

## **SPECIAL ARTICLE**

# **An update on airway management in infants and children**

Senthil G. Krishna, MD\*, Joseph D. Tobias, MD\*\*

*\*Departments of Anesthesiology & Pain Medicine, Nationwide Children's Hospital & The Ohio State University, Columbus, Ohio (USA)*

*\*\*Departments of Anesthesiology & Pain Medicine, Nationwide Children's Hospital, & The Ohio State University, Columbus, Ohio; Department of Pediatrics, The Ohio State University, Columbus, Ohio (USA)*

**Correspondence:** Senthil G. Krishna, MD, Department of Anesthesiology & Pain Medicine, Nationwide Children's Hospital, 700 Children's Drive, Columbus, Ohio 43205 (USA); Phone: (614) 722-4200; FAX: (614) 722-4203; E-mail: Senthil.Krishna@Nationwidechildrens.org

## **ABSTRACT**

'Anesthesia is nothing, but airway management' or 'Anesthesia is nothing without airway management', perhaps both are true. Airway anatomy and physiology in infants and small children differs markedly from the adults, and so are the problems associated with it. We have to adopt protocols, methods and techniques, specifically for this population. This special article is an overview of the current trends with a special reference to the future perspective in infant and pediatric airway management.

**Key words:** Airway management; Infant airway management; Pediatric airway management; Airway assessment; Direct laryngoscopy; Indirect laryngoscopy; Flexible fiberoptic bronchoscope; Videolaryngoscopy; Mallampati Score; Genetic syndromes; Airway adjuncts; Difficult airway

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## **INTRODUCTION**

The airway management of infants and children is a key component of pediatric anesthesia and intensive care practice. When compared to adults, the time available for intervention during resuscitation is less in infants and children as they readily desaturate. Regardless of the patient's age, resuscitation efforts will be ineffective unless oxygenation and ventilation can be quickly re-established. In spite of the general assumption that problems may not occur in the experienced and extensively trained hands in pediatric airway management, the literature (e.g. 'Perioperative Cardiac Arrest registry' - POCA) continues to demonstrate otherwise. Respiratory complications are the second most common cause for perioperative cardiac arrest in children and remains a major cause of morbidity and mortality.<sup>1,2</sup> A closed claims analysis spanning 27 years demonstrated that the claims for death or brain damage still accounted for the majority of the cases in the pediatric population, although there was a decrease in this proportion.<sup>2</sup> In the following manuscript, we have discussed the assessment of the pediatric airway and the equipment and airway adjuncts used in clinical practice.

We have also briefly reviewed laryngospasm, pediatric fiberoptic bronchoscopy, an approach to the pediatric "cannot intubate-cannot ventilate" (CICV) scenario, and options available for an recognized difficult airway. Suggestions for the development of a pediatric difficult airway cart are provided.

## **AIRWAY ASSESSMENT IN INFANTS AND CHILDREN**

The airway examination remains an integral part of pediatric preoperative assessment where the goal is to identify or differentiate those patients in whom airway management may be difficult or challenging. Even well trained and experienced anesthesia providers with limited pediatric experience may find the normal airway of younger children or infants challenging as various anatomical differences between the adult and infant can make mask ventilation and endotracheal intubation difficult.<sup>3</sup> While evaluating the pediatric airway, the anesthesia provider should attempt to answer the questions outlined in Table 1. Even during emergency settings, it is important to remember the statement by the American Society of

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Anesthesiologists (ASA) regarding the assessment of the airway: “assessment of the airway should be conducted, whenever feasible, prior to the initiation of anesthetic care and airway management in all patients”.<sup>1</sup>

**Table 1: Airway evaluation: Questions to consider during the preoperative period**

1. Can ventilation be maintained with a bag-valve-mask device?
2. Will an oral or nasal airway be needed to maintain and/or improve bag-valve-mask ventilation?
3. What if I fail to achieve ventilation with bag-valve-mask?
  - a. Can a supraglottic device be placed
  - b. Can direct laryngoscopy be performed?
  - c. Can endotracheal tube be placed into the trachea?
  - d. If needed is there adequate access to the neck and trachea for surgical airway?

Although a high percentage of difficult airways are encountered in patients with specific clinical syndromes, issues can also arise with the apparently normal looking child. A quick assessment of the airway is mandatory in any child to evaluate the feasibility of endotracheal intubation and identify the characteristics that may indicate the presence of a difficult airway. Unfortunately no screening test, or even a compilation of tests, has the needed specificity and sensitivity to be universally applicable and many of the suggested tools for airway evaluation have only been validated in the adult population. However, many of the potential difficult airways in the pediatrics can be identified with a systematic and thorough preoperative assessment.

Airway assessment begins with obtaining a relevant history of previous airway management and problems. This is followed by performing a general physical examination focused on the airway (symmetry of face and neck, adequacy of mouth opening, mentohyoid distance, thyromental distance, and adequacy of neck flexion and extension). Limitations in any of these physical features or measurements may indicate a potential airway difficulty. The thyromental distance is particularly important as it will help identify patients with micrognathia, a feature that may commonly impede visualization of the glottis during direct laryngoscopy. In general, the thyromental distance should be 3 finger breadths when measured using the patient's own fingers. The Mallampati score is a commonly used tool to predict the potential for difficult endotracheal intubation (Table 2) in the adult population while the Cormack and Lehane scale is used to describe the laryngoscopic view of (Table 3). The latter should be recorded on the anesthetic record so that future practitioners can be

informed regarding the ease of or any difficulty in direct laryngoscopy and/or endotracheal intubation.

**Table 2: The Mallampati scoring system**

Class	Anatomical features seen
Class 1	Complete visualization of the soft palate, uvula and tonsillar pillars
Class 2	Complete visualization of the soft palate with partial visualization of the uvula and tonsillar pillars
Class 3	Visualization of only the base of the uvula and the soft palate. No visualization of the distal uvula or tonsillar pillars.
Class 4	No visualization of the soft palate, uvula or tonsillar pillars.

**Table 3: Cormack and Lehane scale**

Grade 1	Full view of glottic structures
Grade 2	Only posterior commissure is visible (rest of the glottic structures are invisible)
Grade 3	Only the tip of epiglottis is visible (rest of the glottic structures are invisible)
Grade 4	None of the glottic structures are visible

Risk factors reported in the literature, which are associated with a higher incidence of difficulties with airway management, include age less than 1 year, ASA physical status III and IV, Mallampati Score of III or IV, obesity (BMI  $\geq$  35), and patients undergoing oromaxillofacial surgery, ENT surgery or cardiac surgery.<sup>4,5</sup> Additionally, some specific phenotype features have been shown to be associated with difficult airway management (Table 4). Another unique feature that may suggest problems is abnormalities of the external ear (microtia).<sup>6</sup> In 93 patients with microtia presenting for surgical reconstruction of the ear, there were 12 with bilateral microtia and 81 with unilateral microtia. The incidence of difficulty in laryngeal visualization (Cormack and Lehane grade III or IV view) was 42% (5 out of 12) in the patients with bilateral microtia compared to 2% (2 out of 81) in patients with unilateral microtia. In addition to specific phenotypic features, difficulties with airway management may also be seen with various congenital anomalies and genetic syndromes including Goldenhar syndrome, Treacher Collins syndrome and Pierre-Robin sequence.<sup>3</sup> The various syndromes and their impact on airway management have been nicely reviewed by Butler et al.<sup>7</sup>

In both the adult as well as the pediatric groups, there is a growing population of patients with obstructive sleep apnea (OSA). In the adult population with OSA, it has been reported that airway management including

endotracheal intubation may be problematic.<sup>8</sup> In addition to BMI as a predictor of difficult endotracheal intubation, there may also be a correlation of neck circumference and the difficult airway.<sup>9</sup> In a study of 123 obese adults, difficult laryngoscopy correlated with the ratio of the neck circumference to the thyromental distance (NC/TM).<sup>9</sup> Many of these physical features including body weight have been incorporated into the Wilson risk score which is frequently used in the adult population (Table 5).<sup>10</sup> A total of 3 or more of these physical features predicted 75% of difficult laryngoscopies while 4 or more predicted 90%. Given that no specific test or feature has been shown to have 100% sensitivity and specificity, the current trend in clinical practice is to combine the various scoring systems or physical features in an attempt to improve their predictive value especially in the pediatric-aged patient.<sup>11</sup>

**Table 4: Physical features suggestive of a difficult pediatric airway**

<b>Physical feature/action</b>	<b>Clinical finding predictive of difficult airway</b>
Upper incisor length	Longer - lesser available space for blade and endotracheal tube.
Alignment of incisors	Overriding of maxillary incisors or under riding of mandibular incisors.
Protrusion of mandible	Inability to protrude the mandibular incisors in front of maxillary incisors.
Mouth opening	Distance between upper and lower incisors with full mouth opening - less than two finger breadths*. Mallampatti grade 3 or 4 view.
Palate	Highly arched or narrow in shape.
Submandibular space	Narrow and/or indurated, firm.
Thyromental distance	Decreased - less than 3 finger breadths*.
Length of neck	Shorter.
Neck size	Thicker (increased circumference).
Head and neck range of motion	Limited mobility (flexion, extension, and lateral rotation)

\*For this evaluation in a child, one should use the child's own fingers.

**Table 5: Wilson risk score for predicting difficult endotracheal intubation**

<b>Risk factor</b>	<b>0</b>	<b>1</b>	<b>2</b>
Weight	Less than 90 kilograms	Between 90-110 kilograms	Greater than 110 kilograms
Head and neck movement	Greater than 90 degrees	Approximately 90 degrees	Less than 90 degrees
Jaw movement	Incisor gap greater than 5 centimeters and subluxation greater than 0	Incisor gap less than 5 centimeters and subluxation greater than 0	Incisor gap less than 5 centimeters and subluxation less than 0
Receding mandible	Normal	Moderate	Severe
Buck teeth	Normal	Moderate	Severe

Score of 3 or more predicts 75% of difficult endotracheal intubations while 4 or more predicts 90%.

## EQUIPMENT FOR AIRWAY MANAGEMENT

**PEDIATRIC MASKS:** Several shapes and sizes of pediatric masks are available for bag-valve-mask ventilation (Figure 1).

The main differences in the design are related to the shape of the mask and the type of the sealing rim that is applied to the child's face. A circular mask which has a shorter cranio-caudad diameter (more circular in shape when compared to the conventional mask) is preferred for use in neonates and infants. This helps avoid unintended pressure or trauma to the eyes while maintaining an effective seal around the mouth and nose. The pediatric masks are usually made of a clear material which allows continuous visualization of the patient's face and lips under the mask and rapid identification of secretions or vomitus. A full supply of various sizes and shapes of these masks are a key component of the equipment list needed for airway management in infants and children.

**PEDIATRIC LARYNGOSCOPES:** In children, the shape and size (including the length and breadth) of the laryngoscope blade are important factors in determining the success rate of endotracheal intubation. The curved Macintosh and the straight Miller blades are the most commonly used laryngoscope blades in pediatric anesthesia. Various sizes of the Macintosh and Miller blades are available for use in different age groups (Figure 2). As in adults, the flange of the curved blade displaces the tongue to the left past the midline and displaces the epiglottis indirectly by applying force to the vallecula to expose the glottic aperture.

In pre-term babies, neonates, infants, and small children, the straight blade is generally favored over the curved blade. In these patients, it provides better glottic exposure. It is compact so insertion into the mouth is comparatively easier and it is placed on the laryngeal side of the epiglottis. It thereby enables a direct 'lift' of the relatively larger and floppy epiglottis in these age groups.<sup>12</sup>

There are also several hybrid blades available which combine the desirable features from the curved and straight blades

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such as the Robertshaw or Wis-Hipple blade (Figure 3). These blades incorporate a wide flange and a flat surface which allows one to control and displace the tongue to the side. Many of these blades are also available in 1.5 size which can be invaluable given the variations in sizes and weights of the pediatric patients.

**AIRWAY ADJUNCTS:** Airway adjuncts are tools that are used to help enhance the patency of the airway if there is upper airway obstruction during mask ventilation (e.g. oral airway, nasal airway). They should only be used as needed and not as a routine, as with improper placement or use complications can occur. In many cases, upper airway obstruction can be cleared with a triple airway maneuver without the need for these adjuncts. An adequate depth of anesthesia is needed prior for placement of an oral airway as laryngospasm or emesis can be induced. Proper lubrication and gentle pressure is mandatory during placement of a nasal airway to avoid epistaxis. If there is a problem in achieving adequate ventilation, the adjuncts should be utilized sooner rather than later. One prime example is a neonate or infant with a relatively large tongue. Relaxation of the genioglossus muscle due to the effects of general anesthesia may result in posterior displacement of the tongue and upper airway obstruction.

The **oral airway** is a rigid C-shaped device. Several sizes and styles are available to cover the entire spectrum of pediatric patients (Figure 4). The oral airway is designed to establish a patent conduit through the oral cavity to posterior pharynx. The appropriate size should be chosen to minimize upper airway trauma. The oral airway can be sized by measuring from the corner of the mouth to the ipsilateral ear lobe (Figure 5). If the oral airway is too small, then it will fail to displace the redundant soft tissue and the obstruction may still be unrelieved. On the other hand, if the oral airway is too large, it may displace the soft tissue structures and tongue posteriorly against the glottis and make the obstruction worse, or it may irritate the glottis.

**Nasal airways** are soft and flexible tubes that are used to improve the patency through the posterior nares and the posterior pharynx. Just like oral airways, several sizes and styles are available for the pediatric patients (Figure 6). Expertly placed nasal airways are better tolerated than oral airways especially in the lighter planes of sedation and anesthesia. In patients with facial/nasal trauma or fractures and in patients with a history of bleeding disorders, the nasal airway should be avoided. Like an oral airway, the appropriate size of the nasal airway has to be chosen. The distance between the tip of the nose and the ear lobe and the size of the patient's little finger can help determine the approximate length and thickness respectively for the nasal airway (Figure 7). An appropriate size should be chosen prior to placement, as too large a diameter can cause trauma to the nasal passages resulting in epistaxis. A nasal airway

that is too long can stimulate the protective airway reflexes, precipitating cough or laryngospasm while a nasal airway that is too small will not relieve the obstruction. Even when an appropriate size is chosen, a nasal airway should never be inserted against resistance (guided practice is needed to learn the 'normal' resistance that one encounters while the nasal airway passes through the posterior nasal aperture) as trauma may result or a false passage may be created. Care should also be taken to ensure that the concavity of the nasal airway is always facing posterior to minimize the chance of intracranial placement through the cribriform plate. Lubrication of the nasal airway is mandatory before insertion into the nostril to avoid trauma to the nares. Topical application of vasoconstrictors to the nasopharynx can help minimize the associated bleeding. A few drops or sprays of topical oxymetazoline can be applied to the nasal mucosa to provide vasoconstriction and limit the chance of epistaxis. Care must be taken when using oxymetazoline with attention to dosing as excessive dosing can result in systemic absorption and hypertension. Alternatively, a vial of phenylephrine (10 mg) can be added to topical lidocaine gel and used to coat the nasal airways.<sup>12</sup> Care must be taken to avoid excessive use of these topical vasoconstrictors to prevent systemic hemodynamic complications.

**LARYNGEAL MASK AIRWAYS:** The laryngeal mask airway (LMA) has gained widespread acceptance in clinical practice including pediatric anesthesiology. Several of these devices and modifications are now available to cover the range of pediatric ages and weights (Table 6, Figure 8). The modifications to the classic LMA include single-use disposable devices, a pilot cuff with color bands to measure the intracuff pressure, removal of the aperture bars to facilitate passage of an endotracheal tube, esophageal sealing cuffs, an esophageal channel to allow passage of a nasogastric tube, gel cuffs, integrated bite blocks and LMAs with varying rigidity and curvature to facilitate easy placement.<sup>13,14</sup> Commonly available pediatric LMA variants and supraglottic airways include the LMA classic, LMA Pro-seal, AES ultraCPV™, air-Q, Portex soft seal, I-gel, and the King LAD® and LTD®.<sup>12</sup> The modifications may offer some advantages in certain situations, but the overall principles of function and placement of these devices has not changed much. The LMA, its modifications, and the other supraglottic devices facilitate ventilation by favorably displacing the soft tissues and the tongue before sealing the periglottic area, thereby effectively "masking" the glottic aperture.<sup>12</sup> Apart from being a stand-alone ventilation device, the LMA can be used in assisting the placement of the endotracheal tube either directly by sliding the ETT blindly through the LMA (Figure 9) or indirectly by loading a bronchoscope with an ETT. For the latter scenario, the bronchoscope is navigated to the glottic aperture and then into the trachea before sliding the endotracheal tube over the bronchoscope through the LMA and then



←  
Figure 1: Different sizes of disposable clear anesthesia masks with form fitting inflatable rims.



Figure 6: Different sizes of nasal airways



Figure 2: Different sizes of straight and curved laryngoscope blades



Figure 7: Guide to choosing the appropriate size of a nasal airway. The distance between the tip of the nose and the ear lobe and the size of the patient's little finger can help determine the approximate length and thickness respectively for the nasal airway.



Figure 3: Hybrid and conventional laryngoscope blades from top to bottom: Macintosh, Miller, Wis-Hipple and Seward



Figure 4: Different sizes of oral airways



Figure 8: Various sizes of laryngeal mask airways.



Figure 5: Guide to choosing the appropriate size of an oral airway. The oral airway can be sized by measuring from the corner of the mouth to the ipsilateral ear lobe.



Figure 9: Intubating LMA



Figure 10: A fiberoptic view of the glottis through the distal end of a laryngeal mask airway.



Figure 14: Forceps can be used to hold the endotracheal tube in place and slide the air-Q LMA out of the mouth and over the endotracheal tube (same technique can be used with any LMA).



Figure 11: Intubation through the air-Q laryngeal mask airway



Figure 15: Endotracheal intubation through the laryngeal mask airway using a microlaryngoscopy tube (MLT). The longer MLT (top) is shown relative to the conventional ETT (middle) and the LMA (bottom).



Figure 12: Indirect laryngoscope - Glidescope®



↑  
Figure 16: Endotracheal intubation using the Bonfils optical stylet.



Figure 13: Indirect laryngoscope - C-MAC®



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Figure 17: Difficult airway cart with various airway adjuncts and instruments, medications and provision for fiberoptic bronchoscopy and indirect laryngoscopy

into the trachea (Figure 10). The latter two techniques may be useful in cases of difficult or failed laryngoscopy. The initial placement of the LMA can be used to restore oxygenation and ventilation while the ETT is placed in a controlled setting. In this scenario, our clinical practice has demonstrated that the air-Q LMA may be advantageous as the shaft is not only larger to accommodate a larger ETT, but also shorter to facilitate removal of the LMA over the ETT. Additionally, the air-Q LMA has a removable 15 mm adaptor which further facilitates placement of the ETT through its shaft (Figure 11).

**Table 6: LMA in pediatric patients – size based on weight**

LMA size	Weight (kilograms)	Cuff inflation (mL)
1	Less than 5	4
1.5	5-10	7
2	10-20	10
2.5	20-30	14
3	30-50	20
4	50-70	30
5	70-100	40

#### INDIRECT LARYNGOSCOPES AND VIDEOLARYNGOSCOPES:

Indirect laryngoscopy is a method which provides visualization of the glottic aperture indirectly without alignment of the oral, pharynx and larynx axis (conventional laryngoscopy is performed under conditions when the above mentioned 3 axis are in the same plane). Hence, indirect laryngoscopic devices are very useful in managing patients with various causes of a difficult airway (e.g. limited mouth opening, micrognathia, and restricted neck movement). In the recent years, a vast number of indirect laryngoscopic devices have been introduced<sup>15-18</sup> with modifications which facilitate their use in pediatric patients.<sup>19</sup> The devices may be reusable or single use devices. The disadvantage of the reusable devices is that the optics tends to be less optimal than reusable scopes. Given their utility in managing the difficult airway and frequently being the first device used when conventional laryngoscopy fails, these devices remain an important part of the armamentarium when approaching the difficult airway. In our practice, we prefer the reusable devices such as the Glidescope® (Figure 12) or the Storz C-Mac® (Figure 13) devices.

**FIBEROPTIC BRONCHOSCOPE:** The flexible fiberoptic bronchoscope was introduced into clinical practice 1966 by Shigeto Ikeda. Since then, fiberoptic technology has improved considerably and the modern fiberoptic bronchoscope is an extremely useful device for managing the difficult airway in adults and children. Its use has decreased with the introduction of indirect videolaryngoscopes. Additionally, it is generally not

effective in the emergent setting or when there is blood in the airway. The device uses flexible light transmitting cables, the remote tip of which can be precisely navigated at the user end using Bowden cables. The focused image at the tip of the scope is fiberoptically transmitted back to the eye piece. Alternatively the image obtained at the eye piece can be projected onto a monitor for teaching purposes or to improve visibility. Most of the bronchoscopes have a provision for suctioning the secretions and also come equipped with a port for the insufflation. However, it should be remembered that only low flows of oxygen should be used as excessive flow with limited egress of the oxygen can lead to barotrauma.

## CLINICAL SCENARIOS

**LARYNGOSPASM:** The most common cause of unexpected inability to ventilate in a pediatric patient during anesthetic induction is laryngospasm.<sup>12</sup> Laryngospasm is primarily a distorted laryngeal reflex.<sup>20</sup> The laryngeal reflex is a primitive protective reflex which prevents aspiration by temporary closure of glottic aperture.<sup>20</sup> Laryngospasm is precipitated when this reflex becomes sustained. Precipitating factors include a light plane of anesthesia, turbulent air flow, airway secretions, aspiration, stimulation and/or instrumentation of the periglottic area or the trachea or the carina. Laryngospasm is also frequently triggered if tracheal extubation is performed in a lighter plane of anesthesia. There seems to be an increased incidence of laryngospasm in children who had recent respiratory tract infections or in those exposed to passive smoke, both of which may lead to chronic irritability of the airway.<sup>21-23</sup>

The clinical signs exhibited depend on the severity of the laryngospasm. In partial laryngospasm, stridor may be heard and it may be possible to maintain gas exchange and ventilation. As the severity of the laryngospasm increases or when glottic closure is complete, there are diminished or absent breath sounds. In patients with complete laryngospasm in the setting of strong spontaneous breathing, paradoxical movement of the chest and abdomen can be seen. Depending on the duration and severity of the laryngospasm, without effective treatment, there can be associated oxygen desaturation and bradycardia which can lead to hemodynamic compromise and cardiac arrest with irreversible neurological injury or death.

During laryngospasm, the interventions required for treatment depend on the severity. Mild cases may require only airway maneuvers to maintain a clear and patent airway. Application of continuous positive airway pressure (CPAP) with administration of 100% oxygen and increasing the depth of anesthesia (preferably by the intravenous route) until the laryngospasm is broken are generally the first maneuvers that are recommended for treatment.<sup>21-25</sup> Doses of propofol suggested for the successful treatment

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in generally include a subhypnotic dose of 0.5-1 mg/kg.<sup>26,27</sup> However, in our practice we believe that a full anesthetic dose (2 mg/kg) may be preferable resulting in a more rapid and effective response. Complete laryngospasm is a true anesthetic emergency and needs to be treated promptly as oxygen desaturation and cardiac compromise may rapidly ensue. A severe episode of laryngospasm mandates a prompt call for help and invariably requires immediate and definitive pharmacologic interventions to prevent irreversible complications. Aggressive intermittent positive pressure ventilation with a bag and mask during severe laryngospasm may distend the stomach rather than the lungs, impair subsequent ventilation, and predispose the patient to regurgitation or vomiting and gastric aspiration. A quick trial of CPAP may be warranted while awaiting help and definitive pharmacological interventions. However, extended or repeated attempts at non-pharmacologic management are not advisable. Failure to quickly establish ventilation warrants the administration of a neuromuscular blocking agent or a full dose of a potent intravenous anesthetic agent (3-4 mg/kg of propofol). However, propofol is not recommended if oxygen desaturation has already begun. Among the neuromuscular blocking agents, succinylcholine is the agent of choice unless there is a specific contraindication to its use. Small doses of succinylcholine (0.1-0.2 mg/kg) are generally effective while providing only a brief period of neuromuscular blockade. Another scenario where the use of small doses is preferable is when laryngospasm occurs following the administration of cholinesterase inhibitors for reversal of neuromuscular blockade. In this scenario, the duration of succinylcholine may be undesirably prolonged due to the inhibited state of pseudocholinesterase if higher doses are used. In patients with a contraindication to the use of succinylcholine, a non-depolarizing neuromuscular blocking agent can be used; however, this will require endotracheal intubation and mechanical ventilation given the duration of action.

During anesthetic induction in children, complete laryngospasm may occur before intravenous access is established. In such cases, succinylcholine (4-5 mg/kg) should be administered intramuscularly. The site of intramuscular administration and the prevailing hemodynamic state determines the onset time of intramuscularly administered succinylcholine. Reports suggest that the onset may be faster when the drug is administered into the deltoid muscle as compared to the quadriceps muscle.<sup>28,29</sup> While others have suggested that the onset is even faster with the administration of succinylcholine into the tongue or submental space, given its high vascularity and rapid absorption even during bradycardia.<sup>28,29</sup> However, if this route is chosen, the drug should be administered away from the midline to avoid the vasculature and the risk of hematoma formation. In clinical

practice, atropine is also usually administered along with succinylcholine, to treat the associated bradycardia which frequently occurs due to hypoxemia. However, the incidence of bradycardia precipitated by succinylcholine seems to be more common following intravenous administration than with the intramuscular route.<sup>30</sup> Epinephrine should be administered and standard pediatric advanced life support algorithms started including chest compressions if profound bradycardia or cardiac arrest occurs. Alternatively, in critical situations without intravenous access, the intraosseous route for the administration of succinylcholine and other vasoactive medications, should be strongly considered if intravenous access cannot be rapidly achieved.<sup>31,32</sup> Although the onset of IM succinylcholine is fairly rapid, studies have shown that the onset time with the intraosseous administration of succinylcholine and other medications as fast as the intravenous route.<sup>32</sup> In patients with a contraindication to succinylcholine, the intraosseous route is highly recommended as it provides a means to achieve a rapid onset with the non-depolarizing agents for the treatment of laryngospasm because the onset following intramuscular administration is not rapid enough to provide laryngeal relaxation prior to profound hypoxemia.<sup>33</sup>

Previously, if ventilation was inadequate, the administration of a neuromuscular blocking agent was thought to be contraindicated. However, this tenet has recently been questioned. In pediatric patients with a presumed normal airway, who develop an unexpected 'cannot ventilate' situation during anesthetic induction, the chances of having an additional 'cannot intubate' scenario is extremely low. This assumption and belief has led to the recent recommendation of a revolutionary idea of the "cannot ventilate then paralyze" paradigm.<sup>34</sup> This recommendation is different from the conventional algorithms of the "cannot ventilate-cannot intubate" scenario that recommends awakening the patient. The rationale for this recommendation is that in an unanticipated "cannot ventilate" situation in a child with normal airway, the most likely cause of the inability to ventilate is functional airway obstruction. Hence, a new treatment algorithm has been suggested that includes first increasing the depth of anesthesia, then paralyzing with a neuromuscular blocking agent, and then finally administering epinephrine or "epinephrinizing" as needed.<sup>34</sup> This algorithm will treat the causes of functional airway obstruction (laryngospasm or bronchospasm) and as well as the resultant bradycardia which may develop related to hypoxemia.

**PEDIATRIC FIBEROPTIC BRONCHOSCOPY:** Management of pediatric patients during fiberoptic bronchoscopy is very different when compared to adults. In adult cases of anticipated difficult airway or unstable C-spine, while using the fiberoptic bronchoscope to secure the airway,



the preferred method is to keep the patients awake and spontaneously breathing. However, it is usually not feasible to keep children alert and cooperative during fiberoptic bronchoscopy. Either deep sedation or general anesthesia is required in most children except in extremely rare instances. During these situations, our preferred technique is to sedate or anesthetize the child slowly without impeding the child's spontaneous ventilation by incrementally increasing the inhaled concentration of sevoflurane. Alternatively, total intravenous anesthesia or deep sedation can be provided by some combination of agents including dexmedetomidine, propofol, ketamine, midazolam and fentanyl. Provisions to maintain oxygenation and sedation at an acceptable level are needed until the fiberoptic bronchoscope has been successfully navigated through the upper airway and into the trachea. Sedation can be achieved through total intravenous anesthetics or inhalational agents administered through the mask with a diaphragm through which the fiberoptic bronchoscope is placed. Alternatively, once an adequate depth of anesthesia has been obtained with sevoflurane, this can be maintained with the patient breathing spontaneously by connecting the anesthesia circuit to an ETT which is placed in one nare and advanced into the posterior nasopharynx above the glottic opening. Alternatively, a nasopharyngeal airway can be placed and the anesthesia circuit attached to it using a 15 mm adaptor from the ETT. A second ETT is then placed in the other nare and the fiberoptic bronchoscope placed through it for endotracheal intubation. With general anesthesia or deep sedation there may be loss of muscle tone in the genioglossus muscle and other upper airway structures which may make fiberoptic bronchoscopy difficult. A tongue blade, laryngoscope or a non-biting forceps may be used to displace the tongue anteriorly to maintain airway patency and keep the tongue away from the fiberoptic bronchoscope. Oxygenation can be maintained by the insufflation of oxygen through the mask or the port of the fiberoptic bronchoscope. However, the insufflation of oxygen through the fiberoptic bronchoscope should be done cautiously using low flows especially if there is any obstruction to exhalation as air trapping and barotrauma may occur. If the patient becomes apneic during deep or general anesthesia sedation then ventilation may have to be assisted with a mask. Alternatively, an LMA can be placed. In addition to providing a mechanism to ventilate the patient, the LMA overcomes the soft tissue obstruction of the upper airway and provides a conduit for the fiberoptic bronchoscope. When positioned correctly, the LMA will displace the tongue anteriorly and the soft tissue of the posterior pharynx caudally providing an unimpeded path through which to navigate the fiberoptic bronchoscope to the glottic aperture (Figure 10).<sup>12</sup> Following endotracheal intubation, the LMA may be removed using one of several techniques or left in place for a short surgical

procedure. The air-Q LMA variant can be removed over the endotracheal tube as it has a larger internal diameter that is wide enough for the endotracheal tube and the pilot balloon (Figure 11). Alternatively, as shown in Figure 14 a forceps can be used to maintain the placement of the endotracheal tube while the LMA is removed. A bougie introduced into the trachea through the endotracheal tube can be also be used to stabilize the ETT in the trachea as the LMA is removed. It also provides a useful conduit for ETT placement if it is inadvertently removed. Extra-long endotracheal tubes, known as MLT or microlaryngoscopy tubes can also be used. The extra length facilitates maintaining the endotracheal tube in place while the LMA is removed (Figure 15).

**THE PEDIATRIC “CANNOT INTUBATE-CANNOT VENTILATE SCENARIO”:** The actual incidence of “cannot intubate-cannot ventilate” (CICV) events in pediatric patients is difficult to estimate. While the unanticipated CICV scenario in an adult is an anesthetic emergency, the same in pediatric anesthesia can be more appropriately termed an anesthetic catastrophe. The younger or smaller the child, lower the chances of a successful outcome. When compared to adults, in children with CICV situations, the time available to establish a surgical airway is much lesser. Hence, the importance of a proper preoperative airway assessment to eliminate unanticipated CICV situations cannot be over-emphasized. The reader is referred to the guidelines that have been published in detail by the Canadian Task Force, the Difficult Airway Society (DAS), and the American Society of Anesthesiologists for managing the CICV scenario.<sup>35-37</sup> We would encourage all anesthesia providers to have a thorough working knowledge of this algorithm and have the needed equipment available in their anesthetizing locations.<sup>35-37</sup> The primary goal during a CICV situation is to maintain oxygenation while preventing airway trauma. The recommended steps generally include, but are not limited to initially calling for help and then ventilating with another mask, reassessing the head and neck position, attempting two person ventilation with one person holding the mask with both hands, using adjuncts including oral and nasal airways, insertion of an LMA, second look direct laryngoscopy and/or changing the choice of laryngoscope handles and blades. It is also recommended that clinical judgment be used in making a decision to awaken the patient rather than attempting repeated laryngoscopies which are likely to increase airway edema and trauma which can convert a “cannot intubate, but can ventilate” scenario to a CICV scenario. If all the other pathways have failed to reestablish ventilation, then adult guidelines recommend a surgical airway using needle cricothyrotomy with transtracheal jet ventilation. A review by Cote et al<sup>38</sup> deals with cricothyrotomy and transtracheal jet ventilation in the pediatric patients, but palpation of the cricothyroid membrane in children can be difficult and placement of a

## pediatric airway update

catheter into the lumen of the pediatric, infant or neonatal trachea may be impossible. Given the risks of jet ventilation such as subcutaneous emphysema, tension pneumothorax, tension mediastinum, and air embolism without a properly positioned catheter, this technique is generally not recommended in this age group.<sup>39</sup> Cricothyrotomy is generally the procedure of choice for emergency surgical airway access in pediatric patients.<sup>40</sup> Given these factors, we would highly recommend that an ear, nose and throat (ENT) surgeon be present when dealing with the known or anticipated difficult airway in children.

Although not currently included in the management of the CICV scenario, we would suggest that if an LMA rescue is unsuccessful, some form of indirect laryngoscopy or video laryngoscopy is an appropriate step prior to a surgical airway. Alternatively, the ENT surgeon may attempt to instrument the airway using the rigid bronchoscope. An ETT can be placed over the rigid bronchoscope and the bronchoscope used as an optical stylet to facilitate placement of the ETT into the trachea. The reasoning behind these recommendations is that establishing an emergency surgical airway is extremely difficult in pediatrics, especially in neonates and infants, and outcomes are extremely poor. Devices such as the Glidescope® and rigid bronchoscope can be made ready for use generally within 60 seconds. More importantly clinicians should familiarize themselves beforehand with these new generation rescue devices in patients with normal airways and in non-emergency situations to limit set-up times during emergency situations. Regardless of the sequence in which these devices are called for and used, the important first step as in adults, should be to call for help from other pediatric anesthesiologists and pediatric ENT surgeons. In the event of persistent failure to reestablish ventilation, the decision to secure a surgical access to the airway should not be delayed. In pediatric patients, the time available for rescue measures as mentioned earlier is extremely limited and the surgical airway interventions are exceedingly difficult. The CICV episodes are unforgiving.

**THE RECOGNIZED DIFFICULT AIRWAY:** If prior history or examination of a child indicates a potential difficult airway (difficult mask ventilation or difficult endotracheal intubation), the airway should be approached after an analysis of the risks involved and the benefits achieved. The following questions may help evolve a plan to approach this scenario:

1. Is the surgery or procedure elective, urgent or emergent?
2. Are any evaluations necessary to further define the airway?
3. Can the airway be optimized before anesthesia or sedation?
4. What will be the level of consciousness of the

child while securing the airway: awake, sedated or anesthetized?

5. Can spontaneous ventilation be maintained during sedation or anesthesia?
6. What is the optimal route of endotracheal intubation: oral versus nasal?
7. What kind of difficult airway equipment is needed?
8. If in trouble what will be the escape route – wake the patient up vs advanced airway procedures?
9. Does the situation mandate an ENT surgeon in the room at the time of anesthetic induction?
10. Is there a need for complex escape procedures like sternotomy or extracorporeal membrane oxygenation (e.g. mediastinal mass)?

Even when a difficult airway is suspected, in the pediatric patient, the airway is usually instrumented after the induction of general anesthesia except in exceptional circumstances. This practice is unlike the adult population where mild sedation may be combined with topical and regional anesthesia of the airway following by awake endotracheal intubation. The approach of providing general anesthesia for a patient with perceived difficult airway should always include the maintenance of spontaneous ventilation until effective-bag-valve mask ventilation can be achieved. Spontaneous ventilation is critical as it ensures oxygenation and ventilation as well as providing the time necessary to evaluate the airway and achieve endotracheal intubation. If spontaneous ventilation can be maintained, then there are several advanced airway techniques that are available to secure the airway. The commonly used approaches are listed below. As with many airway devices, the prior training and comfort level in using a particular device is more important than the search for the ideal device.

1. Indirect laryngoscopy: Several devices are available for clinical use such as Glidescope® (Verathon Inc, Bothwell, WA) or C-MAC (Karl Storz, Tuttlingen, Germany) (Figures 12 and 13).
2. Endotracheal intubation using the fiberoptic bronchoscope as described above.
3. LMA to facilitate endotracheal intubation. Intubating LMA (Figure 11) or endotracheal intubation through the LMA using fiberoptic guidance (Figure 10).
4. Use of an optical stylet. The technique is similar to the one practiced by ENT surgeons while using the rigid bronchoscope. An optical stylet (similar to the rigid bronchoscope) loaded with an ETT is advanced under indirect vision (using a video screen) into the trachea. The ETT is advanced into the trachea and the stylet is removed (Bonfils, Karl Storz, Tuttlingen, Germany) (Figure 16).

In rare circumstances, if awake instrumentation of the airway is the only safe option, then a combination of airway nerve blocks and topical anesthesia can be used

to facilitate the procedure. These techniques are outlined elsewhere<sup>41-43</sup>. Airway nerve blocks may not be feasible in the younger child. The less invasive nebulization of a local anesthetic agent may be the preferred option. A nebulizer similar to the one used for bronchodilators can be utilized to aerosolize lidocaine (2-4%). Given the potential for systemic absorption, the total dose of lidocaine should be limited to 5 mg/kg. An anticholinergic (e.g. glycopyrrolate) administered 30-60 minutes prior to the aerosolization will dry secretions, facilitate contact of the local anesthetic solution with the mucosa, and improve visualization.

### THE EMERGENCY DIFFICULT AIRWAY CART

Despite a robust preoperative assessment and significant clinical experience, pediatric anesthesiologists encounter unanticipated difficult intubations. Proper planning and an organized approach are required to mitigate the complications. In a CICV situation apart from calling for help, the means and methods to oxygenate should be readily available. In order to achieve this goal, a dedicated pediatric difficult airway cart is required for any institution caring for children (Figure 17).<sup>43</sup> There are several different difficult airway trays and carts available in the market. It is generally necessary to organize and tailor difficult airway carts with gadgets, devices and instruments based on the preferences of the practicing clinicians. Typically difficult airway carts are stocked with the following:

1. Airway adjuncts:
  - a. nasal airways
  - b. oral airways
  - c. stylets
  - d. intubating guides
  - e. tube exchangers
  - f. gum elastic bougies
2. Endotracheal tubes: conventional, MLT, armored, uncuffed and cuffed
3. Laryngoscope blades: curved, straight and hybrid
4. Laryngoscope handles: regular and short
5. Laryngeal Mask Airways: Classic, intubating and other hybrids
6. Masks
7. Combitubes
8. Lung isolation devices: bronchial blockers, double

- lumen endotracheal tubes
9. Surgical airway access kits
10. Accessory equipment: Easy Cap ETCO<sub>2</sub> detector, ambu bag, suction catheters, forceps, local anesthetic
11. Fiberoptic bronchoscope
12. Indirect laryngoscope

It is important that anesthesiologists and trainees be familiar with the indications and limitations of these devices. Increased use of simulation to practice such scenarios allows one to have experience with assembling and using these devices. This should greatly facilitate use of these devices during an actual scenario

### SUMMARY AND FUTURE TRENDS

Recently there have been some exciting developments in the field of pediatric airway management. Apart from the devices mentioned in the discussion above, ultrasound can be used to visualize and observe the airway structures and endotracheal intubation in real time.<sup>44,45</sup> This may be particularly useful not only in evaluating the airway, but also in guiding endotracheal intubation in difficult clinical scenarios. Another noteworthy pharmacological development was the introduction of the drug sugammadex, which can rapidly reverse the effects of the non-depolarizing aminosteroid neuromuscular blocking agent, rocuronium.<sup>46,47</sup> Newer techniques and technologies in airway assessment and management will continue to improve the safety of airway management. The role that simulation plays in education of dealing with difficult airway is likely to continue to expand.

The child with a difficult airway presents significant challenges for the anesthesia provider. The management of the pediatric patient with a potential or documented difficult airway begins with the preoperative assessment of the airway, devising a proper plan, and ensuring the ready availability of the equipment needed to intervene. Consultation should be sought from airway specialists including ENT and consideration given to the referral of children to facilities specializing in pediatric care. Even among well trained pediatric anesthesiologists, since seconds matter in a hypoxemic patient, constant training must be maintained with the current devices and techniques in non-emergent settings.<sup>12</sup>

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