# Neonatal Airway Management

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Expertise in neonatal airway management requires an understanding of early human anatomical development as well as a set of clinical skills to provide safe mask ventilation and tracheal intubation in this extremely small-sized population of patients. Since neonatal airway experiences are not a daily occurrence in most anesthesiology training programs, this skill set is acquired only after repeated patient encounters over a prolonged period of time that may span years or decades. In this chapter, we review the foundations upon which management of the neonatal airway is based. The reader should note that these foundations are largely based on our collective experience, which is complemented by case reports and case series that reflect the experience of others as there is a dearth of prospective studies on airway management in the neonate. The chapter is divided into three sections: (1) anatomy and physiology of the neonatal upper airway, (2) techniques for standard neonatal airway management, and (3) techniques for managing the anatomically abnormal neonatal airway.

## Neonatal Upper Airway Anatomy

Management of the neonatal airway is primarily governed by the unique anatomical features of the upper airway at this early age. The occipital portion of the neonatal skull is relatively larger than that of older infants and children (neurocranium-to-face size ratio is 8:1 in neonates, 6:1 in 2-year-olds, and 4:1 in 5-year-olds [1, 2]). This anatomical feature provides a natural state of cervical flexion that facilitates direct laryngoscopy in the supine child [3] but may predispose to upper airway obstruction during spontaneous respiration and mask ventilation [4]. Many neonatal and pediatric textbooks have emphasized the importance of obligate nasal breathing in neonates, as a means to facilitate and coordinate the suck-swallow-breathing mechanism. Although neonates born with congenital choanal atresia occasionally develop life-threatening upper airway obstruction [5], healthy neonates are able to coordinate both mouth and nasal breathing [6].

A major anatomical consideration in the management of the neonatal airway stems from the relatively cephalad position of the larynx (i.e., close proximity of the uvula and epiglottis) that facilitates the swallowing-breathing mechanism in neonates. The larynx descends from the C2–C3 level to C4–C5 level by 3 years of age, increasing the distance between the larynx and other facial structures such as the mandible [7]. The tip of the epiglottis also descends throughout childhood from C2 to C3 [8]. This more cephalad position of the larynx in neonates enables a direct view of the glottic aperture with a straight rather than curved laryngoscope blade.

The high compliance of the neonatal chest wall (due to incomplete ossification of the ribs and weak intercostal muscles) prevents the passive outward recoil that contributes to maintenance of functional residual capacity (FRC) in older children. In contrast, neonates preserve FRC volumes using their laryngeal adductor muscles as expiratory "valves" to restrict exhalation and maintain positive end-expiratory pressure in a process referred to as "laryngeal braking" [9–11].

## Neonatal Upper Airway Reflexes

Neonatal upper airway reflexes protect against inhalation of foreign substances into the lower respiratory tract. Although these reflexes have been studied in both the awake and sedated states, much less is known about their effects at deeper levels of anesthetic-induced unconsciousness.

In children beyond early infancy, mechanisms that protect against the ingestion of foreign materials into the lower

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respiratory tract include swallowing and coughing [12]. Neonates and young infants, however, primarily manifest this protection as central apnea (with bradycardia), upper airway obstruction [13], laryngospasm, and arousal [14]. These laryngeal chemoreflexes mature rapidly during early development [15]. In addition, these adaptive responses are more prominent in direct relationship to a younger gestational age [13, 16–21] and may play a role in the etiology of sudden infant death syndrome (SIDS) [22]. The apneic reflex (with bradycardia) may be prolonged in the presence of sedative or anesthetic agents [23–25], hypoxemia [26, 27], anemia [28], and RSV infection [29, 30]. The administration of central stimulants such as theophylline may abbreviate this reflex [24].

## Neonatal Airway Management

Routine airway management for neonates presents challenges that are not confronted in older children. Neonates usually require emergency surgeries; thus the issues that pertain to the urgent nature of the surgery add to the difficulties and risks. In this section, we consider the unique aspects of neonatal airway management that are encountered during the preanesthetic assessment and preparation and routine airway management techniques.

### Preanesthetic Assessment

Preanesthetic assessment of the neonate includes a thorough review of previous airway management episodes. If tracheal intubation has been performed previously, the involved providers should be queried and the medical records reviewed to clarify any difficulties that were encountered. For all neonates, the underlying diagnoses and conditions should be reviewed with specific attention to the upper and lower airways, since the airway management may have to be tailored accordingly. Some conditions that lack direct airway involvement may indirectly impact on the airway. For example, the neonate with a giant omphalocele may rapidly desaturate during induction of anesthesia due to pulmonary hypoplasia and a reduced FRC. Similarly, neonates with congenital diaphragmatic hernia require special attention to limit the peak inspiratory pressures during induction of anesthesia to prevent intestinal insufflation during mask ventilation and a pneumothorax after tracheal intubation.

Physical examination of the airway should focus on the presence of anatomical abnormalities that may hinder face mask ventilation or direct laryngoscopy. Physical findings such as micrognathia should alert the anesthesiologist to prepare appropriate techniques for a difficult airway. Diagnosing micrognathia in neonates may be tricky; careful examination of the facial profile with the neonate in the neutral position may reveal a mandible that is recessed in relation to the maxilla.

### Preoperative Preparation

All equipment that may be required to manage the airway should be prepared before the infant arrives in the operating room or before anesthesia is induced for procedures in the neonatal intensive care unit. Induction agents and emergency medications (as appropriate) should be prepared in unit doses to reduce drug errors should an urgent intraoperative situation ensue. The functionality of the selected laryngoscope handle and blade together with backup equipment should be verified before induction of anesthesia. A styleted tracheal tube for the anticipated tube size as well as one that is one-half size smaller and larger should be available, as well as appropriately sized oral airways for managing upper airway obstruction. Because of its important role as a ventilation rescue device, a laryngeal mask should also be immediately available. If difficulty with face mask ventilation or tracheal intubation is anticipated, additional equipment (vide infra) and personnel should be available.

## Induction of Anesthesia

### Face Mask Ventilation

The neonate should be positioned supine to facilitate mask ventilation and direct laryngoscopy. The selected mask size and fit should be checked before induction of anesthesia. A properly sized mask covers the nose and mouth without overlying the eyes or extending beyond the chin. Face masks designed to minimize dead space may be advantageous in the neonatal population. The Rendall-Baker face mask has been mostly replaced by the cuffed (cushioned), low-profile face mask, which seals against air leaks around the mouth and nose. After loss of consciousness, upper airway obstruction is relieved primarily by chin lift, which is easily accomplished by placing the body of the left-hand middle finger across the bony portion of the chin, and extending the neck (Fig. 5.1). However, in anesthetized neonates, this maneuver closes the mouth, which may obstruct the upper airway, a problem often incompletely relieved by simply extending the neck. Furthermore, digital pressure is often inadvertently applied to the submental triangle, which may further obstruct the upper airway. An essential maneuver to establish a patent airway in neonates and young infants is temporomandibular joint subluxation, which is accomplished by placing the operator's fifth digit(s) in the retromandibular notch, at the apex of the ascending ramus of the mandible, immediately below the external auditory canal and behind the pinna. The condyles are pulled in an upward direction, toward the frontal hairline (i.e., a full "jaw thrust") [31]. This maneuver anteriorly translocates the jaw as well as rotates the temporomandibular joint, thereby opening the mouth and pulling the tongue off the posterior pharyngeal wall. The face mask is

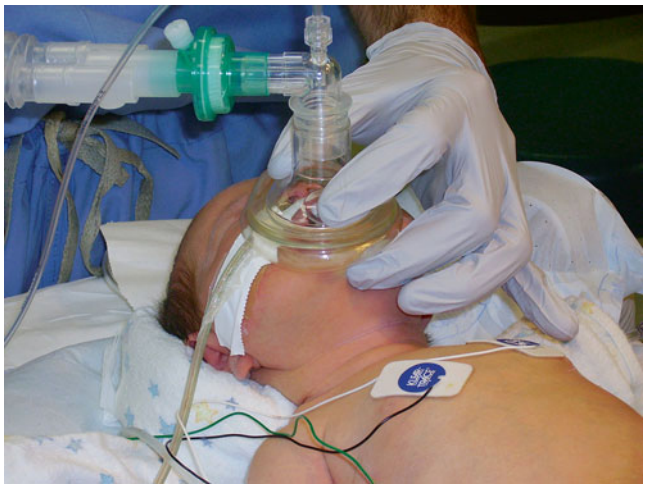

**Fig. 5.1** When mask ventilating a small infant, the middle finger rests on the mandible to provide chin lift without compression of soft tissues in the submental triangle

held on the face using the operator's thumbs. A far less effective "jaw-thrust maneuver" that is widely taught involves applying digital pressure to the angle of the mandible. In this maneuver, the mandible is translocated anteriorly, but the temporomandibular joint does not rotate. This partially relieves the airway obstruction. Given the lack of familiarity with the proper application of the full "jaw thrust," many prefer yet another maneuver, to insert an oral airway device. This latter technique is not uniformly effective as too large an oral airway may push the epiglottis into the glottic opening and too small an airway may push the tongue into the glottic opening. Furthermore, in the neonate with a difficult airway, the oral airway may be more difficult to seat properly. Hence, it is crucial to understand how to optimize the upper airway in the neonate by manipulating the temporomandibular joint rather than relying on oral airways.

In most neonates, effective face mask ventilation can be accomplished at peak inspiratory pressures of <15 cm $H_2O$ and rates of 20–40 breaths per minute. Maintaining positive end-expiratory pressure during ventilation (5–10 cm $H_2O$) promotes alveolar patency and improves gas exchange. Occasionally, an alveolar recruitment maneuver is required (see below).

## Laryngeal Mask Airways and Supraglottic Devices

Although tracheal intubation remains the standard of care for intraoperative airway management in emergency surgery, some practitioners prefer a supraglottic device for elective surgery in neonates [32]. Initial studies and clinical experience with the Classic Laryngeal Mask Airways (LMAs) in neonates demonstrated a greater failure rate during insertion and decreased efficacy with the size 1 LMA compared with larger size airways in older children [33]. This was attributed to a cuff design flaw that failed to account for the unique anatomy of the neonatal airway. However, clinical experience suggests that placing an LMA is no more difficult in this age group than older children, although these small LMAs may be dislodged easily. Therefore, the capnogram must be observed continuously.

LMAs may offer advantages over tracheal intubation during airway resuscitation outside of the operating room because the LMA is simple to insert, requires technical skills that are easily acquired, and is associated with a high success rate, even in the hands of inexperienced operators [34]. Recent studies have demonstrated that the failure rates for tracheal intubation by resident pediatricians in the delivery room is substantial [35–38]. In one study, 87 % of residents reported their level of confidence with tracheal intubation as good or excellent after the completion of residency training, despite their failure to satisfy objective standards for technical competence [38]. Limited evidence to date suggests that the LMA is effective in neonatal resuscitation in infants >34 weeks and possibly comparable to tracheal intubation, although the LMA has not been compared with bag-mask ventilation [39, 40]. It remains to be established whether the LMA or other supraglottic airway should be used for primary airway management in neonatal resuscitation [41]. However, its use has been recommended as a secondary tool in near-term and term neonates who have failed resuscitation with bag-mask ventilation or tracheal intubation [42].

The ProSeal LMA is a laryngeal mask airway with a wider laryngeal bowl and a channel for gastric drain tube insertion. This device is now available in a size 1 and has been studied in neonates and infants weighing 2–5 kg [43, 44]. The initial results suggest that in addition to the 100 % success rate inserting the ProSeal LMA [43, 44], the quality of the initial airway, the effectiveness of the seal, and the maximum tidal volume were significantly better than with the cLMA [43, 44].

Laryngeal tube suction II (LTS II; VBM Medizintechnik, Sulz, Germany) is another supraglottic airway device available in a size suitable for use in neonates. It is inserted blindly in a manner similar to the LMA. The LTS II has an esophageal and a pharyngeal cuff that are interconnected as well as a channel for placement of a gastric drain tube. Ventilation is delivered through multiple holes in the tube that are positioned between these two cuffs. While a case series describing the utility of this device in 10 neonates and infants has been published [32], larger prospective trials evaluating its safety or efficacy in neonates have not yet been conducted.

The LMA can also be utilized as a valuable adjunct for tracheal tube placement in neonates with difficult airways. This is reviewed in the following sections of the chapter.

## Laryngoscopy and Orotracheal Intubation

Indications for tracheal intubation are traditionally determined by the surgical procedure, duration of the surgery, risk of aspiration of gastric contents, and pulmonary function. In anesthetized neonates, airway maintenance with a face mask is less desirable because of the high dead space-to-tidal volume ratio and concerns for the development of atelectasis. As a general rule, tracheal intubation is indicated for open cavity procedures of the abdomen or chest, intracranial procedures, and in cases where control of arterial $PCO_2$ is required. It is also indicated when the anesthesiologist has limited access to the airway during surgeries such as those involving the head and neck and when positions other than supine are required. Tracheal intubation and mechanical ventilation are also useful in neonates to avoid atelectasis that could develop during prolonged anesthesia with spontaneous ventilation.

The "sniffing position" is classically described as the optimal head position to facilitate direct laryngoscopy and tracheal intubation. In adults, a number of recent publications suggested that the sniffing position offers no advantage over simple head extension [45, 46]. In children, there is better alignment of pharyngeal structures with simple neck extension as compared with the "sniffing position." [47] Because of the relatively large occiput, the neonate may naturally be in the sniffing position without active head flexion. The large occiput of the neonate, when placed on a pillow, flexes the head and, in some extreme cases, may contribute to airway obstruction. Comparative trials to determine the optimal position for laryngoscopy and intubation in neonates have not been performed.

Direct laryngoscopy is the most common method of achieving tracheal intubation in neonates. Traditionally, the Miller blade has been favored in this age group because of anatomical considerations including a relatively cephalad larynx and to facilitate alignment of the oral and laryngeal axes [3], although there is no evidence that the straight blade provides either an improved view or easier tracheal intubation than the curved blade in neonates [48–50]. The Miller blade offers greater control and displacement of the base of the tongue, particularly for difficult intubations. The smaller size and reduced profile of the Miller blade (alternatively, the Wisconsin or Wis-Hipple size 0 blade) may also give the operator more room to pass the tracheal tube through the mouth and pharynx into the trachea rather than down the visual path under the blade. When laryngoscopy is performed with a straight blade, the blade is usually inserted into the mouth in the midline after sweeping the tongue to the left. However, when faced with a difficult intubation, this blade is preferably introduced at the right commissure of the lips, not in the midline, an approach known as the paraglossal approach [51, 52]. The blade follows the right alveolar groove until the tip reaches the epiglottis, at which point the epiglottis is lifted exposing the glottis. This approach yields a superior access to the glottis over the midline approach as the angle of the blade and the distance to the larynx are both reduced compared with the same variables that are associated with inserting the blade into the mouth in the midline.

Traditionally, the Miller is advanced to lift the epiglottis to expose the larynx. Some however use this blade in a manner analogous to the curved blade by advancing it into the vallecula to lift the tongue. If the glottis exposure is suboptimal after advancing the laryngoscope and positioning it, the laryngoscopist can externally manipulate the larynx to bring the glottis into view. A small amount of external, posterior pressure with or without lateral displacement often significantly improves laryngeal exposure and facilitates intubation. This practice should be a reflex maneuver for the pediatric anesthesiologist to improve the view of the glottis. In neonates, laryngeal manipulation can be performed using the operator's fifth digit of the left hand (Fig. 5.2).

In select circumstances outside of the obstetric delivery room, tracheal intubation may be performed in unmedicated neonates who might not tolerate the cardiovascular depressant effects of anesthetic or sedative drugs or whose airways are compromised or potentially difficult to secure. However, infants and neonates experience pain, and performing laryngoscopy without sedative premedication or general anesthesia has untoward cardiovascular (and behavioral) effects and should be avoided whenever possible [53–55]. Furthermore, the administration of anesthetic, sedative, and neuromuscular-

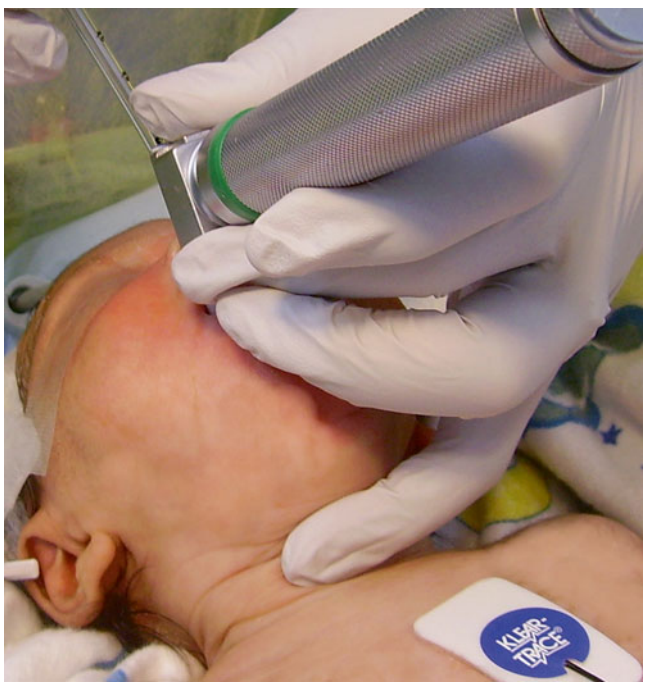


**Fig. 5.2** Orotracheal intubation in the neonate is facilitated by using the fifth finger of the left hand, which provides posterior or lateral external displacement of the larynx

blocking drugs improves conditions for intubation and decreases the likelihood of trauma to the airway [56–59]. A consensus statement published by The International Evidence-Based Group for Neonatal Pain states "tracheal intubation without the use of analgesia or sedation should be performed only for urgent resuscitations in the delivery room or for life-threatening situations associated with the unavailability of intravenous access" [54]. In selected cases, such as when face mask ventilation or tracheal intubation is expected to be difficult, intubation may be performed after sedative premedication rather than general anesthesia. Various medication regimens have been evaluated for nonemergency tracheal intubation in the neonatal ICU [60–63], although most studies are seriously flawed precluding the determination of a preferred regimen [64].

Tracheal intubation in an unsedated critically ill neonate may be a lifesaving maneuver. Although it has been eschewed by many, if the need arises, it is important to know how to perform an "awake" intubation. This is not a technique that should be first attempted in a lifesaving situation. When planning an awake intubation, the operator should ensure that the stomach is empty (e.g., suction is readily available), and atropine 0.02 mg/kg IV and oxygen have been administered. In advance of the intubation, a styleted tracheal tube of the appropriate size (in a hockey stick configuration), laryngoscope handle and appropriate size blade, and suction should be available. An experienced assistant holds the infant's arms fully extended against the side of the head to prevent the head and upper torso from wiggling and the shoulders from lifting off the table during laryngoscopy. Once laryngoscopy begins, tracheal intubation should be completed within 10–12 s. The laryngoscope blade should be inserted into the mouth at the right commissure aiming the tip of the blade toward the midline in one fluid motion. The laryngoscope should be held in one hand and the tracheal tube in the other. As soon as the neonate gags as the blade is inserted, the epiglottis should be lifted and the tube passed between the vocal cords. When carbon dioxide is detected, 2–3 mg/kg IV propofol or other anesthetics may then be administered to attenuate any cardiovascular responses to laryngoscopy. The tracheal tube should then be taped and secured at an appropriate depth.

## Nasotracheal Intubation

Nasotracheal intubation is more challenging to perform than orotracheal intubation, especially in neonates. Although no studies have specifically reported the sequelae after nasotracheal intubation in neonates, complications in older children include epistaxis, retropharyngeal perforation, sinusitis, bacteremia, and turbinate avulsion [65–70]. Nonetheless, this approach is preferred for neonates undergoing cardiac surgery, posterior fossa neurosurgery, and for prolonged intubation in the intensive care in many institutions. A topical vasoconstrictor such as 0.025 % oxymetazoline may be applied before intubation to prevent bleeding from the nasal mucosa. The dose of the vasoconstrictor should be carefully calculated as severe hypertension and reflex bradycardia progressing to cardiac arrest have been reported after inadvertent overdoses of phenylephrine [71–74] and oxymetazoline [75, 76]. Hence, these agents should be used judiciously in neonates. An alternative technique to minimize nasal bleeding is to telescope the tracheal tube into the flange end of a red rubber catheter and draw the lubricated catheter containing the tube through the nose [77].

## Tracheal Tube Size Selection

A variety of methods exist for determining the expected uncuffed tracheal tube diameter in children, including formulas based on age and height. However, in neonates, the diameter of the tracheal tube is determined empirically, based on the neonate's weight. For neonates < 1.5 kg, we use a size 2.5 mm ID uncuffed tube, for those between 1.6 and 3.5 kg, we use a size 3.0 mm ID uncuffed tube, and for those weighing > 3.5 kg, a 3.5 mm ID uncuffed tube. In the latter part of the first year after birth, for infants weighing 5 kg or more, we use a 4.0 mm ID tube. The appropriate tube size for each neonate may need to be adjusted based on preexisting medical conditions (e.g., subglottic stenosis, Down syndrome) (Fig. 5.3a–c) and whether the tube is cuffed or uncuffed.

## Uncuffed Versus Cuffed Tracheal Tubes

Uncuffed tracheal tubes have traditionally been used in neonates out of the concern that a cuffed tube may cause subglottic injury. However, modern cuffed tracheal tubes with high-volume, low-pressure cuffs have not been associated with an increased incidence of subglottic airway injury or an increased incidence of post-extubation stridor during general anesthesia in children and may reduce operating room pollution and anesthetic gas waste compared with uncuffed tubes [78, 79, 80]. No long-term studies with cuffed tubes have been published in neonates. However, one study in the pediatric intensive care unit reported no cases of post-extubation stridor or significant long-term sequelae when cuffed tracheal tubes were in place for up to 6 days, although only 21 infants were allocated cuffed tubes [81]. In a recent study with the Microcuff® tube in young children, 326 infants were studied with a 2.8 % incidence of stridor [79]. The number of neonates in the latter study was not reported as a distinct group. Recently, post-extubation stridor was reported in three neonates after the use of Microcuff® tubes, although the tubes that were used were NOT

recommended for their ages [82]. *Readers should be cognizant of two additional issues regarding the Microcuff® tubes*: *1. the 3.0* (*not 3.5*) *mm ID Microcuff® tube is recommended for full-term neonates >3 kg up to 8 months of age*, *and 2. if the cuff of the Microcuff® tube is inflated*, *it is prudent to monitor the cuff pressure throughout the anesthetic to preclude excess cuff pressures*, *although the critical pressure that interrupts mucosal blood flow in the neonate is unknown.*

When a cuffed tube is used, the cuff inflation volume should be adjusted to achieve the desired leak pressure. The Microcuff® tracheal tube seals the airway at pressures that are less than traditional cuffed tubes. Accordingly, the time interval until the cuff pressure requires adjustment with the Microcuff® tube exceeds that with traditional polyvinylchloride tracheal tube [83]. Irrespective of the brand of tracheal tube used and whether nitrous oxide is used or not, it is prudent to either monitor the cuff pressure intermittently or deflate and reinflate the cuff periodically to preclude excessive cuff pressures and possible mucosal ischemia.

Cuffed tracheal tubes offer a number of theoretical and practical advantages over uncuffed tubes. Theoretical advantages include a better seal of the trachea from macroaspiration than uncuffed tubes (Fig. 5.3e), although the incidence of aspiration pneumonia with an uncuffed tube is exceedingly small and aspiration is known to occur even with cuffed tubes. In addition, they enable the use of small fresh gas flows (and associated economic advantages) and decrease operating room pollution, although fresh gas flows in North America are minimal with uncuffed tubes [80, 84]. Third, cuffed tracheal tubes reduce the number of laryngoscopies to achieve a proper size tube as well as reducing the associated morbidity from multiple tube changes, although the morbidity from reintubation is exceedingly small in experienced hands. Subglottic damage after intubation has been attributed, for the most part, to intubation with oversized tubes, prolonged intubation, the use of cuffed tubes, and head movement [104]. There are, nonetheless, at least two practical advantages of cuffed tubes. The first is to facilitate ventilation of lungs with reduced lung compliance such as in chronic lung disease. The second is for surgical procedures close to the airway, where these tubes limit the escape of oxygen-enriched gases thereby decreasing the risk of fires.

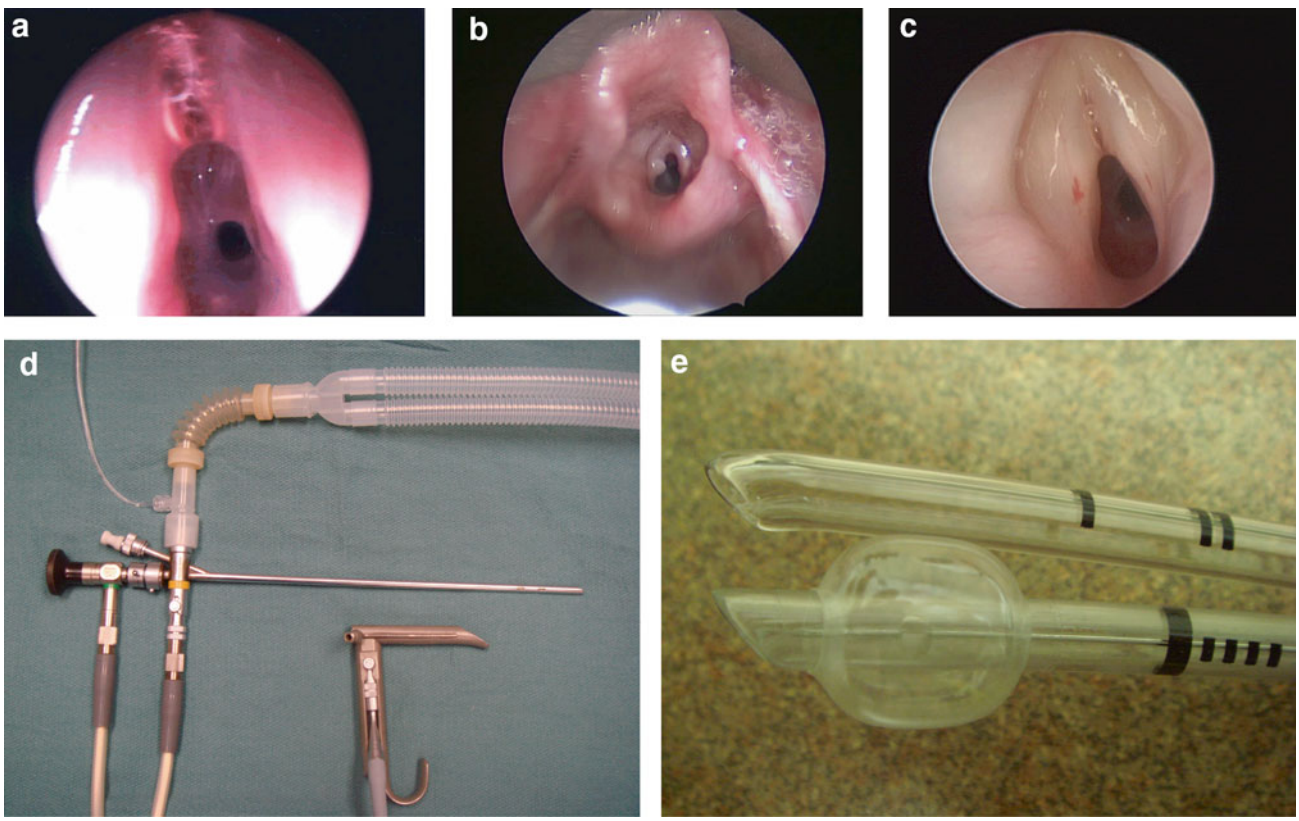


**Fig. 5.3** (**a**) Bronchoscopic view of a subglottic web. (**b**) Bronchoscopic view of subglottic cysts. Courtesy of Dr. M. Benoit, Department of Otolaryngology, Strong Hospital, University of Rochester, NY. (**c**) Bronchoscopic view of subglottic stenosis after prolonged intubation. Courtesy of Dr. M. Benoit, Department of Otolaryngology, Strong Hospital, University of Rochester, NY. (**d**) A rigid bronchoscope with telescope and light source. Anesthesia breathing circuit with a flexible connector attached to the ventilation port of the bronchoscope. In the *lower right* of the photo, an anterior commissure laryngoscope is shown. (**e**) An uncuffed and an inflated Microcuff® cuffed tracheal tube for comparison. Note the absence of the Murphy eye in the Microcuff® tube. The heavy *black line* on the Microcuff® tube corresponds with the vocal cord position in the neonate

Uncuffed tubes remain advantageous when a maximal internal airway diameter is a priority, as in spontaneous respiration. Because the resistance to turbulent airflow is inversely proportional to the fifth power of the radius of the tube, the work of breathing spontaneously may become impaired by selecting a cuffed tracheal tube with a radius that is smaller than the equivalent uncuffed tube. In addition, suctioning and pulmonary toilet are more difficult in tubes of smaller internal diameters. The magnitude of the differences in diameter is magnified in smaller size tubes that are used in preterm and very low birth weight infants.

## Assessing Tube Size for Intubation

It is important to estimate the diameter of the tracheal tube that will fit the neonate's airway in preparation of tracheal intubation. A tube whose outer diameter is too large will be too snug in the cricoid ring and will exert excessive pressure on the subglottic or tracheal mucosa, resulting in mucosal ischemia. In the short term, this can lead to edema of the loose pseudostratified columnar epithelium that lines the subglottic region and to stridor from an edematous narrowed airway after extubation. In the long term, it may contribute to the development of scarring and subglottic stenosis.

The diameter of the uncuffed tracheal tube that is most appropriate for a neonate may be assessed using either the "air leak test" or by manually assessing the resistance to its passage through the subglottis. For the "air leak test," the tip of the tube is positioned mid-trachea and the adjustable pressure-limiting (APL) valve is closed. While the pressure within the breathing circuit increases, a stethoscope is positioned over the suprasternal notch. The pressure at which a leak is first auscultated is noted. Indirect evidence indicates that the leak pressure should be limited to 15–20 cm $H_2O$ to minimize the risk of mucosal edema and tissue damage in adults [86]. Comparable evidence in neonates has not been forthcoming. When performing the "air leak test," it is important to avoid a slow and prolonged leak test as this might compromise the circulation, similar to that observed during a prolonged Valsalva maneuver.

A second sizing approach is to choose the tube that passes through the glottis and subglottis without substantial manual resistance. If resistance is detected as the tube passes through the subglottic region, then a half-size smaller tube should be inserted. If the tube passes easily through the subglottis, it is important to auscultate for excessive gas leak to ensure that the tube is not too small for the larynx, otherwise it is replaced with a tube a half-size larger.

It is noteworthy that the recommended diameter for Microcuff® tracheal tubes is 3.0 mm ID for neonates >3 kg and up to 8 months. The diameter is 3.5 mm ID for infants >8 months of age. These sizes are one-half size smaller than those recommended for uncuffed tubes in neonates and infants of the corresponding ages. We recommend the readers follow the manufacturer's guidelines for the appropriate tube size.

## Positioning the Tracheal Tube Tip

Ideally, the tip of the tracheal tube should be mid-tracheal level. A variety of formulae have been developed to predict the optimal positional length of the tracheal tube within the trachea. In neonates, a commonly used rule of thumb is the "123–789 rule," where a 1 kg baby should have the tube taped at approximately 7 cm at the maxillary alveolar ridge, a 2 kg baby should have the tube taped at 8 cm, and a 3 kg baby should have the tube taped at 9 cm for a mid-tracheal position. When the cuff passes just beyond the vocal cords or in the case of an uncuffed tube, the tip passes 1–2 cm beyond the vocal cords; the centimeter marking on the tube at the level of the gums (or incisors) should be noted. Some operators advance the uncuffed tube until the breath sounds become unilateral, i.e., a right endobronchial intubation producing no breath sounds over the left chest. The centimeter depth at which breath sounds become unilateral is identified as the level of the carina. The tube is then withdrawn until it rests approximately midway between the carina and the vocal cords. Knowing the centimeter marking with this depth of insertion as well as the depth of the carina gives the anesthesiologist an idea of how much tracheal tube displacement can safely occur before an endobronchial intubation or tracheal extubation occurs. The distance between the glottis and the carina in full-term neonates is approximately 4–5 cm [87, 88]. Therefore, once the distance to the carina is found, the tracheal tube is pulled back approximately 2 cm to achieve a position that is mid-tracheal. A shortened tracheal length (i.e., a more cephalad bifurcation) is associated with certain medical conditions such as trisomy 21 [89] and myelomeningocele [90, 91]. These neonates are therefore at greater risk of accidental right main bronchial intubation, even when the tube is believed to be mid-tracheal. One should always be wary of a tracheal takeoff of the right upper lobe bronchus if a mild hemoglobin oxygen desaturation persists or air entry is diminished in the right upper chest. Confirmation of a mid-tracheal tube position can be determined by palpating the tube tip or the cuff in the suprasternal notch and by chest radiograph [92].

Investigators have determined that the markings on the Microcuff® tube just proximal to the cuff more reliably ensure a properly positioned tube tip and cuff in the trachea than the cm markings at the lips (Fig. 5.3e) [93]. Since the Microcuff® tube has no Murphy eye and does have a cuff, it is prudent to respect this recommendation and use the tube markings near the tip when positioning the tracheal tube rather than the distance at the lips.

## Rapid Sequence Intubation in Neonates

The traditional rapid sequence induction (RSI) without ventilation is not usually feasible in neonates because of their relatively greater oxygen consumption, reduced FRC, and increased closing volumes compared with older children, all of which result in rapid desaturation and hypoxemia during the apneic period. Furthermore, it is difficult to preoxygenate the neonate because they cry and move, preventing the application of a tight face mask, and breathe shallowly. These factors lead most pediatric anesthesiologists to perform a "modified" RSI induction in neonates [94]. With this technique, the lungs are gently ventilated manually after loss of consciousness via a face mask using low airway pressures (<10–15 cm $H_2O$), which prevent a significant decrease in oxyhemoglobin saturation.

Controversy exists regarding the effectiveness of cricoid pressure to prevent regurgitation in patients after induction of anesthesia [95]. Although a full discussion of this subject is beyond the scope of this chapter, what is known is that the force required to occlude the lumen of the esophagus in neonates has not been established, that a force as little as 5 N may deform the airway in the infant [96], and that the esophagus is often displaced laterally, an effect that is far more prevalent in younger children [97]. In adults, the application of up to 50 newtons cricoid pressure reduced the visibility of the glottis by 50 % [98]. Furthermore, at 30 newtons cricoid pressure, the duration of fiber-optic intubation was prolonged compared with no cricoid pressure [99]. Although comparable data in neonates and children are not available, it is reasonable to expect the effect of cricoid pressure on visibility of the glottis opening to be limited even further. In the absence of evidence that cricoid pressure prevents regurgitation, we do not recommend the routine application of cricoid pressure in neonates. Nonetheless, supplementary maneuvers to minimize aspiration of gastric contents include emptying the stomach with a red rubber catheter before induction of anesthesia, as well as rapidly administering the induction agents and rapidly securing the airway with a tracheal tube. In the event that cricoid pressure is applied, it should be maintained until complete neuromuscular blockade is established. In support of this practice, appropriately applied cricoid pressure has been shown to be effective in preventing gastric inflation during gentle bag-mask ventilation in anesthetized infants and children [100]. If the initial attempt at tracheal intubation fails while cricoid pressure continues to be applied, gentle face mask ventilation should be performed. If ventilation is difficult while cricoid pressure is applied, despite the use of adjunctive devices such as an oral or nasopharyngeal airway or an LMA, cricoid pressure should be lessened or released [101, 102]. The evidence that cricoid pressure prevents pulmonary regurgitation in this clinical setting remains unproven [85].

**Table 5.1** Difficult airway in neonates

| |
|---|
| Difficult mask ventilation |
| Maxillary hypoplasia |
| Crouzon's syndrome |
| Apert's syndrome (acrocephalosyndactyly type I) |
| Pfeiffer's syndrome |
| Choanal atresia |
| Marshall–Smith syndrome |
| Rubinstein–Taybi syndrome |
| Possible difficult laryngoscopy/intubation |
| (a) *Micrognathia* |
| Pierre Robin sequence |
| Stickler syndrome |
| Smith–Lemli–Opitz syndrome |
| Treacher Collins syndrome |
| Goldenhar's syndrome; hemifacial microsomia |
| First arch syndrome; midfacial cleft |
| (b) *Possible micrognathia and other soft tissue facial anomalies* |
| Arthrogryposis trisomy 8 |
| Trisomy 9 |
| Trisomy 13 (Patau syndrome) |
| Trisomy 18 (Edwards syndrome) |
| CHARGE association |
| Cornelia de Lange syndrome |
| Velocardiofacial syndrome (Shprintzen syndrome) |
| Freeman–Sheldon syndrome (whistling face syndrome) |
| (c) *Macroglossia* |
| Beckwith-Wiedemann syndrome |
| Congenital hypothyroidism |
| Down syndrome |
| Cystic hygroma |
| Congenital lingual tumor/intraoral tumor |
| Mucopolysaccharidoses (Hurler, Hunter, Morquio, and Maroteaux–Lamy syndromes)[a] |
| Lipoid proteinosis trisomy 4p |
| Weaver syndrome |
| (d) *Intraoral/tracheal pathology* |
| Microstomia |
| Congenital temporomandibular joint dysfunction |
| Laryngeal/vallecular cyst, laryngeal web |
| Laryngotracheal cleft |
| Laryngeal/tracheal hemangiomas |
| Tracheal and subglottic stenosis |
| Other defects that may complicate the airway |
| Cervical spine immobility |
| Arthrogryposis |
| Emery–Dreifuss muscular dystrophy |
| Fibrodysplasia ossificans progressiva syndrome |

[a]Data from Frawley G, Fuenzalida D, Donath S, Yaplito-Lee J, Peters H. A retrospective audit of anesthetic techniques and complications in children with mucopolysaccharidoses. Pediatr Anesth 2012: 22; 737–744

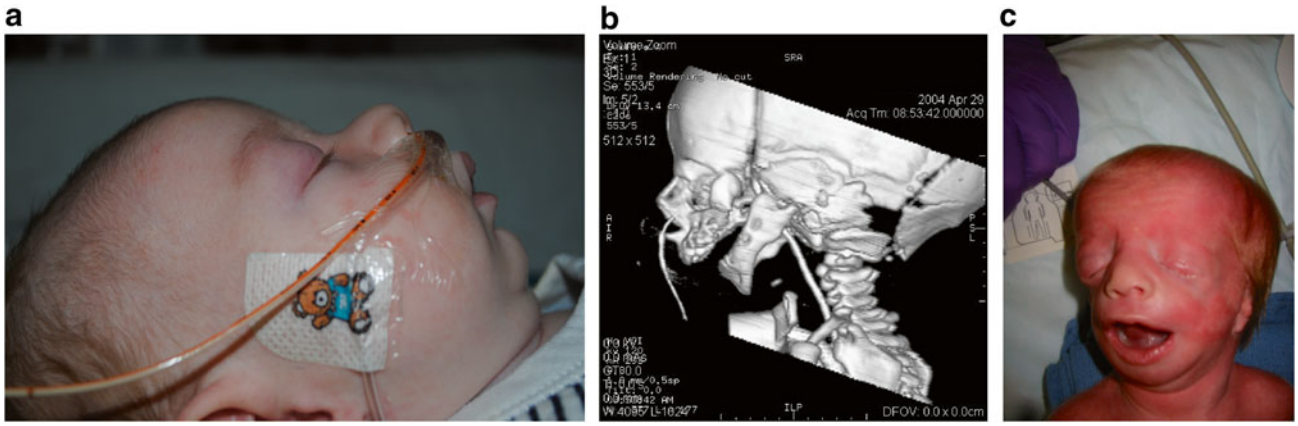


**Fig. 5.4** (**a**) Lateral profile of a 3-week-old male with Pierre Robin sequence. Note the retrognathic chin, which will impair laryngoscopy and tracheal intubation. (**b**) A three dimensional CT reconstruction of a neonate with Pierre Robin sequence. Note the hypoplastic mandibular body length and severely obtuse gonial angle (see text). Courtesy of Dr. J. Girotto, Department of Plastic Surgery, Strong Hospital, University of Rochester, NY. (**c**) Neonate with Treacher Collins syndrome. Note the small mandible, deformed ears, and teardrop eyelids, which are characteristic facial features of this syndrome

## Management of the Difficult Airway

The neonatal airway represents the extremes of the differences between pediatric and adult airways. Epidemiologically, difficult airways occur more frequently in infants <1 year of age (with neonates comprising the second most common age group), Mallampati 3 or 4, ASA physical status III and IV, cardiac and craniofacial surgeries, and a low BMI [103]. Consequently, anesthesiologists find airway management in this population to be the most challenging. The spectrum of congenital and acquired [104, 105], airway disorders ranges from difficult mask ventilation to difficult tracheal intubation due to a panoply of different causes (Table 5.1).

The difficult airway in the neonate presents several unique challenges, as well as sharing many challenges that parallel those of the older child. The dimensions of the face, mandible, and neck present challenges for maintaining a patent airway with the face mask. Superimposed on the difficulties of the normal neonatal airway, the flat face, maxillary hypoplasia, and small mouth of the neonate with Crouzon's disease and Apert's syndrome often lead to an obstructed airway. In many instances, an oropharyngeal airway or laryngeal mask airway will relieve the obstruction. However, direct laryngoscopy and orotracheal intubation is usually uncomplicated. As infants with these syndromes mature, mask anesthesia remains a challenge, whereas direct laryngoscopy remains uncomplicated. Neonates with Pierre Robin sequence (Fig. 5.4a) [106], Treacher Collins syndrome (Fig. 5.4c), and Goldenhar's syndrome may also present challenging but not insurmountable airways. Mask anesthesia may be difficult as the mandibular deformities render temporomandibular joint subluxation difficult (Fig. 5.4b) [107]. Pierre Robin sequence is characterized by a triad of micrognathia, glossoptosis, and respiratory distress in the first 24–48 h after birth. Direct laryngoscopy may be particularly challenging in neonates with Pierre Robin sequence in part as a result of a short mandibular body length (Fig. 5.4b) [107]. However, the airway becomes easier to manage with age such that by 2 years of age, the mandible is often aligned with the maxilla [108]. In contrast, laryngoscopy in neonates with Treacher Collins syndrome is easier at birth and becomes progressively more difficult with increasing age [108, 109]. This may be directly attributable to a shortened ascending ramus of the mandible [107]. In both Pierre Robin sequence and Treacher Collins syndrome, the gonial angle (or the angle between the ascending ramus and body of the mandible) is significantly more obtuse than in unaffected neonates, which may contribute to difficult laryngoscopy exposure. Neonates with Goldenhar's syndrome may be split in airway management: 50 % have airways that are not difficult to manage, and 50 % are exceedingly difficult to manage. Interestingly, the difficulty presented by the airway in this last syndrome does not change with age.

Neonates with subglottic webs (Fig. 5.3a), hemangiomas, cysts (Fig. 5.3b), tumors, and laryngomalacia as well as those with subglottic stenosis from prior tracheal intubation (Fig. 5.3c) may present a challenge to those using a face mask as well as a laryngoscope blade [110, 111]. The degree of airway obstruction and the dynamic changes that may occur with induction of anesthesia are often unknown in neonates with these defects.

Before embarking on an anesthetic for a child with a difficult airway, it is essential that a proper operating room and airway equipment setup is in place as well as expert assistance present before induction of anesthesia [112]. In elective cases, severely dysmorphic neonates and those with only a single means of accessing their airways (e.g., severe temporomandibular joint dysfunction that limits mouth opening and eliminates the ability to rescue ventilation with an LMA) should be evaluated by an otolaryngologist before induction of general anesthesia. This allows the otolaryngologist to assess the airway for alternate approaches to tracheal intubation (such as rigid bronchoscopy or surgical tracheostomy) (Fig. 5.2d) in the event that noninvasive attempts at tracheal intubation also fail. The availability of an otolaryngologist does not necessarily guarantee an expeditious airway rescue since the anatomical reasons that may lead to a failed intubation may also create difficulties for a tracheostomy [113].

The approach to the anticipated difficult neonatal airway is similar to that in older children. Although general anesthesia is the preferred approach to securing the airway in these infants, topical administration of local anesthesia supplemented with sedation and awake tracheal intubation should also be considered as alternative approaches. During induction of general anesthesia, spontaneous ventilation is preferred as it ensures ventilation is maintained and inhalational anesthesia can be reversed should the operators fail to secure the airway. However, spontaneous ventilation may be difficult to maintain in some neonates (particularly in the preterm neonate and those with hypoplastic mandibles) because of the small dimensions of their upper airways, sensitivity to inhalational agents, and chest wall instability in addition to the defect at the root of the difficult airway. The decision to administer a muscle relaxant depends on the risk/benefit ratio of paralysis including difficulty ventilating the lungs and realizing a "cannot-intubate-cannot-ventilate" scenario may develop, although the latter is rare in neonates [114–116]. Induction of anesthesia must be carried out carefully, avoiding upper airway obstruction, which in most neonates, results in the rapid onset of arterial hemoglobin desaturation.

Topical anesthesia applied to the airway combined with sedation has been used to blunt cardiorespiratory responses during laryngoscopy. However, a recent review (in older children) suggested that not only does topical local anesthesia not reduce the incidence of perioperative airway reflexes, but that it actually may paradoxically increase the incidence of laryngospasm, although this was only an observational study [117]. Alternately, sedation may be provided by midazolam and fentanyl, propofol, dexmedetomidine, or ketamine administered intravenously [57, 63, 118–122]. These approaches have all been used to secure the airway, although the responses were generally optimally controlled when a muscle relaxant was coadministered. Lastly, an awake intubation may be necessary in order to secure the difficult airway, particularly in the absence of otolaryngology support or alternatives. The approach described earlier in this chapter to performing an awake orotracheal intubation should be followed closely in order to reliably and rapidly secure the airway in the neonate. Once the airway is secured and carbon dioxide is identified in the airway, then a bolus of intravenous propofol should be administered immediately to induce general anesthesia.

We remain firmly committed to perfecting our skills with the laryngoscope and direct laryngoscopy. The discussion above provides a detailed description of how to properly use the Miller blade in neonates with a difficult airway. Nonetheless, in some circumstances, the airway cannot be secured by direct laryngoscopy and alternative airway devices are required. The following describes those airway devices.

Adjuncts such as an oropharyngeal airway or LMA may be useful, particularly in the child with a dysmorphic face, in whom the jaw thrust [31] only partially preserves the patent upper airway. The LMA has served as an effective bridge to tracheostomy in several difficult airway reports in neonates [108, 114, 123]. The appropriate size LMA should always be readily available in the event it is needed urgently. Before instrumenting the airway however, intravenous access should be established to facilitate the administration of resuscitative medications.

Several different video and optical technologies are available to manage difficult neonatal airways [108]. Much of the evidence for the effectiveness of these devices is based on investigations in adults and older children. As a result, the information presented here is a synthesis of published reports and the clinical experience of the authors using these devices in neonates.

The Storz Video (Karl Storz GmbH, Tuttlingen, Germany, Fig. 5.5) and the GlideScope (Verathon, Bothell, Washington, Fig. 5.6) are two video laryngoscopes that may be used to facilitate tracheal intubation in neonates [124, 127]. The Storz video laryngoscope consists of a size 0 and 1 straight

**Fig. 5.5** Neonatal-sized Storz video laryngoscope

**Fig. 5.6** Neonatal-sized GlideScope

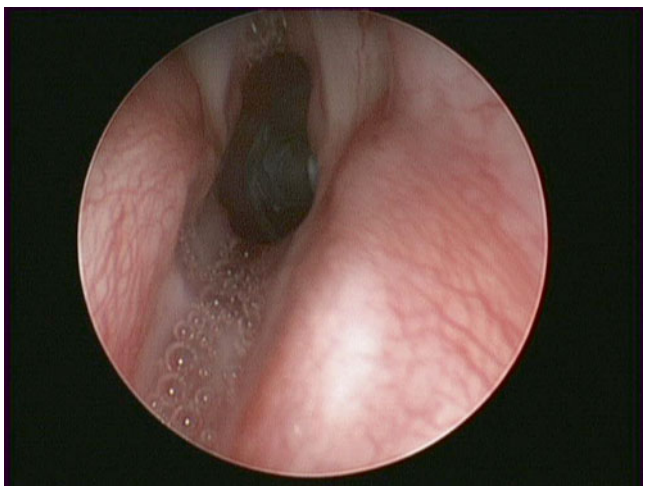

**Fig. 5.7** Laryngeal cleft

**Fig. 5.8** Neonatal-sized Airtraq optical laryngoscope

blade, which incorporates a 2.8 mm image and light bundle within a stainless steel tube. This video laryngoscope has been used successfully in the delivery room, to facilitate tracheal intubation in neonates as small as 500 g [125]. The detailed view from the camera allows visual inspection of the airway in those suspected of having vocal cord dysfunction, laryngeal clefts (Fig. 5.7), and gastroesophageal reflux.

Despite the large number of publications on the GlideScope video laryngoscope in adults and older children, there are few publications documenting its use in infants and neonates [126]. The redesigned GlideScope Cobalt is a MAC-style plastic blade that fits onto a video baton. It is available in all pediatric sizes and almost always provides a clear, crisp view of the glottic opening, except in the most anatomically deformed neonates. However, there is a learning curve to navigating the tracheal tube through the oropharynx and into the glottic opening, while focusing on the video screen. Once this maneuver has been mastered, the device provides a reliably high success rate in most neonates with craniofacial anomalies as long as mouth opening is sufficient to accept the blade. The tracheal tube should be visualized throughout its advancement so as to avoid injury to the airway in neonates with limited oropharyngeal space.

The Airtraq optical laryngoscope (Prodol, Vizcaya, Spain) is a single-use curved laryngoscope that uses mirrors and prisms to transmit the image from the tip of the device to a viewfinder (Fig. 5.8) [127]. It has a conduit for the tracheal tube along its side that directs the tracheal tube toward the glottic opening as it is advanced. The Airtraq has been used successfully in managing the difficult airway in the neonate, although there are no controlled systematic evaluations in this population [127–132]. Despite the built-in channel, one publication described two cases (one neonate and one infant) in which a full glottic view was obtained, and yet difficulty was encountered directing the tube into the trachea.

**Fig. 5.9** Neonatal-sized Truview EVO2 (courtesy of Dan White, Truphatek, Inc.)


**Fig. 5.10** A single fiber-optic light bundle is attached to a rheostat-controlled light source and placed inside a styleted endotracheal tube to form a "homegrown" lighted stylet

The authors attributed the failures to the bulk of the device that limited its maneuverability [133]. Others have had success utilizing a gum elastic bougie to facilitate placement of the tracheal tube when the standard approach failed [134].

The Truview EVO2 (Truphatek, Netanya, Israel) incorporates a prismatic lens in an angulated rigid blade (Fig. 5.9) [127]. It has a side port for oxygen insufflation during intubation. When the Truview was compared with the Miller blade in neonates, the former provided improved Cormack-Lehane views and a clinically insignificant increase in the time to tracheal intubation [135]. Caution should be exercised when insufflating oxygen at excessive flows (i.e., Bonfils recommends <3 l per minute of oxygen flow) through these intubation devices as subcutaneous emphysema has been reported [136].

When using any of the video-assisted intubation devices described above (with the exception of the Airtraq), the selected tracheal tube should be prepared with a lightly lubricated stylet before laryngoscopy. Although the stylet is not absolutely necessary in all cases, an anterior curve matching the blade angle of the selected device facilitates tube placement. Laryngoscopy is performed by introducing the blade in the midline or to the right of the tongue, and airway structures are progressively visualized until the blade tip is placed either in the vallecula or under the epiglottis. Vallecular placement with engagement of the glossoepiglottic ligament will elevate the epiglottis exposing the glottic opening in most infants. On occasion, the epiglottis obstructs the camera view because of its length in neonates and infants. In this case, the epiglottis should be gently lifted with the blade to expose the glottic inlet. After a satisfactory view has been obtained, the tracheal tube is passed along the shaft of the blade (unlike the lateral insertion typical with standard direct laryngoscopy). This insertion technique guarantees that the tracheal tube will come into the view of the video camera as it is advanced and reduces the risk of soft tissue injury.

The lighted stylet remains a viable option for intubating the neonate with a difficult airway [137, 138]. A stylet for neonatal use can easily be fashioned from readily available equipment in the operating room. A single fiber-optic light bundle (20 g Fiberoptic Endoilluminator, Cat No. MVS1011, Storz, St. Louis, MO, USA) can be inserted into the chosen tracheal tube alongside a rigid stylet, and the fiber-optic bundle is then connected to a rheostat-controlled fiber-optic light source (Fig. 5.10) [138]. Transillumination of light in the neck is used to guide the placement of the tracheal tube; however, because of the relative lack of subcutaneous fat in neonatal patients, changes in light intensity with esophageal

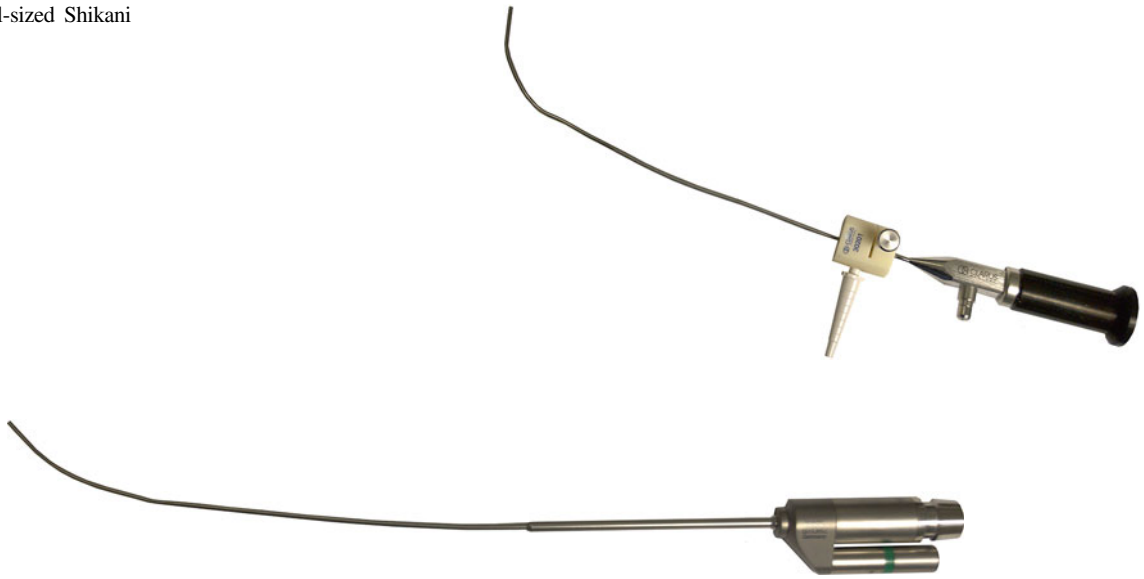

**Fig. 5.11** Neonatal-sized Shikani Optical Stylet

**Fig. 5.12** Neonatal-sized Bonfils fiber-optic laryngoscope

placement may not be readily appreciated. Thus, lighted stylet intubation in the neonate requires an element of feel and observing continuous illumination of the transilluminated light. A brief disappearance and reappearance of the transilluminated light suggests esophageal placement, and the visualization of a cone of light in the caudad direction suggests correct glottic positioning.

Optical stylets combine the rigidity of the lighted stylet with fiber optics to allow direct visualization during intubation. The Shikani Optical Stylet (SOS; Fig. 5.11) and the Bonfils fiber-optic laryngoscope (Fig. 5.12) represent two designs with neonatal application. The SOS is malleable whereas the Bonfils is rigid with a fixed curve of 40°. Both are limited by the presence of secretions but have been successfully utilized in neonates. Optical stylets can be combined with the anterior commissure laryngoscope or a standard laryngoscope to facilitate intubation; the laryngoscope displaces soft tissue and provides an unobstructed path for the stylet to be maneuvered [139]. Some authors have reported less success with the Bonfils when compared with standard laryngoscopy [140], while others question its utility in children [141, 142]. The Bonfils has been used successfully with a 2.5 mm tracheal tube in a small-for-gestational-age neonate in whom direct laryngoscopy failed [143].

The flexible fiber-optic bronchoscope remains the gold standard for managing the neonate with a difficult airway. A working channel has been incorporated into neonatal size bronchoscopes with variable effectiveness in removing secretions [144]. If difficulty is encountered with the oral and nasal approaches, fiber-optic intubation through the nose or an LMA should be considered. This technique has been used successfully for tracheal intubation in this age group. A correctly positioned LMA simplifies intubation with the flexible fiber-optic bronchoscope and allows continuous ventilation via a swivel adapter [145–151]. With the increasing use of cuffed tubes in children, practitioners should be aware that most neonatal LMAs will not allow the passage of cuffed tracheal tubes without some modifications to the pilot balloon cuff. [152] The exception to this observation is the air-Q intubating LMA (Mercury Medical, Clearwater, FL) which readily accepts the pilot balloon of the cuffed tube [153, 154]. In neonates with severe upper airway obstruction, the LMA can be placed in the awake infant and followed by induction of general anesthesia and fiber-optic intubation [155–158]. Placement of a modified nasal airway provides an alternative option for oxygenation during intubation in a neonate. In small infants with the potential for life-threatening upper airway obstruction during administration of general anesthesia (e.g., large cystic hygroma), moderate sedation may be considered using small, incremental doses of ketamine and midazolam after the application of topical anesthesia [159].

In neonates, multiple attempts at tracheal intubation can rapidly result in upper airway edema that is sufficiently significant to compromise ventilation. An otolaryngologist should be consulted for evaluation for a tracheostomy if the intubation of the airway is essential. In the unlikely event of life-threatening airway obstruction unrelieved by an LMA, needle cricothyroidotomy is the recommended invasive technique for nonsurgically trained providers to establish

life-sustaining oxygenation. However, the neonatal cricothyroid membrane is described as slit-like with overlap of the cricoid and thyroid cartilages [160]. The neonatal cricothyroid membrane is too small for surgical cricothyroidotomy to be performed measuring 2.61 mm in length and 3.03 mm in width in neonatal cadavers, dimensions that are too small for a neonatal tracheal tube [161]. Attempts to pass a tracheal or tracheostomy tube could result in laryngeal fracture or severe airway injury. The lack of a laryngeal prominence in the neonate combined with a more cephalad glottic position makes localizing the membrane in the neonate more difficult than in the adult. After identification of the cricothyroid membrane, a 16- to 18-gauge needle/catheter with a saline-filled 3 ml syringe attached should be inserted in a caudad direction through the membrane. Aspiration of air confirms entry into the tracheal air column; the catheter is left in place and the needle is removed. Before ventilation is attempted, it is crucial to verify that the tip of the needle and catheter are within the air column of the trachea rather than extratracheal, e.g., in subcutaneous tissue or cerebrospinal fluid, lest potential fatal sequelae occur. A number of techniques to deliver oxygen and connect to the in situ catheter (including using a stopcock, 3 cc syringe barrel, and a 15 mm adapter) have been described, using pressures of 25–35 psi obtained from a high-pressure oxygen source [160]. Commercial devices (e.g., Enk oxygen flow modulator set, Cook Critical Care, Bloomington, Indiana) are available for regulating oxygen insufflation.

The difficult neonatal airway represents one of the most challenging clinical scenarios for the pediatric anesthesiologist. If the difficult airway is anticipated, then appropriate planning may take place. However, in those rare instances in which the difficult airway is unanticipated, it may be prudent to ensure appropriate management by referring to a difficult pediatric airway algorithm [112, 162]. Consistent success requires adequate preparation, maintenance of skill with indirect visualization devices, and assembling the appropriate personnel when assistance is required.

## Airway Management and Ex Utero Intrapartum Treatment

Rare conditions may occasionally result in compromised and potentially life-threatening neonatal airway immediately after birth. These conditions include (but are not limited to) congenital cystic hygroma of the neck, congenital high airway obstruction syndrome (CHAOS) caused by obstruction at the level of the larynx or trachea, and cervical teratoma (see Fig. 5.13) or other tumor of the face, mouth, and neck. Antenatal diagnosis permits scheduling the time of delivery to ensure that an ex utero intrapartum treatment (EXIT) technique is prepared to manage the neonates airway [163–165]. The EXIT procedure is performed on the partially delivered fetus while it continues to receive oxygen through an intact uteroplacental circulation. EXIT procedures include direct laryngoscopy/bronchoscopy and tracheal intubation, tracheostomy, or tumor resection. Figures 5.14a, b show a neonate and MRI scan of that neonate who presented antenatally with

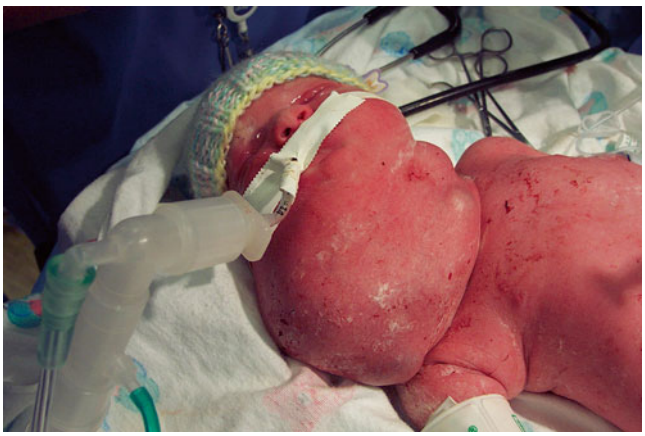

**Fig. 5.13** Cervical teratoma

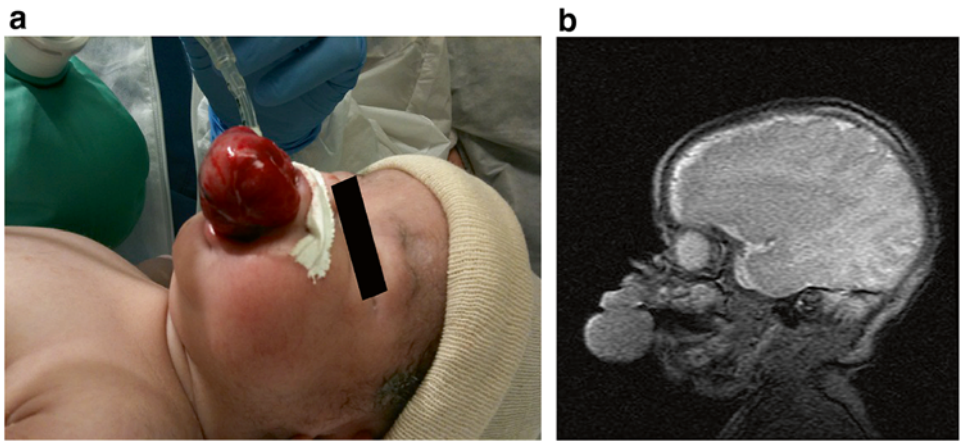


**Fig. 5.14** (**a**) Neonate with a hamartoma of the hard palate. (**b**) CT scan of the neonate in Fig. 5.11a demonstrating a clear and patent nasopharyngeal airway

a hamartoma of the hard palate. An EXIT procedure was undertaken, although orotracheal intubation was successful performed by anesthesia upon delivery. The benign tumor was subsequently resected. In some centers, such as ours, airway management is performed entirely by the surgical team. Once the neonate's airway is secured using a tracheal tube or surgical airway (depending on the size and location of the obstructing lesion), the placental cord may be severed.

Fetal anesthetic management consists of transplacental transfer of volatile anesthetics (via the mother who receives general endotracheal anesthesia) and an intramuscular injection of atropine, fentanyl, and vecuronium into the fetus, once it is exposed via a uterine incision. Muscle relaxation is critical to prevent the fetus from taking a breath, which would cause a switch from fetal to transitional circulatory pattern.

EXIT procedures may also be performed for resection of congenital pulmonary masses and cannulation for extracorporeal membrane oxygenator (ECMO) support for select congenital cardiac conditions. One of the original indications for the EXIT procedure was to remove a tracheal plug that was placed during mid-gestation in an attempt to promote pulmonary development in fetuses with congenital diaphragmatic hernia [166].

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