<tr>
<td></td>
<td>Hematoma</td>
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<tr>
<td></td>
<td>Cyst</td>
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<td></td>
<td>Papilloma</td>
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<tr>
<td></td>
<td>Vascular rings and slings</td>
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<tr>
<td>Infectious</td>
<td>Laryngotracheobronchitis (Croup)</td>
</tr>
<tr>
<td></td>
<td>Peritonsillar abcess</td>
</tr>
<tr>
<td></td>
<td>Retropharyngeal abcess</td>
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<tr>
<td></td>
<td>Bacterial tracheitis</td>
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<tr>
<td></td>
<td>Epiplottis (“supraglottitis”)</td>
</tr>
<tr>
<td></td>
<td>Infectious mononucleosis</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Postextubation airway obstruction</td>
</tr>
<tr>
<td></td>
<td>Angioedema</td>
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<tr>
<td></td>
<td>Foreign body aspiration</td>
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<td></td>
<td>Airway trauma</td>
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</table>

The Venturi effect, the pressure exerted by a gas (i.e., air) as it flows through a partially closed tube is equal in all directions except when there is linear movement, which creates additional pressure in the forward vector with a corresponding fall in the lateral vectors. This decrease in lateral pressure (i.e., the distending pressure keeping the collapsible tube open) causes the tube to narrow, leading to partial obstruction. In addition, according to the Bernoulli principle, the velocity of a gas increases as it flows through a partially obstructed tube, creating an additional decrease in intraluminal pressure and further exacerbating the obstruction. This pattern of intermittent flow produces audible sounds that are characterized (depending on the level of partial obstruction) as stertor, gurgling, stridor, wheezes, rhonchi, and rales. For example, stertor is a snoring or snorting sound that is produced by turbulence within the nasopharynx. Gurgling is produced by turbulence within the oropharynx caused by the mixture of air and secretions. Stridor is the sound produced by turbulent air flow in a partially obstructed trachea because of either intrinsic obstruction or extrinsic compression. Careful assessment of the time in the respiratory cycle in which stridor predominates may provide valuable diagnostic clues in determining the site of airway obstruction [14,19–25]. For example, partial obstruction of the extrathoracic, supraglottic airway usually manifests as inspiratory stridor (i.e., occurring during the initial phase of inspiration). Partial obstruction of the intrathoracic, subglottic airway usually manifests as biphasic (inspiratory and expiratory) stridor. Changes in the severity of stridor may suggest the presence of an expanding lesion, such as a papilloma or congenital cyst. Wheezing, on the other hand, is produced by partial obstruction in the smaller, peripheral airways.

The differential diagnosis of AAO is provided in Table 24.1. Initial attention should focus on the child’s overall appearance and cardiorespiratory status, as this will influence subsequent decision making with respect to the necessary speed and sequence of subsequent diagnostic and therapeutic actions [14,19,20]. The child’s level of consciousness should be assessed immediately, as an obtunded or unconscious child may require immediate control of the airway. Restlessness, anxiety, and diaphoresis are usually signs of air hunger and hypoxemia. Drooling or the inability to handle oral secretions results from an inability to swallow secondary to pain or swelling of affected tissues and is typically seen with supraglottic pathology (e.g., supraglottitis, retropharyngeal abscess). Accessory muscle use is an additional sign of increased work of breathing and is indicative of compromised gas exchange.

During quiet breathing, air flow is laminar and resistance to air flow is inversely proportional to the fourth power of the airway radius as stipulated by Poiseuille’s law. When air flow is turbulent (e.g., during crying) resistance to air flow is inversely proportional to the fifth power of radius such that even a minor reduction in the cross-sectional area of the airway will result in a marked increase in air flow resistance and work of breathing. For these reasons, the infant or child with airway obstruction should be kept calm and as quiet as possible to prevent generation of turbulent air flow, increased airway resistance, and worsening respiratory distress. In general, any child in severe respiratory distress will assume a position that maximizes oxygenation and ventilation and should be allowed to remain in this position of comfort (Figure 24.7). For example, the child with supraglottitis will sit erect with the head tilted forward in the sniffing position, whereas a child with a retropharyngeal abscess will assume a head tilt or opisthotonus posture because of spasm of the muscles supporting the cervical spine [14].
Basic Airway Management

Stabilization of the airway is of primary importance during the initial resuscitation of the critically ill or injured child. No matter what the cause or underlying condition, further attempts at resuscitation or treatment will fail without proper control of the airway. The goals of airway management are threefold: (1) relieve anatomic obstruction, (2) prevent aspiration of gastric contents, and (3) promote adequate gas exchange.

Emergency management of the airway proceeds in a sequential order and begins with proper positioning of the head and protection of the cervical spine—all critically injured children have cervical spine injury until proven otherwise. Collapse of the tongue and soft tissues leads to obstruction of the upper airway and is the most common cause of airway obstruction in children (see Table 24.1). The triple airway maneuver is a simple method of relieving airway obstruction in this scenario and includes (1) proper head positioning while avoiding neck flexion (head tilt maneuver or sniff position—although the head tilt should be avoided whenever cervical spine injury is suspected), (2) anterior displacement of the mandible (jaw thrust maneuver), and (3) placement of an oral airway (Figure 24.8).

![Triple Airway Maneuver Diagram]

**Figure 24.8.** The triple airway maneuver. (A) Head tilt–chin lift maneuver (B) Jaw thrust maneuver (C) Placement of an oral airway. (Reprinted with permission from Foltin G, Tunik MG, Cooper A, Markenson D, Treiber M, Phillips R, Karpeles T. Teaching Resource for Instructors in Prehospital Pediatrics. New York: Center for Pediatric Emergency Medicine; 1998.)
Airway adjuncts such as the oral airway and nasopharyngeal airway help to relieve obstruction of the airway by lifting the tongue from the soft tissues of the posterior pharynx. Oral airways consist of a flange, a short bite-block segment, and a curved body made of hard plastic that is designed to fit over the back of the tongue, thereby relieving airway obstruction and providing a conduit for air flow and for suctioning of the oropharynx. Proper sizing of the oral airway is imperative, as an incorrectly sized (either too long or too short) oral airway may exacerbate airway obstruction (Figure 24.9). Sizes generally range from 4 to 10 cm in length (Guedel sizes 000 to 4). An oral airway is inserted by depressing the tongue with a blade/tongue depressor and following the curve of the tongue. Another commonly described method in which the oral airway is inserted with its concave side facing the palate and then rotating it to follow the curve of the tongue may damage the oral mucosa and/or teeth and should be avoided. Oral airways are poorly tolerated in children with an intact gag reflex and are therefore contraindicated in awake or semiconscious children.

A nasopharyngeal airway (nasal trumpet) should be used if the patient is semiconscious, as use of the oral airway can lead to vomiting and potential aspiration of gastric contents in this scenario. The nasopharyngeal airway consists of a soft, rubber tube that is designed to pass through the nasal alae and beyond the base of the tongue, thereby relieving airway obstruction (Figure 24.10) and providing a conduit for air flow. An appropriately sized nasopharyngeal airway extends from the nares to the tragus of the ear and should be of the largest diameter possible—it should pass relatively easy through the nasal alae with lubrication. The
Respiratory failure (defined in terms of either inadequate oxygenation or ventilation)
Shock or hemodynamic instability
Upper airway obstruction
Cardiac arrest (for emergency drug administration)

TABLE 24.2. Indications for tracheal intubation.

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<tr>
<td>Upper airway obstruction</td>
</tr>
<tr>
<td>Shock or hemodynamic instability</td>
</tr>
<tr>
<td>Neuromuscular weakness with progressive respiratory compromise</td>
</tr>
<tr>
<td>Absent protective airway reflexes</td>
</tr>
<tr>
<td>Inadequate respiratory drive</td>
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<td>Cardiac arrest (for emergency drug administration)</td>
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</table>

Tracheal Intubation

Indications

If all of the aforementioned measures fail to stabilize the airway, tracheal intubation should be performed in an expeditious manner (Table 24.2). The most common indication for tracheal intubation in the pediatric intensive care unit (PICU) is acute respiratory failure. Acute respiratory failure is conceptually defined as an inadequate exchange of O₂ and CO₂, resulting in an inability to meet the body’s metabolic needs. Clinical criteria, arbitrarily set at a PaO₂ <60 mm Hg (in the absence of congenital heart disease) and a PaCO₂ >50 mm Hg, are not rigid parameters but rather serve as a context in which to interpret the clinical scenario. Failure of the anatomic elements involved in gas exchange—the conducting airways, the alveoli, and the pulmonary circulation—results in disordered gas exchange and is clinically manifested as hypoxemia (hypoxic respiratory failure). Failure of the respiratory pump—the thorax, respiratory muscles, and nervous system—results in an inability to effectively pump air into and out of the lungs, thereby leading to hyperventilation and subsequent hypercarbia (hypercarbic respiratory failure). Although there are clear consequences of dysfunction of each of these components, each also interacts significantly with the other. Therefore, failure of one frequently is followed by failure of the other.

Other common indications for tracheal intubation in the PICU include upper airway obstruction (e.g., epiglottitis, croup, airway trauma), neuromuscular weakness leading to neuromuscular respiratory failure (e.g., Guillain-Barré syndrome, myasthenia gravis, Duchenne muscular dystrophy), central nervous system disease, resulting in the loss of protective airway reflexes and inadequate respiratory drive (e.g., head trauma, stroke), and cardiopulmonary arrest. Importantly, tracheal intubation in the latter situation provides an avenue for administration of resuscitation medications (the medications that may be administered via the tracheal tube are easily recalled by the mnemonic LEAN = Lidocaine, Epinephrine, Atropine, Naloxone) when vascular access is unavailable. Tracheal intubation may become necessary for children with impaired mucociliary clearance (e.g., secondary to inhalation injury, prolonged tracheal intubation) or copious, thick, tenacious respiratory secretions as a means for aggressive pulmonary toilet and frequent suctioning. Tracheal intubation may also provide a means for administration of therapeutic gases (e.g., carbon dioxide, nitrogen, inhaled nitric oxide) in order to manipulate pulmonary vascular resistance in children with pulmonary hypertension or cyanotic congenital heart disease with single ventricle physiology.

Children with hemodynamic instability (e.g., shock, low cardiac output syndrome following cardiopulmonary bypass) may also benefit from early tracheal intubation and mechanical ventilation. Agitation and excessive work of breathing increase oxygen consumption, which may lead to cardiovascular collapse in the face of an already compromised oxygen delivery. The excessive oxygen consumption often associated with the shock state has been compared by some investigators to running an 8-min mile 24 hr a day, 7 days a week [26]. For example, Aubier and colleagues [27] induced cardiogenic shock in dogs via cardiac tamponade and noted that the arterial pH was significantly lower and the lactate concentration significantly higher in dogs that were spontaneously breathing compared with dogs that were mechanically ventilated. Using the same model, these investigators studied respiratory muscle and organ blood flow with radioactively labeled microspheres in order to assess the influence of the working respiratory muscles on the regional distribution of blood flow when arterial pressure and cardiac output were lowered. Blood flow to the respiratory muscles increased significantly during cardiac tamponade in spontaneously breathing dogs—diaphragmatic flow, in fact, increased to 361% of control values—whereas it decreased in dogs that were mechanically ventilated. More importantly, although the arterial blood pressure and cardiac output were comparable in the two groups, blood flow distribution during cardiac tamponade was quite different. The respiratory musculature received 21% of the cardiac output in spontaneously breathing dogs compared with only 3% in the dogs that were mechanically ventilated. Blood flows to the liver, brain, and quadriceps muscles were significantly higher during tamponade in the dogs that were mechanically ventilated than in the dogs that were spontaneously breathing [28]. These findings have been further corroborated in experimental models of
septic shock [29] and clinical studies involving adults with cardiorespiratory disease [30] and critical illness [31,32]. Therefore, with the judicious and careful use of sedation, neuromuscular blockade, tracheal intubation, and mechanical ventilatory support, a large fraction of the cardiac output used by the working respiratory muscles can be made available for perfusion of other vital organs during the low cardiac output state [27–32].

Assessment and Preparation

Resuscitation of any critically ill or injured child is chaotic even under ideal circumstances, and emergency airway management is often fraught with difficulties. Prior preparation and appropriate training of personnel therefore assume vital importance [33]. The appropriate equipment and medications should be prepared well in advance [34]. Ideally, all of the necessary equipment for basic and advanced airway management should be readily accessible in an easily identifiable, central location in the PICU. Many PICUs keep all of the necessary airway equipment in specialized airway carts (similar to the crash cart) or airway rolls that can be brought to the bedside in an emergency.

The American Society of Anesthesiology defines a difficult airway by the presence of anatomic and/or clinical factors that complicate either mask ventilation or tracheal intubation by an experienced physician [35]. A difficult intubation is defined by the need for more than three tracheal intubation attempts or attempts lasting longer than 10 min [35]. Notably, this definition was developed specifically for the operating room scenario—most critically ill patients probably would not tolerate an intubation attempt lasting longer than 10 min. Difficult ventilation is defined as the inability of a trained physician to maintain the oxygen saturation >90% with bag-valve-mask ventilation at an FIO2 of 1.0 [35]. Some children (e.g., children with neuromuscular disease, cerebral palsy, obstructive sleep apnea) are dependent on coordinated tone of the upper airway muscles to maintain a patent airway and are very sensitive to sedation, anesthesia, and neuromuscular blockade, resulting in significant difficulty with mask ventilation. The inability to mask ventilate has considerably more implications than does failure to tracheally intubate, as subsequent management options are limited (see later). Importantly, there is tremendous overlap among anatomic factors that predict a difficult airway, difficult intubation, and difficult ventilation (Table 24.3). In one study as many as 15% of difficult intubations were also associated with difficult mask ventilation [36]. Fortunately, however, difficult intubations are relatively uncommon, even in children, with an estimated incidence between 2% and 4%. Inability to mask ventilate has an even lower incidence, 0.02%–0.001% [37].

A number of quick, easy techniques have been proposed to predict a difficult airway. Unfortunately, a recent retrospective analysis suggested that performing this kind of airway assessment was not feasible in 70% of critically ill adults [38]. An airway assessment may be even more difficult for children, as most of the reported techniques require cooperation on the part of the patient [20,39,40]. Moreover, most studies demonstrate that these bedside techniques have both poor interobserver agreement and positive predictive value [41,42]. Regardless, whenever feasible, an airway assessment should be performed so that problems with either bag-valve-mask ventilation or tracheal intubation can be anticipated and prepared for in advance.

Generally, in the absence of any obvious airway abnormality or specific syndrome associated with a difficult airway (see later), most difficult airways can be recognized by performing the following three maneuvers: (1) oropharyngeal examination, (2) assessment of atlanto-occipital joint mobility, and (3) assessment of the potential displacement area. These three tests correctly predict a difficult airway in adults virtually 100% of the time. However, these three tests may not be applicable to the pediatric patient as they require cooperation on the part of the patient. The relative size of the oral cavity is assessed by asking the child to open his or her mouth. The Mallampati classification system [43], as modified by Samsoon and Young [44], classifies the degree of airway difficulty based on the ability to visualize the faucial pillars, soft palate, and uvula (Figure 24.12). A Mallampati class of I or II predicts a relatively easy airway, whereas a Mallampati class >II predicts an increased difficulty with adequate visualization of the airway during laryngoscopy. Critically ill patients with altered mental status or children may be unable to cooperate with this kind of assessment, although evaluation of the oropharyngeal airway with a tongue blade may be feasible and worthwhile [20,39,45]. Cormack and Lehane [46] proposed a classification system based on the ability to visualize the glottic opening during laryngoscopy, although this type of assessment is probably more useful as a means to facilitate communication of the degree of difficulty between providers and not as a screening tool for predicting a difficult airway at the bedside. The interincisor distance can also be assessed at this time—an interincisor distance less than two fingertips in breadth can be associated with a difficult airway [20,39]. Decreased range of motion at the atlanto-occipital joint leads to poor visualization of the glottis during laryngoscopy. Cervical spine immobilization with a C-collar may also limit atlanto-occipital joint extension, leading to a potentially difficult airway. Finally, if three fingers in adolescents, two fingers in children, and one finger in infants can be placed between the anterior ramus of the mandible and the hyoid bone, the so-called potential displacement area, adequate visualization of the glottis during laryngoscopy usually will be successful (Figure 24.13). If the potential displacement area is too small, excessive extension of the neck will only

![Figure 24.12. Samsoon and Young modification of the Mallampati airway classification.](image)
shift the larynx into a more anterior position [47]. The BURP maneuver (Back, Up, and Rightward Pressure on the laryngeal cartilage) displaces the larynx in three directions, (1) posteriorly against the cervical vertebra, (2) superiorly as possible, and (3) laterally to the right, and may improve visualization of the glottic opening in this situation (see Figure 24.13) [48,49].

Several malformation syndromes are associated with a difficult airway based on the presence of a few notable anatomic features:

1. **Macroglossia:** A large tongue in children with Beckwith-Wiedemann syndrome or trisomy 21 (Down syndrome) may be difficult to control and make visualization of the glottis during laryngoscopy difficult. Mask ventilation under these circumstances may also be difficult and frequently requires placement of an oral or nasal airway. A curved laryngoscope blade may be more appropriate in this scenario.

2. **Mandibular hypoplasia:** Mandibular hypoplasia is frequent in children with the Pierre-Robin sequence (see later), Crouzon disease, Goldenhar syndrome, and Treacher-Collin syndrome. Mandibular hypoplasia forces the tongue posteriorly in the oropharynx and hinders visualization of the glottis during laryngoscopy. Alternative techniques, including use of a laryngeal mask airway, light wand, or fiberoptic bronchoscope, are frequently required for these children and should be readily available.

3. **Limited cervical motion:** Limited atlanto-occipital range of motion is frequently found in children with Goldenhar syndrome and Klippel-Feil syndrome, thereby limiting an adequate line of
sight to the glottis because of failure of the three axes (discussed above) to align. Other disease processes such as juvenile rheumatoid arthritis and neuromuscular scoliosis also can result in limited cervical spine mobility. Children with Trisomy 21 or trauma, on the other hand, have atlanto-occipital instability, and cervical spine precautions should be followed.

4. *Mucopolysaccharidoses*: Children with the mucopolysaccharidoses often have difficult airways for a number of reasons.

**Equipment**

All the necessary equipment for airway management must be available at the bedside before any attempts at tracheal intubation are made! At a minimum, this list includes (1) a source of oxygen (either wall or tank) with the necessary tubing, ventilation bag (either a self-inflating or standard anesthesia bag, appropriately sized), and mask (appropriately sized); (2) a source of suction (either portable suction or wall suction) and appropriate suction catheters (preferably the rigid, wide-bore *tonsil tip* or Yankauer suction catheters); (3) laryngoscope and proper-sized blade with a well-functioning light; (4) tracheal tubes of the anticipated size, plus the next size largest and smallest (see below); (5) stylet; and (6) a means of securing the tracheal tube. Additional items include oral airways, nasopharyngeal airways, and a Magill forceps.

**Oxygen Source**

There are two types of oxygen sources commonly used in the critical care setting—wall oxygen sources and gas cylinders. Federal regulations require that wall oxygen sources utilized in hospitals in the United States provide a working pressure of at least 50 psi, thereby ensuring at least the 35 psi of pressure required by most commercially available mechanical ventilators. Oxygen cylinders are available in a variety of sizes and operate at much higher internal pressures—generally on the order of 1,800–2,400 psi. Therefore, the oxygen cylinder must be interfaced with a pressure-reducing valve in order to reduce the pressure between the oxygen source and the patient to a level that is consistent with the pressure supplied by a wall oxygen source (i.e., around 50 psi). However, an additional reduction in the driving pressure is required and is provided by a flowmeter, in which flow can be adjusted to a level that is comfortable for the patient. Importantly, the flowmeters commonly used in the PICU are equipped with a *back pressure compensation* mechanism such that the introduction of resistance distal to the valve does not result in spuriously elevated flow readings [50,51]. Finally, when using an oxygen cylinder as opposed to a wall oxygen source, a sufficient supply of oxygen should be on hand. The amount of time that a cylinder will supply oxygen can be determined using the following formula:

\[
\text{Minutes of oxygen flow} = \frac{\text{Cylinder pressure} \times \text{cylinder factor}}{\text{Flow of oxygen (in liters per minute)}}
\]

where the cylinder factor of a size D, E, and H tank is 0.16, 0.28, and 3.14, respectively [52].

**Bag-Valve-Mask Ventilation**

The advantages and disadvantages between self-inflating and standard anesthesia bags are discussed in Chapter 23.

**Suction Devices**

Removal of secretions, blood, or vomitus from the oropharynx, nasopharynx, or trachea is frequently necessary to achieve a patent airway. There are two sources of suction commonly used in the critical care setting—wall suction (vacuum outlet) and battery-operated, portable suction devices. Suction force should be limited to 80–120 mm Hg in order to minimize suction trauma to the airway mucosa. Both flexible, plastic suction catheters and rigid, wide-bore suction cannulas (*tonsil tip* or Yankauer) should be available. The Yankauer suction catheter is preferable for suctioning thick secretions and particulate matter in the airway, whereas the thin, flexible catheters are used to directly suction the tracheal tube. The combination of a small tracheal tube, dry gases, and airway secretions increases the risk of tube plugging and occlusion, and the instillation of 3–5 mL of sterile 0.9% saline followed by suctioning of the airway should be performed on a frequent basis. Sterile technique will minimize the risk of ventilator-associated pneumonia [53–55]. The catheter should be gently inserted into the airway just beyond the tip of the tracheal tube without applying suction; rather, suction is applied while withdrawing the suction catheter in a rotating, twisting motion. Suction attempts should not exceed 5 sec and should be preceded by a short period of ventilation with 100% oxygen in order to avoid hypoxemia. Heart rate and blood pressure should be monitored closely, as suctioning may stimulate the vagus nerve and produce bradycardia. Lidocaine (administered tracheally, 5–6 mg/kg dose diluted in 6 mL 0.9% saline 5–10 min before suctioning) may be administered in children with head trauma [56–58] before the airway is suctioned in order to blunt the increase in intracranial pressure (ICP) that may result from the suctioning [59–62].

**Laryngoscopes**

Laryngoscope blades are available in several different shapes and sizes but are usually classified into straight (e.g., Miller, Phillips, Wis-Hipple) versus curved (e.g., Macintosh) blades. Straight blades are preferable to curved blades for neonates, infants, and young children because of the relatively cephalad position of the glottis, the large tongue (relative to the size of the oral cavity), and the large, floppy epiglottis, which may be difficult to control with a curved blade (see earlier). Perhaps the most important consideration for selection of the laryngoscope blade is its length (Table 24.4). Shorter blades make visualization of the glottis difficult, whereas longer blades make it difficult to avoid direct pressure on the upper lip, teeth, and gums. The laryngoscope should be checked for proper functioning and adequate illumination before use.

**Tracheal Tubes**

The appropriate size for the tracheal tube is based on the child’s age. Generally, a 3.0- or 3.5-mm tracheal tube should be used in

<table>
<thead>
<tr>
<th>Child’s weight (kg)</th>
<th>Laryngoscope</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–3</td>
<td>Miller 0</td>
</tr>
<tr>
<td>3–5</td>
<td>Miller 0.1</td>
</tr>
<tr>
<td>5–12</td>
<td>Miller 1</td>
</tr>
<tr>
<td>12–20</td>
<td>Macintosh 2</td>
</tr>
<tr>
<td>20–30</td>
<td>Macintosh 2, Miller 2</td>
</tr>
<tr>
<td>&gt;30</td>
<td>Macintosh 3, Miller 2</td>
</tr>
</tbody>
</table>
term infants, and a 4.0-mm tracheal tube should be used for infants older than 6–8 months of age. Beyond 8 months of age, the appropriate size for the tracheal tube can be determined according to the following rule:

$$\text{Tracheal tube (mm i.d.)} = \frac{\text{Age (y)}}{4} + 4$$

The outside diameter of the tracheal tube usually approximates the diameter of the child’s little finger. It is important to note that this rule is only a starting guideline, and different-sized tubes (one size smaller and one size larger) should be readily available during attempts at tracheal intubation. The tracheal tube should pass through the glottis easily and with minimal force, and the presence of a minimal air leak heard around the tracheal tube with inflating pressures of 20–30 cm H₂O will ensure adequate perfusion of the tracheal mucosa and lessen the risk of tissue necrosis, edema, scarring, and postextubation stridor.

Historically, uncuffed tubes have been generally recommended for children less than 8 years of age. A prolonged period of tracheal intubation and a poorly fitted tracheal tube are significant risk factors for damage to the tracheal mucosa regardless of whether the tracheal tube is cuffed or uncuffed. Cuffed tracheal tubes may have significant advantages over uncuffed tracheal tubes, including better control of air leakage and decreased risk of aspiration and infection in mechanically ventilated children, and they are being used with greater frequency in this age group, especially when high inflation pressures are required to provide adequate oxygenation and ventilation in the setting of severe acute lung disease. The available data suggest that there is no difference in the incidence of postextubation stridor in children who were tracheally intubated with cuffed tubes compared with those who received uncuffed tubes [63–67]. A good rule of thumb is that whenever a cuffed tube is used, a half-size smaller tube from what would normally be used (based on the rule above) should be selected.

**Stylets**

A malleable, yet rigid stylet may be inserted into the tracheal tube in order to shape the tube to the desired configuration (e.g., hockey stick) before attempting tracheal intubation. However, the tip of the stylet must not protrude beyond the distal tip of the tracheal tube in order to minimize the potential of airway trauma. In addition, the stylet should be lubricated with a water-soluble lubricant before insertion into the tracheal tube in order to facilitate its easy removal once the tracheal tube has been placed.

**Airway Pharmacology**

Laryngoscopy and tracheal intubation are commonly associated with profound physiologic disturbances that may adversely affect the critically ill or injured child. In addition to pain and anxiety, laryngoscopy causes an increase in blood pressure and heart rate [59–62,68,69], although decreased heart rate and hypotension may be more common in infants as a consequence of their increased parasympathetic tone [70]. Hypoxia and hypercarbia are also common, especially in children with impending respiratory failure. Laryngoscopy and tracheal intubation increase ICP (which may exacerbate intracranial hypertension in children with head injury or lead to intracranial hemorrhage in children with coagulopathies or vascular malformations) [59–62], intracranial pressure, and intraocular pressure (further compounding the risk of regurgitation and aspiration of gastric contents) [71]. Tracheal intubation may also provoke bronchospasm, especially in children with asthma. The use of appropriate preinduction agents or adjuncts, induction agents, and neuromuscular blockade may modify these physiologic responses and lessen the potential for adverse effects related to laryngoscopy and tracheal intubation. It is extremely important to remember that attenuation of these normal responses following tracheal intubation may unmask hemodynamic instability leading to, at times, profound hypotension [72].

**Preinduction Agents**

Several preinduction agents are commonly used for tracheal intubation in critically ill or injured children, including cholinergic antagonists, lidocaine, opioids, β-adrenergic antagonists, and non-depolarizing neuromuscular blocking agents (NDNMBA) (Table 24.5). Cholinergic antagonists such as atropine (0.01–0.02 mg/kg intravenous [IV], with a minimum dose of 0.1 mg) and glycopyrrolate (3–5µg/kg IV) may be administered in order to prevent bradycardia (especially in critically ill infants with high parasympathetic tone) and decrease oral secretions. Succinylcholine also causes bradycardia, especially in infants and young children [73–75]. Atropine is usually recommended when using succinylcholine in children less than 1 year of age, although the use of atropine in

<table>
<thead>
<tr>
<th><strong>Table 24.5. Preinduction agents used for tracheal intubation.</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agent</strong></td>
</tr>
<tr>
<td>Oxygen</td>
</tr>
<tr>
<td>Atropine</td>
</tr>
<tr>
<td>Glycopyrrolate</td>
</tr>
<tr>
<td>Lidocaine</td>
</tr>
<tr>
<td>Fentanyl</td>
</tr>
<tr>
<td>Vecuronium</td>
</tr>
<tr>
<td>Rocuronium</td>
</tr>
<tr>
<td>Esmolol</td>
</tr>
</tbody>
</table>
inappropriate in another. The induction agent should therefore be administered immediately before laryngoscopy and tracheal intubation in order to blunt the associated hypertensive response and increase in ICP. Unfortunately, strong evidence to suggest that this practice improves neurologic outcome is not available [80–82]. Topical lidocaine may be just as effective as intravenous lidocaine in blunting the physiologic response to laryngoscopy and tracheal intubation [83–86]. Fentanyl is also commonly used as an induction agent and is discussed further below.

Esmolol is a rapid-onset, short-acting, cardioselective β-adrenergic antagonist that is frequently used in adults to attenuate the tachycardia and hypertension resulting from laryngoscopy and tracheal intubation [83,85,87]. Esmolol, either alone or in combination with fentanyl, may be more effective than either lidocaine or fentanyl [84,88–93], and the combination of fentanyl and esmolol may be particularly effective in this situation. However, caution should be exercised as there are currently no reports on the use of esmolol as a preinduction agent for tracheal intubation in children. Most adult studies use an esmolol dose of 2 mg/kg IV administered 1–2 min before laryngoscopy. Esmolol is contraindicated for children with reactive airways disease or asthma and is probably contraindicated in situations where hemodynamic instability could be anticipated.

Finally, some protocols recommend the use of a defasciculating dose of NDNMB before the use of succinylcholine. This is discussed further below.

**Induction Agents**

There are a variety of anxiolytic, analgesic, and sedative agents commonly used to facilitate tracheal intubation (Table 24.6). An ideal induction agent induces unconsciousness predictably with a rapid onset of action, short duration of action, and few side effects. Unfortunately, the ideal induction agent does not exist. Although the choice of which induction agent to use in any given situation depends primarily on individual physician preference and comfort, there are some important caveats to bear in mind. One particular agent may be appropriate in a given clinical scenario and entirely inappropriate in another. The induction agent should therefore be selected based on the particular clinical scenario with the goal of rapid induction and minimal adverse effects (Table 24.7).

Fentanyl is a rapid-onset barbiturate with a rapid onset of action (10–20 sec) at the recommended dose of 2–3 mg/kg IV. Thiopental decreases cerebral oxygen consumption and effectively reduces ICP [94,95] and is therefore the agent of choice for children with closed head injury [96–100]. However, thiopental is a potent vasodilator (decreases systemic vascular resistance), venodilator (decreases preload in hypovolemic patients), and, at higher doses, a potent cardiac depressant and should be used with caution in the hypovolemic or hypotensive child. These effects may be minimized with a decreased rate of administration or with the use of a smaller dose (some authorities recommend decreasing the dose by half in this situation) [98]. Additional side effects include histamine release, with subsequent hypotension or bronchospasm, coughing, and laryngospasm. The barbiturates as a group may cause mild muscular movements such as tremors, hypertonus, or twitching.

Etomidate (0.3 mg/kg IV) is another agent that decreases cerebral oxygen consumption and hence ICP but without significant detrimental effects on either the heart or systemic vascular resistance, making it a good alternative to thiopental for children with closed head injury and hypotension [101]. Etomidate lacks analgesic effects and should be administered in conjunction with an opioid such as fentanyl. Etomidate does cause adrenal suppression [102–107] and should not be used for long-term sedation in the PICU. Some experts have further suggested that etomidate should not be used for induction for tracheal intubation in critically ill patients [108–112]. Etomidate appears to cause adrenal suppression for at least 12–24 hr following a single dose [106,108,113,114], although some investigators have questioned the clinical significance of these effects [115,116]. Etomidate should be used with caution in critically ill patients, although no definitive statements against its use can be made until additional evidence becomes available from randomized, placebo-controlled trials in this setting. Etomidate does cause myoclonic activity and may lower the seizure threshold in children with either central nervous system pathology or epilepsy [117].

The benzodiazepines (midazolam, lorazepam, and diazepam) are potent anxiolytics and amnestic but lack analgesic properties and are therefore commonly co-administered with a narcotic such as morphine or fentanyl (see later). Midazolam (0.1–0.2 mg/kg IV) has a relatively rapid onset of action (3–5 min) and shorter duration

### Table 24.6. Commonly used induction agents for tracheal intubation.

<table>
<thead>
<tr>
<th>Agent</th>
<th>Dose</th>
<th>Onset</th>
<th>Recovery</th>
<th>Indications</th>
<th>Precautions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thiopental</td>
<td>2–3 mg/kg IV</td>
<td>10–20 sec</td>
<td>15–30 min</td>
<td>Status epilepticus, isolated head trauma (with normal hemodynamics)</td>
<td>Bronchospasm, hypotension</td>
</tr>
<tr>
<td>Etomidate</td>
<td>0.15–0.3 mg/kg IV</td>
<td>30–60 sec</td>
<td>3–5 min</td>
<td>Trauma, shock (?)</td>
<td>Causes adrenal suppression, decreases seizure threshold</td>
</tr>
<tr>
<td>Ketamine</td>
<td>1–2 mg/kg IV</td>
<td>1–2 min</td>
<td>5–10 min</td>
<td>Status asthmaticus</td>
<td>May increase intracranial pressure</td>
</tr>
<tr>
<td>Propofol</td>
<td>2–4 mg/kg IV</td>
<td>30–60 sec</td>
<td>3–5 min</td>
<td>Isolated head trauma, status epilepticus</td>
<td>Hypotension</td>
</tr>
<tr>
<td>Midazolam</td>
<td>0.1–0.2 mg/kg IV</td>
<td>3–5 min</td>
<td>20–30 min</td>
<td>Isolated head trauma, status epilepticus</td>
<td>Hypotension</td>
</tr>
<tr>
<td>Fentanyl</td>
<td>5–10 µg/kg IV</td>
<td>30–60 sec</td>
<td>10–15 min</td>
<td>Isolated head trauma, status epilepticus</td>
<td>Rarely used as the sole agent; rigid chest syndrome</td>
</tr>
</tbody>
</table>

older children is more controversial and frequently not necessary [76–79].

Lidocaine (1–1.5 mg/kg IV) may be administered 3–5 min before laryngoscopy and tracheal intubation in order to blunt the associated hypertensive response and increase in ICP. Unfortunately, strong evidence to suggest that this practice improves neurologic outcome is not available [80–82]. Topical lidocaine may be just as effective as intravenous lidocaine in blunting the physiologic response to laryngoscopy and tracheal intubation [83–86]. Fentanyl is also commonly used as an induction agent and is discussed further below.

**Table 24.7. Suggested induction agents for specific clinical scenarios.**

<table>
<thead>
<tr>
<th>Status epilepticus</th>
<th>Isolated head trauma</th>
<th>Shock</th>
<th>Head trauma + shock</th>
<th>Status asthmaticus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propofol</td>
<td>Propofol</td>
<td>Etomidate (?)</td>
<td>Etomidate</td>
<td>Ketamine</td>
</tr>
<tr>
<td>or-Thiopental</td>
<td>or-Thiopental</td>
<td>or-Etomdiate</td>
<td>or-Etomdiate</td>
<td>Ketamine</td>
</tr>
<tr>
<td>or-Midazolam</td>
<td>or-Midazolam</td>
<td>or-Etomdiate</td>
<td>or-Etomdiate</td>
<td>Ketamine</td>
</tr>
</tbody>
</table>
of action (20–30 min) and is more frequently used in this setting than either lorazepam or diazepam. Midazolam does have some effects on reducing ICP [118–120], although clearly thiopental and etomidate are superior in this regard. Midazolam may reduce mean arterial blood pressure (MAP), thereby lowering cerebral perfusion pressure (CPP), as CPP = MAP – ICP [119] and should be used with caution in children with hemodynamic instability [121–124]. The hemodynamic effects may be more pronounced in newborns and infants [121,123], so particular caution should be exercised in this patient population.

Morphine (0.1–0.2 mg/kg IV) causes profound histamine release and potential hypotension of bronchospasm and is generally not used as an induction agent for tracheal intubation [86,96–98,125,126]. Fentanyl is approximately 180 times more potent than morphine and does not cause histamine release, but it may cause chest wall rigidity when large doses are administered rapidly [127–131]. Opioid-induced chest wall rigidity may be reversed with IV naloxone or neuromuscular blockade [126,132]. Although largely devoid of significant cardiovascular side effects, hypotension can occasionally occur with the use of fentanyl [133–135]. The dose required for induction of anesthesia (doses as high as 30–150 μg/kg IV have been reported in the literature) is much higher than the dose required for analgesia alone [96–98,125,126,133,134,136], although reports on the use of fentanyl for tracheal intubation in the critically ill or injured are relatively limited [137]. For these reasons, fentanyl is probably better utilized as either a preinduction agent (see earlier) or as an adjunct to another induction agent.

Ketamine is a phencyclidine (PCP) derivative that has potent amnestic, angesic, and sympathomimetic properties. It is generally considered a dissociative anesthetic agent and acts by selectively inhibiting the cerebral cortex and thalamus while stimulating the limbic system [125,126]. Although ketamine has direct negative inotropic effects [138,139], systemic blood pressure is preserved, primarily through increased sympathetic stimulation [96–98,125,126,140]. The hemodynamic safety of ketamine in children with congenital heart disease is well established [141–144]. Critically ill patients have rarely been known to respond to ketamine with profound hypertension caused by the depletion of endogenous catecholamines [140,145], otherwise ketamine is widely considered the induction agent of choice for hemodynamically unstable patients [96–98,125,126], including those with cardiac tamponade [146,147]. Ketamine is also a potent bronchodilator (related to its sympathomimetic effects) and has been used therapeutically in children with status asthmaticus [148–151] and is also the induction agent of choice for laryngoscopy and tracheal intubation of children with reactive airways disease or asthma. Contrary to common belief, although spontaneous ventilation is preserved in most children, larger doses may precipitate laryngospasm or apnea. Ketamine also increases cerebral blood flow and ICP and should be used with caution, if at all, in children with closed head injury and high ICP, although recently these concerns have been questioned [152,153]. Ketamine was historically thought to be contraindicated for patients with pulmonary hypertension, as it was thought that it could increase pulmonary vascular resistance and provoke a pulmonary hypertensive crisis. Recent studies, however, support the use of ketamine for this patient population [143,154,155]. Additional side effects of ketamine include hypersalivation and emergence dysphoria and/or hallucinations.

Propofol (2–4 mg/kg IV) is an induction agent with a rapid onset of action (30–60 sec) and short duration of action (3–5 min) that is frequently used for rapid sequence intubation in adults [86,126]. Propofol reduces ICP and decreases cerebral metabolism [86,126] and effectively attenuates the hemodynamic response to direct laryngoscopy and tracheal intubation [156]. Propofol is a potent vasodilator and venodilator, and to some extent it has negative inotropic effects, thereby limiting its use to patients with stable hemodynamics [86,126,156].

### Neurumuscular Blocking Agents

Several excellent reviews are available on the pharmacology of neuromuscular blocking agents [86,96–98,157–161]. In addition, the reader is referred to Chapter 138. Nondepolarizing neuromuscular blockers act by competitively inhibiting the interaction of acetylcholine (ACh) with its receptor on the motor endplate. Neurumuscular transmission requires the binding of two ACh molecules (one ACh molecule binds to each α-subunit); thus, even if only one binding site is occupied by an NDNMB, ACh activation is effectively inhibited. However, approximately 90%–95% of the ACh receptors must be blocked before neuromuscular transmission is completely inhibited [157]. The diaphragm is more densely populated with ACh receptors than are other muscles, so the diaphragm may continue to function even after the muscles of the hands and upper airway have been effectively paralyzed [157]. The NDNMBs (Table 24.8) are all highly water-soluble, positively charged quaternary ammonium compounds commonly subdivided into two main classes. The benzylisoquinolines include mivacurium, atracurium, cis-atracurium, doxacurium, and d-tubocurarine. All of these compounds, with the exception of mivacurium, are degraded by a nonenzymatic chemical process called Hofmann elimination at physiologic pH and temperature and are therefore commonly used in children with renal insufficiency or liver failure. Mivacurium, on the other hand, is metabolized by plasma cholinesterase. The

<p>| Table 24.8. Neuromuscular blocking agents used for tracheal intubation. |
|-----------------------------|---------------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Agent</th>
<th>Class</th>
<th>Dose</th>
<th>Onset</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Succinylcholine</td>
<td>DNMB</td>
<td>1–2 mg/kg IV</td>
<td>60 sec</td>
<td>5–10 min</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2–4 mg/kg IM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atracurium</td>
<td>NDNMB</td>
<td>0.6 mg/kg IV</td>
<td>2–3 min</td>
<td>20–30 min</td>
</tr>
<tr>
<td>Cis-atracurium</td>
<td>NDNMB</td>
<td>0.1 mg/kg IV</td>
<td>2–3 min</td>
<td>25–40 min</td>
</tr>
<tr>
<td>Rocuronium</td>
<td>NDNMB</td>
<td>0.6 mg/kg IV</td>
<td>60 sec</td>
<td>25–35 min</td>
</tr>
<tr>
<td>Vecuronium</td>
<td>NDNMB</td>
<td>0.1 mg/kg IV</td>
<td>2–3 min</td>
<td>15–30 min</td>
</tr>
<tr>
<td>Pancuronium</td>
<td>NDNMB</td>
<td>0.1 mg/kg IV</td>
<td>60–120 sec</td>
<td>20–40 min</td>
</tr>
</tbody>
</table>

Note: DNMB, depolarizing neuromuscular blocker; NDNMB, nondepolarizing neuromuscular blocker.
aminosteroids include pancuronium, vecuronium, and rocuronium (the newest aminosteroid, rapacuronium, was removed from the market because of concerns regarding its associated side effects of severe bronchospasm). These compounds are metabolized in the liver and excreted in the urine and bile. Duration of neuromuscular blockade may therefore be prolonged in patients with either renal or hepatic disease. The choice of which NDNMB to use in any given situation depends primarily on individual physician preference and comfort. However, caution should be exercised when using the longer acting NDNMBs if a difficult airway and/or difficult intubation is anticipated—these drugs should not be given to children who may be difficult to ventilate with bag-valve-mask ventilation.

Succinylcholine (SCh), the only depolarizing NMB currently available for clinical use, was introduced into clinical practice in 1951. Succinylcholine consists of two acetylcholine molecules joined together. Succinylcholine binds to the ACh receptor (AChR) and produces initial depolarization and muscle contraction, which is observed clinically as fasciculations. However, the AChR remains in an inactive state and muscle relaxation occurs (phase I block). Neuromuscular blockade persists until SCh is hydrolyzed to succinate and choline by plasma pseudocholinesterase, which occurs much more slowly than the breakdown of ACh by true AChE. Further exposure of the neuromuscular junction to SCh may result in a prolonged state of muscle relaxation that cannot be reliably reversed pharmacologically (phase II block). The duration of blockade may also be increased if there is a decrease in endogenous pseudocholinesterase (e.g., familial pseudocholinesterase deficiency, hepatic disease). Succinylcholine has numerous side effects that have limited its use in routine clinical settings (Table 24.9). In addition to the receptors localized to the neuromuscular junction, SCh will also occupy other nicotinic, cholinergic receptors located throughout the body. For example, administration of SCh to infants may produce vagally mediated bradycardia, and for this reason most clinicians will administer atropine before SCh in this patient population. Succinylcholine also produces initial contraction of the extraocular muscles, which may lead to increased intraocular pressure. Similarly, SCh may also produce increased ICP. Many physicians recommend the use of a defasciculating dose, or one-tenth of the intubation dose of an NDNMB such as vecuronium before administering SCh [86,96–98,125,126]. Theoretically, the use of a defasciculating dose prevents the muscle soreness and pain, as well as the increase in intracranial, intra gastric, and intraocular pressure following administration of SCh. However, the available evidence that such a protocol improves outcome is limited [162].

### Oral Tracheal Intubation

Oxygen should be administered to all critically ill and/or injured children in the highest possible concentration and regardless of the measured oxygen saturation until an initial assessment of cardiorespiratory status is completed. Breathing 100% oxygen for 2–3 min creates a nitrogen washout that will fill ventilated alveoli with oxygen, and under most conditions an alveolar oxygen tension of 663 mm Hg yields an adequate reservoir to provide sufficient oxygen delivery following the onset of apnea that occurs following sedation and neuromuscular blockade [163,164]. This oxygen reservoir theoretically permits adequate oxygenation of blood circulating through the pulmonary blood vessels for up to 3 or 4 minutes following the onset of apnea [165]. However, infants and young children, in particular, have a high metabolic rate or oxygen consumption (7 mL/kg/min in children compared with 3 mL/kg/min in adults) [163,165] and will develop hypoxia faster than adults. Once this oxygen reservoir is used up, arterial oxygen saturation will decrease precipitously after the onset of apnea.

Heart rate, blood pressure, and oxygen saturation should be monitored continuously during attempts at tracheal intubation, as mechanical stimulation of the airway may induce bradycardia-bradypnea, particularly in neonates and infants (see above). If either hypoxemia or bradycardia occurs, tracheal intubation should be interrupted and the child should be ventilated at FIO\(_2\) 1.00 via

### Table 24.9. Succinylcholine, its side effects and relative contraindications.

<table>
<thead>
<tr>
<th>Side effect</th>
<th>Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle soreness/pain</td>
<td>Fasciculations caused by initial depolarization of the NMJ (may be prevented with the use of a defasciculating dose, typically one-tenth dose of an NDNMB, e.g., 0.01 mg/kg vecuronium)</td>
</tr>
<tr>
<td>Hyperkalemia</td>
<td>Succinylcholine will typically raise serum K(^+) 0.5–1 mEq/L because of initial depolarization of the NMJ (serious and life-threatening hyperkalemia may occur with renal failure or when extravascular acetylcholine receptor are upregulated (crush injury, burns, disuse atrophy, muscular dystrophy))</td>
</tr>
<tr>
<td>Malignant hyperthermia (syndrome characterized by unrelenting muscle rigidity, hyperthermia, hypercapnia, and metabolic acidosis)</td>
<td>Mechanism not completely understood Contrediscovered for patients with family history of malignant hypertension</td>
</tr>
<tr>
<td>Increased intraocular pressure</td>
<td>Contraction of extraocular muscles during initial depolarization of NMJ (may be prevented with &quot;defasciculating dose&quot;)</td>
</tr>
<tr>
<td>Increased intracranial pressure</td>
<td>Fasciculations and muscle rigidity (may be prevented with &quot;defasciculating dose&quot;) Use with caution in patients with head injury</td>
</tr>
<tr>
<td>Increased intra gastric pressure</td>
<td>Contraction of abdominal muscles (may be prevented with &quot;defasciculating dose&quot;) Use with caution in patients with full stomach (increased risk of aspiration)</td>
</tr>
<tr>
<td>Prolonged neuromuscular blockade</td>
<td>Plasma pseudocholinesterase deficiency (liver disease, pregnancy, h/o oral contraceptive use, familial pseudocholinesterase deficiency)</td>
</tr>
</tbody>
</table>

Note: NDNMB, nondepolarizing neuromuscular blocker; NMJ, neuromuscular junction.
bag-valve-mask ventilation. Immediately before laryngoscopy, the child is positioned (sniff position as described earlier, with manual cervical spine stabilization if cervical spine injury is suspected) (Figure 24.14), and preinduction medications are administered, as clinically indicated. Once all preparations have been made, the appropriate induction agents and NMB are administered. The laryngoscope is held in the left hand, and the blade is inserted into the right side of the mouth following the natural contour of the pharynx to the base of the tongue (Figure 24.15).

Control of the tongue is achieved by sweeping the proximal end of the blade to the midline, thereby moving the tongue toward the middle of the mouth, providing a channel along the right side of the mouth for visualization of the airway and passage of the tracheal tube. The tip of a curved blade is inserted into the vallecula, thereby lifting the epiglottis and visualizing the glottis by valvelcular suspension. In contrast, the tip of a straight blade is used to lift the epiglottis directly in order to visualize the glottis (Figure 24.16). Once the blade is positioned correctly, traction is exerted in the direction of the long axis of the laryngoscope handle—the laryngoscope blade must not be used as a lever, and the teeth/gums are not to be used as the fulcrum! It is frequently helpful to have a second provider place a slight amount of traction on the corner of the mouth to enable better visualization of the airway. The BURP maneuver [48,49] may be used to further facilitate visualization of the glottic opening (see Figure 24.13). However, the BURP maneuver may worsen visualization of the glottic opening when used in


24. Management of the Pediatric Airway

Conjunction with cricoid pressure [166]. Alternatively, a laryngeal lift [167] or mandibular advancement [168] maneuver can be performed to better visualize the glottic opening. The utility of cricoid pressure has recently been questioned, as undue or improperly applied force may cause complete loss of adequate visualization of the glottis [169–171]. The tracheal tube is inserted from the right corner of the mouth and not down the barrel of the laryngoscope blade. The tracheal tube is then passed through the vocal cords under direct visualization. The black glottic marker of the tube is placed at the level of the vocal cords. Alternatively, when a cuffed tracheal tube is used, the cuff is placed just below the vocal cords. The depth of insertion of the tracheal tube is also commonly estimated either by multiplying the inside diameter of the tube by 3 or by using the following formula:

\[
\text{Depth of insertion} = \frac{\text{Age (y)}}{2} + 12
\]

Immediately following tracheal intubation, the correct position of the tracheal tube is confirmed by observation for symmetric chest movements, auscultation of equal breath sounds over each axilla and not over the abdomen, and documentation of end-tidal CO₂ [172–174]. Capnometry/capnography is the most reliable and most valid way to confirm tracheal intubation [172] and is now widely viewed as the standard of care. A chest radiograph should be obtained to document proper position with the distal tip of the tracheal tube above the carina in the midtrachea (Figure 24.17).

**Nasal Tracheal Intubation**

Under the vast majority of circumstances, oral tracheal intubation is preferred for emergency management of the airway. However,
nasotracheal intubation is generally more comfortable for semi-conscious children, causes less stimulation of the gag reflex, and is more easily secured, especially in children with copious oral secretions or saliva. In addition, oral tracheal tubes are more easily kinked or bitten. Nasotracheal tubes appear to be safe for use in neonates, infants, and children [175–178], although some studies suggest an increased risk of nosocomial sinusitis and pneumonia associated with nasotracheal intubation [179–181]. Anecdotally, we have found that the use of nasotracheal tubes decreases the risk of unplanned or accidental extubation, which in and of itself may be associated with an increased risk of nosocomial pneumonia [182–185]. The available literature appears to support this contention [186–188]. Nevertheless, nasotracheal intubation is technically more challenging than orotracheal intubation and may be more time consuming. For these reasons, whenever nasotracheal intubation is preferred in a critically ill infant or child, it should generally follow orotracheal intubation in order to facilitate adequate oxygenation and ventilation until a nasotracheal airway is established. The nasotracheal route is contraindicated in the presence of a coagulopathy, maxillofacial trauma, and basilar skull fractures.

A topical vasoconstricting agent such as 0.25% phenylephrine or 0.05% oxymetazoline may minimize the risk of bleeding. The nare is anesthetized and lubricated with lidocaine jelly, and a tracheal tube the same diameter as the oral tube is gently passed through the nare and advanced along the floor of the nasal cavity into the nasopharynx. The oral tracheal tube is placed in the left-hand corner of the mouth while an assistant continues applying positive pressure ventilation. The oral and nasal tracheal tubes are visualized with the laryngoscope; the orotracheal tube may need to be moved away from the nasotracheal tube using the Magill forceps. The tip of the nasotracheal tube is grasped with the Magill forceps and positioned directly above the cords, anterior to the orotracheal tube. As the assistant removes the orotracheal tube, the nasotracheal tube is gently advanced through the vocal cords; the Magill forceps should not be used to advance the tracheal tube through the vocal cords, as this may cause trauma to the glottis. Several methods of estimating the depth of insertion of nasotracheal tubes have been described [189–191], although the following formula [190] works well for children up to 4 years of age:

\[
\text{Depth of insertion (in cm)} = 10.5 + \left(\frac{\text{weight, in kg}}{2}\right)
\]

Complications of nasotracheal intubation include bleeding, adenoid injury, sinusitis, and trauma to the nasal turbinates, nasal septum, or nares (e.g., pressure necrosis) [177,192].

**Rapid Sequence Intubation**

Unlike elective tracheal intubation performed in the operating room suite, critically ill or injured children should be assumed to have a full stomach and are at risk for regurgitation and aspiration of gastric contents. Trauma, pain, anxiety, and critical illness all reduce gastric emptying, such that regardless of when the child last ate, he or she is still considered to have a full stomach. Rapid sequence intubation (RSI) should be performed to decrease the risk of aspiration in these situations. The keys to successful RSI can be easily recalled by the six Ps: Preparation, Preoxygenation, Premedication, Paralysis, Passage of the tracheal tube, and Postintubation care [126]. Preparation is paramount to a smooth, safe, and successful tracheal intubation. If possible, an AMPLE (Allergies, Medications, Past medical history, Last meal, Existing circumstances) history is obtained. A directed physical examination should be performed, with particular attention to the anatomy of the upper airway. All the necessary medications and equipment are assembled at the child’s bedside (see earlier).

Preoxygenation or nitrogen washout is performed by the administration of 100% oxygen via a tight-fitting face mask without positive pressure ventilation. Preoxygenation creates a reservoir of oxygen in the lung that limits hypoxemia during subsequent attempts at tracheal intubation (see earlier). Premedication consists of the administration of both premedication (e.g., lidocaine, atropine) and induction agents, and the combination of medications should be tailored specifically to the clinical circumstance (see Table 24.7). Sellick’s maneuver (cricoid pressure) is employed immediately before sedation and neuromuscular blockade in order to compress the upper esophagus between the cricoid cartilage and the cervical vertebral column and should be maintained until proper placement of the tracheal tube is confirmed [193]. Sellick’s maneuver prevents the passive regurgitation of gastric contents [194–196], although excessive cricoid pressure may worsen airway obstruction or interfere with visualization of the glottis during laryngoscopy [reviewed in 125].

A rapid-acting, short-duration NMB is administered next. Succinylcholine provides safe and effective neuromuscular blockade for the majority of patients, although rocuronium or high-dose vecuronium (0.25–0.3 mg/kg) is an acceptable alternative if there are contraindications or concerns regarding the use of succinylcholine. Pretreatment with a defasciculating dose of an NDNMB may prevent the muscle fasciculations (and the subsequent pain and soreness that result) associated with succinylcholine, although the available evidence is limited [85,162,197–200]. Typically, one-tenth of the normal dose of an NDNMB is administered 1–3 min before administering succinylcholine, although the available evidence is limited [85,162,197–200]. Typically, one-tenth of the normal dose of succinylcholine (e.g., vecuronium, one-tenth of 0.1 mg/kg/dose = 0.01 mg/kg defasciculating dose). Priming, on the other hand, entails the administration of a smaller dose (again, typically one-tenth the normal dose) of an NDNMB administered 3–5 min before the full dose of the same NDNMB. Priming is thought to shorten the time of onset of neuromuscular blockade, although again evidence suggesting any real clinical benefits or improvements in outcome is limited.

Once the child is relaxed, laryngoscopy and intubation are performed (see earlier). If laryngoscopy is not immediately successful and the child’s oxygen saturation begins to fall, assisted ventilation is administered via bag-valve-mask ventilation with cricoid pressure. Tracheal intubation is confirmed by direct visualization of the tracheal tube passing through the glottis, auscultation of the chest and abdomen (breath sounds auscultated in both axilla and not the epigastric area), and detection of end-tidal CO₂. A chest radiograph is the final method of verification of proper placement of the tracheal tube and should be obtained with the head and neck in the midline, neutral position (Figure 24.17). Flexion and extension of the neck moves the tracheal tube toward the carina (flexion, chin moves down) and away from the carina (extension, chin moves up), respectively [201,202]. After proper placement of the tracheal tube is verified, a long-acting sedative should be administered.

The importance of RSI should be emphasized. Rapid sequence intubation, when performed properly, provides superior, safer intu-
bating conditions compared with either nasotracheal or oral tracheal intubation performed with sedation alone [98,100]. However, RSI is not necessary and provides no additional advantages for children with cardiopulmonary arrest. Finally, RSI should be performed with caution, if at all, in children who are dependent on their own upper airway musculature to maintain adequate airway patency. In these cases, neuromuscular blockade may impair the ability to visualize the airway during laryngoscopy, and, more important, it may impair or even preclude the ability to provide adequate oxygenation and ventilation with bag-valve-mask ventilation.

Complications of Tracheal Intubation

Complications following tracheal intubation are variable. Excluding failed tracheal intubation, right main bronchial intubation, and esophageal intubation, immediate complications include hemodynamic derangements in response to laryngoscopy (described earlier), such as bradycardia, dysrhythmias, and hypertension, as well as hypoxia, aspiration, subluxation of the cervical spine (especially in children with either a congenital deformity of the cervical spine or traumatic injury to the cervical spine), loss of teeth, injury to the lips and gingivae, and injury to the airway.

Positive pressure ventilation, especially application of positive end-expiratory pressure (PEEP), often improves gas exchange by opposing the forces causing airway collapse. Postobstructive pulmonary edema (POPE) frequently occurs following the relief of upper airway obstruction [203–212]. Postobstructive pulmonary edema, also known as negative pressure pulmonary edema, is believed to result from the excessive negative pressures required to inhale against an upper airway obstruction, resulting in increased venous return, increased right ventricular preload, and increased pulmonary blood volume. In addition, the negative intrathoracic pressure during inspiration leads to increased left ventricular afterload. These factors tend to favor the development of pulmonary edema [206,207,210,211]. Although frequently asymptomatic, POPE may cause hypoxia, increased work of breathing, and shortness of breath. Treatment, although rarely required, includes administration of supplemental oxygen, positive pressure ventilation, and diuretics. Once the child is initially stabilized, further management depends upon the degree of obstruction and the etiology. The child should be admitted to the PICU where constant supervision and airway intervention can take place immediately, if required [210,212].

Most late complications of tracheal intubation (e.g., postextubation stridor and, in rare instances, acquired subglottic stenosis) occur because of incorrect tracheal tube size [213,214], traumatic or multiple intubations [215], and inadequate sedation/analgesia resulting in excessive up and down movement of the tracheal tube [213,216–218]. The air-leak test is a poor predictor of extubation success, although it may predict the presence of postextubation stridor with some degree of accuracy [219,220]. The use of corticosteroids in the prevention and/or treatment of postextubation stridor is advocated by many pediatric intensivists, although there is very little evidence to support the universal use of corticosteroids at this time [220]. The most serious late complication of tracheal intubation is acquired subglottic stenosis, although several studies support the safety of tracheal intubation (rather than early tracheotomy) for children requiring long-term ventilatory support because of burns, botulism, acute lung disease, and prematurity [221–223].

Tracheal Extubation

A trial of extubation is appropriate when the conditions that resulted in tracheal intubation are no longer present. However, extubation failure is associated with significant morbidity, including an increased incidence of ventilator-associated pneumonia [224], an increased length of stay in both the ICU and hospital [224,225], and an increased risk of mortality [224–226]. Specific, concrete guidelines and objective criteria regarding when to attempt tracheal extubation are lacking, and, unfortunately, adult weaning indices based on direct measurements of pulmonary function have been applied to children with only varied success [227–236]. General recommendations include (1) reversal of the disease process that prompted tracheal intubation (e.g., resolution of hypoxemic respiratory failure, improvement in mental status); (2) presence of an intact cough and gag reflex (i.e., ability to maintain and protect the airway); (3) acceptable oxygenation and ventilation on minimal mechanical ventilatory support; (4) appropriate neurologic status (generally, either a Glasgow Coma Score >8 or spontaneous eye opening and the ability to follow simple commands); and (5) hemodynamic stability. Additional criteria that are commonly listed, although infrequently used in the clinical setting, include a negative inspiratory force (NIF) of 25–50 cm H₂O and a forced vital capacity of 15 mL/kg [51]. In children who were tracheally intubated secondary to upper airway obstruction, the presence of an audible leak around the tracheal tube is also a criterion for extubation. Finally, adequate reversal of neuromuscular blockade must be present—adequate reversal is generally assumed by the ability to sustain a head lift or, in an infant, a leg lift. Although the use of pharmacologic agents to reverse either sedation or neuromuscular blockade may be occasionally necessary (Table 24.10), reliance on these medications to make a child ready for extubation is fraught with danger and should be summarily avoided.

It is a common practice to hold nasogastric feedings for 4–6 hours before an attempt at extubation, although a recent study showed that continuous transpyloric feeding during tracheal extubation was safe and improved the delivery of more optimal nutrition [237]. Sedation during weaning from mechanical ventilation toward extubation may be difficult. For example, the need for continued sedation to prevent an uncontrolled or accidental extubation often conflicts with the desire to decrease sedation to the point where a child is awake enough to attempt extubation. Anecdotally, we and others have found that the use of a short-acting agent such as propofol or dexmedetomidine facilitates opioid or benzodiazepine withdrawal during the perextubation period (Wheeler,

| Table 24.10: Reversal agents. |
|---|---|---|
| Agent | Dose | Onset | Duration |
| Neostigmine | 0.025–0.1 mg/kg IV | 3–5 min | 1–2 hr |
| Pyridostigmine | 0.1–0.25 mg/kg IV | 3–5 min | 2–3 hr |

Note: These agents should be administered either in conjunction with (neostigmine) or after (pyridostigmine) atropine, 0.01–0.02 mg/kg IV (minimum dose of 0.1 mg), or glycopyrrolate, 3–5 μg/kg IV.
The Difficult Airway

The Difficult Airway Algorithm

The American Society of Anesthesiology (ASA) Task Force on Management of the Difficult Airway published Practice Guidelines for Management of the Difficult Airway in 1993 [35]. These guidelines were revised to incorporate the laryngeal mask airway (see later) in 2003 [242] and should be familiar to pediatric anesthesiologists, emergency medicine physicians, and intensivists alike. These guidelines were developed specifically for use in the operating room suite and may not necessarily apply directly to the practice of pediatric intensive care. However, the guidelines serve as a framework for management of the difficult airway in the intensive care setting (Figure 24.18). It is important to note that an otolaryngologist or pediatric surgeon should be available at the bedside whenever a difficult airway is encountered should the need for an emergency surgical airway arise. Pediatric intensivists must optimize their first attempt at tracheal intubation but should be facile with at least one alternative device for securing the airway. Several alternatives to laryngoscopy exist, although their use in the PICU has not been adequately studied. The following specialized techniques are available when the situation calls for their use.

Laryngeal Mask Airways

The British anesthesiologist Archie Brain designed the first laryngeal mask airway (LMA™, LMA North America, San Diego, CA) in 1988, and since that time the LMA has had a profound impact on management of the difficult airway. The original purpose of the LMA, however, was more or less to serve as an intermediately invasive, artificial airway, bridging the gap between the use of bag-valve-mask ventilation and tracheal intubation [243]. Regardless of its original intended use, the LMA is now considered a primary option for the management of the difficult and failed airway [242,244,245]. The LMA consists of a semirigid tube and an inflatable mask that is designed to be placed into the hypopharynx and advanced over the glottic opening (Figure 24.19A). When fully inflated, the mask cuff provides a tight seal around the glottic opening, thereby providing a conduit into the airway (Figure 24.19B). The LMA is available in both pediatric and adult sizes (Table 24.11) and provides more effective ventilation than bag-valve-mask ventilation alone, as bag-valve-mask ventilation frequently requires two hands to maintain an adequate mask seal around the face [246].

Successful placement of the LMA (Figure 24.20) is unaffected by Mallampati score, Cormack score, or the presence of either manual inline cervical spine stabilization or a rigid cervical collar [247–250]. Laryngeal mask airways have even been placed successfully in patients in the prone position [251–253]. The LMA is not designed to prevent aspiration of gastric contents and therefore should not
be used for elective, nonemergent management of the airway in children with either a full stomach or decreased gastric emptying. Another relative contraindication for the LMA is the need for high pulmonary inflation pressures caused by poor lung compliance or increased airways resistance. Finally, the LMA can be used as a conduit for passing a tracheal tube with the use of a flexible bronchoscope (see later) [12,13,254–258]. An intubating LMA (LMA-FastrachTM, LMA North America) is available for use in children >30kg and in adults. The intubating LMA is reviewed elsewhere [259].

**Fiberoptic Laryngoscopy and Tracheal Intubation**

The use of fiberoptic laryngoscopy and fiberoptic tracheal intubation was historically limited by the lack of fiberoptic bronchoscopes appropriately sized for use in children. However, this hindrance
FIGURE 24.20. Placement of the LMA\textsuperscript{TM}. (A) The LMA\textsuperscript{TM} airway is held tightly like a pen with the index finger at the cuff–tube junction. In order to position the LMA\textsuperscript{TM} airway correctly, the cuff tip must avoid entering the valleculae or the glottic opening and must not become caught up against the epiglottis or the arytenoids. (B) Under direct visualization, the LMA\textsuperscript{TM} is inserted into the mouth, and the tip of the cuff is pressed upward against the hard palate. The cuff must be deflated in the correct wedge shape and should be kept pressed against the patient's posterior pharyngeal wall. To avoid contact with anterior structures during insertion, the inserting finger must press the tube upward (cranially) throughout the insertion maneuver. (C) As the index finger passes further into the mouth, the finger joint begins to extend. The jaw should not be held widely open during this movement as this may allow the tongue and epiglottis to drop downward, blocking passage of the mask. (D) Using the index finger, the mask is pressed backward toward the other hand, which exerts counterpressure, although excessive force should not be used. (E) The LMA\textsuperscript{TM} is advanced into the hypopharynx until a definite resistance is felt. Depending on patient size, the finger may be inserted to its fullest extent into the oral cavity before resistance is encoun-
tered. (F) Before removing the index finger, the nondominant hand is brought from behind the patient's head to press down on the airway tube. This prevents the LMA\textsuperscript{TM} airway from being pulled out of place when the finger is removed. It also permits completion of insertion in the event that this has not been achieved by the index finger alone. At this point the LMA airway should be correctly located with its tip firmly pressed up against the upper esophageal sphincter. (G) After insertion, the tubes should emerge from the mouth directed caudally. The cuff is inflated with just enough air to achieve an intracuff pressure of 60 cm H\textsubscript{2}O. Note that the cuff inflation volume listed in Table 24.11 (as well as directly on the airway tube itself) is the maximum clinical inflation volumes and should not automatically be considered the recommended inflation volumes. Frequently, only half the maximum volumes are sufficient to obtain a seal and/or achieve 60 cm H\textsubscript{2}O intracuff pressure. The cuff should never be overinflated, and intracuff pressures greater than 60 cm H\textsubscript{2}O should be avoided. (Reprinted with permission from LMA\textsuperscript{TM} Airway Instruction Manual. San Diego, CA: LMA North America; 2005.)
has been dramatically improved with introduction of smaller fiberoptic bronchoscopes. The thinnest fiberoptic bronchoscopes with flexible angle are 2.2 mm, although these do not have a suction port (Olympus BF-N20, Olympus Corp.; and Machida ENT-30 F III, Machida Endoscopy Co., Ltd.). The 1.4-mm multipurpose fiberoptic bronchoscope may also be a choice for tracheal intubation in special cases (e.g., intubating an infant with a 2.5-mm i.d. tracheal tube). Fiberoptic intubation can be performed either awake or with sedation, the latter being preferred for infants and young children because of a lack of cooperation. Topical anesthesia assists in blunting the afferent response associated with instrumentation. It should be stressed that fiberoptic bronchoscopic intubation in the hands of inexperienced personnel is potentially hazardous. However, we strongly feel that pediatric intensivists should be facile with the use of the fiberoptic bronchoscope for tracheal intubation.

**Light Wand or Lighted Styles**

A light wand consists of a handle containing a switch and a battery, connected by a flexible tube to a distal light bulb. Several devices are currently available. The lighted stylet or wand is lubricated and positioned within a standard tracheal tube (with the light bulb at the distal end of the tracheal tube). The tracheal tube is then placed blindly into the back of the mouth at the midline and slowly advanced until the light is visualized at the thyroid prominence. The tracheal tube is then advanced until the light disappears just below the sternal notch and the stylet or wand is removed. Proper placement of the tracheal tube within the trachea is then verified via standard means (see above). This technique requires training and is no longer a popular alternative for management of the difficult airway. In addition, a tutorial on the use of the light wand (as well as many of the other devices listed here) may be found at www.simanest.org.

**Bullard Laryngoscope**

The Bullard Laryngoscope® (Circon ACMI Corp, Southborough, MA) is a rigid fiberoptic laryngoscope designed to be used when a conventional laryngoscope may be difficult. The Bullard Laryngoscope aids with visualization of the glottic opening even when there is an inability to align the oral, pharyngeal, and laryngeal axes, and, compared with conventional direct laryngoscopy, the Bullard Laryngoscope only requires minimal head manipulation and positioning. The Bullard Laryngoscope is available in both pediatric and adult sizes and should be a part of every difficult airway cart.

**Combitube®**

The Combitube® (Kendall-Sheridan Catheter Corp, Argyle, NY) is a blindly inserted, double-lumen tube designed specifically for management of the airway during cardiopulmonary resuscitation and represents a vast improvement from its early predecessor, the esophageal obturator airway. The Combitube is inserted blindly into either the trachea or esophagus and is designed specifically for use by individuals who are unskilled in airway management. For this reason, the Combitube is frequently used in the prehospital setting. The main drawback to the Combitube is that it is not currently available in sizes appropriate for children.

**Gum Elastic Bougie**

The gum elastic bougie consists of a semirigid, yet malleable device designed to facilitate tracheal intubation when visualization of the glottis is poor or impossible. The bougie is placed while visualizing the epiglottis via standard laryngoscopy and is used more or less as an introducer for subsequent placement of the tracheal tube. The smallest tracheal tube that the standard bougie can accommodate, however, is a 6.0-mm tube, thereby limiting its use to adolescents and adults.

**Retrograde Tracheal Intubation**

Retrograde tracheal intubation is an invasive technique that involves the percutaneous passage of either a wire or an epidural catheter cephalad through the cricothyroid membrane. A tracheal tube is then advanced into the trachea over the guidewire and the guidewire is removed through the proximal end of the tracheal tube. Retrograde intubation has been a popular technique in the past [260]; however, with the advent of thin fiberoptic bronchoscopes, it is now infrequently used.

**Airway Exchange Catheters**

Airway exchange catheters (e.g., the Cook airway exchange catheter, Cook, Bloomington, IN) are occasionally used in the critical care setting whenever a tracheal tube needs to be changed (up-sized or down-sized) for a patient with a known difficult airway. Several reports have described the use of airway exchange catheters during a trial of extubation in children with known difficult airways who are at risk for a difficult reintubation [261–264], although these devices are by no means foolproof. The use of these devices requires that a tracheal tube is already in place, although they are mentioned here as part of the difficult airway armamentarium.

**Percutaneous Needle Cricothyrotomy**

Needle cricothyrotomy is rarely necessary, although it may facilitate adequate oxygenation and ventilation in children with complete upper airway obstruction caused by a foreign body, severe maxillofacial injuries, or laryngeal fracture (Figure 24.21). Further data are needed on the use of this potentially life-saving, but highly invasive modality in critically ill or injured children.

**Transtracheal Jet Ventilation**

If tracheal intubation or ventilation by any means described above is impossible, the patient requires emergency tracheostomy or transtracheal jet ventilation (TTJV). A large-bore intravenous catheter (14 to 20 gauge, depending on the size of the trachea) should be inserted through the cricothyroid membrane, and the catheter should be connected to a jet ventilator. If a jet ventilator is not available (which may be the case, as these devices are no longer frequently used in the PICU), a high-pressure oxygen source can be used. Intermittent insufflation of high-flow oxygen may be adequate as a temporizing measure because of the potential hazards associated with the jet ventilator if the tip of the catheter is not in the lumen of the trachea (e.g., pneumothorax, pneumomediastinum, subcutaneous emphysema).
FIGURE 24.21. Percutaneous needle cricothyotomy. (A) The head is placed in the midline position with a rolled towel or folded sheet beneath the shoulders. The anterior portion of the neck is cleansed and prepped in a sterile fashion. The trachea is stabilized with the right hand, and the cricothyroid membrane is palpated with the index fingertip of the left hand between the thyroid and cricoid cartilages (this space is very narrow, approximately 1 mm, in infants and only a fingernail will discern it). (B) A small-bore (20 or 22 gauge) needle is used as a finder needle and is introduced while pulling back on the syringe. If air is aspirated, a large-bore cannula (12 or 14 gauge) is inserted via the same technique, directed toward the midline caudally and posteriorly at a 45° angle. Intraluminal placement of the needle is again confirmed when air is aspirated. (C) The needle is slowly withdrawn as the cannula is advanced into the tracheal lumen. The adaptor from a 3.0 mm i.d. tracheal tube is connected to the cannula, and ventilation can then be administered via transtracheal jet ventilation. Alternatively, 100% oxygen can be administered using either a self-inflating bag or an anesthesia bag. (Reprinted from Coté et al. [11]. Copyright 1993 with permission of Elsevier.)

References

24. Management of the Pediatric Airway


92. Levitt MA, Dresden GM. The efficacy of esmolol versus lidocaine to attenuate the hemodynamic response to intubation in isolated head trauma patients. Acad Emerg Med 2001;8:19–24.


122. Davis DP, Kimbro TA, Vilke GM. The use of midazolam for prehospital rapid-sequence intubation may be associated with a dose-related increase in hypotension. Prehosp Emerg Care 2001;5:163–168.


24. Management of the Pediatric Airway


Pediatric Critical Care Medicine
Basic Science and Clinical Evidence
Wheeler, D.S.; Wong, H.R.; Shanley, Th.P. (Eds.)
2007, XXXVIII, 1805 p. 597 illus., 50 illus. in color.,
Hardcover