CHAPTER 25

Differentiating Aspects of the Pediatric Airway

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THE CLINICAL CHALLENGE

Airway management in the pediatric population presents many potential challenges, including age-related drug dosing and equipment sizing, anatomic variation that continuously evolves as development proceeds from infancy to adolescence, and the performance anxiety that invariably accompanies the resuscitation of a critically ill child. Clinical competence in managing the airway of a critically ill or injured child requires an appreciation of age- and size-related factors, and a degree of familiarity and comfort with the fundamental approach to pediatric airway emergencies.

The general principles of airway management in children and adults are the same. Medications used to facilitate intubation, the need for alternative airway management techniques, and the basic approach to performing the procedure are similar whether the patient is 8 or 80 years of age. Differences, where they occur, are most exaggerated in the first 2 years of life, after which the pediatric airway gradually develops more adultlike features.

In contrast to the case of adults, in which recognition and management of the difficult airway is a foundational skill to be mastered, the challenge in children is to develop comfort in managing the predictable differences in anatomy and physiology that occur during development. Developing airway skills and maintaining them is arguably easier in adults because there is ample opportunity during clinical practice, as opposed to pediatrics, where the paucity of sick children encountered during training and practice makes attaining the same level of comfort difficult to achieve. This chapter will review those differences with the aim of simplifying them and making the key skills more easily learned and maintained.

APPROACH TO THE PEDIATRIC PATIENT

General Issues

The cognitive burden on providers during a pediatric resuscitation is different than that in adults owing to the unique anatomic and physiologic variables inherent in children. Age- and size-related variables unique to children introduce the need for more complex, nonreflexive, or knowledge-based mental activities, such as calculating drug doses and selecting equipment. The concentration required to undertake these activities while under stress may detract from other important mental activities such as assessment, evaluation, prioritization, and synthesis of information, referred to in the resuscitative process as critical thinking activities. The cumulative effect of these factors leads to inevitable time delays and a corresponding increase in the potential for decision-making errors during pediatric resuscitation. This is in sharp contrast to adult resuscitation, where drug doses, equipment sizing, and physiologic parameters are usually familiar to the provider, allowing for these decisions to be reflexive and thus freeing up the provider's attention for critical thinking. In children, drug doses are based on weight and may vary by an order of magnitude depending on age (ie, 3-kg neonate vs a 30-kg 8-year-old vs a 100-kg adolescent). The use of resuscitation aids in pediatric resuscitation significantly reduces the cognitive load (and error) related to drug dosing calculations and equipment selection by relegating these activities to a lower order of mental function (referred to as "automatic" or "rule based"). The results are reduced error, attenuation of psychological stress, and an increase in critical thinking time. **Table 25.1** is a length-based, color-coded equipment reference chart, based on the "resuscitation guide" of Broselow-Luten, for pediatric airway management that eliminates error-prone strategies based on age and weight. Both equipment and drug dosing information are included in the Broselow-Luten system and can be accessed by a single length measurement or patient weight. This system is also available as part of a robust online resource (www.ebroselow.com).

Specific Issues

Anatomic and Functional Issues

The approach to the child with airway obstruction (the most common form of a difficult pediatric airway) incorporates several unique features of the pediatric anatomy.

1. Children obstruct more readily than adults do, and the pediatric airway is especially susceptible to airway obstruction resulting from swelling (see Chapter 27, which outlines the effect of 1-mm edema on airway resistance in the infant [4-mm airway diameter] vs the adult [8-mm airway diameter]). Nebulized racemic epinephrine causes local vasoconstriction and can reduce mucosal swelling and edema. For diseases such as croup, where the anatomic site of swelling occurs at the level of the cricoid ring, functionally the narrowest part of the pediatric airway, racemic epinephrine can have dramatic results. Disorders located in areas with greater airway caliber, such as the supraglottic region of epiglottitis or the retropharyngeal region of an abscess, rarely produce findings as dramatic. In clinical practice, efforts to force a nebulized medication on a child with epiglottitis may agitate the child, leading to increased airflow velocity and dynamic upper airway obstruction.
2. Noxious interventions can lead to dynamic airway obstruction and precipitate respiratory arrest. This has historically led to the admonition to "leave them alone" and allow the patient to assume a position of comfort. The work of breathing in the crying child increases 32-fold, elevating the threat of dynamic airway obstruction. Therefore, these children should be managed in a quiet, comfortable environment when presenting for upper airway obstruction (**Fig. 25.1A-C**).
3. Bag-mask ventilation (BMV) may be of particular value in the child with upper airway obstruction. Note in Figure 25.1C that efforts by the patient to alleviate the obstruction may exacerbate it, because increased inspiratory effort creates increased negative extrathoracic pressure, leading to collapse of the malleable extrathoracic trachea. The application of positive pressure through BMV can stent the airway open and relieve the dynamic component of obstruction (**Fig. 25.1C,D**). Thus, BMV is appropriate as a temporizing first maneuver if the patient arrests from obstruction. There have been numerous case reports of children with epiglottitis being successfully resuscitated utilizing BMV.
4. Apart from differences related to size, there are certain anatomic peculiarities of the pediatric airway. These differences are most pronounced in children <2 years of age, whereas children >8 years of age are similar to adults anatomically and the 2- to 8-year-old period is one of transition. The glottic opening is situated at the level of the first cervical vertebra (C-1) in infancy. This level transitions to the level of C-3 to C-4 by age 7 and to the level of C-5 to C-6 in the adult. Thus, the glottic opening tends to be higher up in the neck in children as opposed to adults. The size of the tongue with respect to the oral cavity is larger in children, particularly infants, and the epiglottis is also proportionately larger, making efforts to visualize the airway without direct control more difficult. Thus, a straight (ie, Miller) blade, which is used to get underneath and directly elevate the epiglottis, is recommended in children younger than 3 years (**Table 25.2**).

TABLE 25.1 Equipment Selection

	Pink[a]	Red	Purple	Yellow	White	Blue	Orange	Green
Length (cm)-Based Pediatric Equipment Chart								
Weight (kg)	6-7	8-9	10-11	12-14	15-18	19-23	23-31	31-41
Length (cm)	60.75-67.75	67.75-75.25	75.25-85	85-98.25	98.25-110.75	110.75-122.5	122.5-137.5	137.5-155
ETT size (mm)	3.5 cuff 3.0 uncuff	3.5 cuff 3.0 uncuff	4.0 cuff 3.0 uncuff	4.5 cuff 4.0 uncuff	5.0 cuff 4.5 uncuff	5.5 cuff 5.0 uncuff	6.0 cuff	6.5 cuff
Lip-to-tip length (mm)	10-10.5	10.5-11	11-12	12.5-13.5	14-15	15.5-16.5	17-18	18.5-19.5
Laryngoscope size+blade	1 straight	1 straight	1 straight	2 straight	2 straight	2 straight or curved	2 straight or curved	3 straight or curved
Suction catheter	8F	8F	8F	8F-10F	10F	10F	10F	12F
Stylet	6F	6F	10F	10F	10F	10F	14F	14F
Oral airway (mm)	50	50	60	60	60	70	80	80
Nasopharyngeal airway	14F	14F	18F	20F	22F	24F	26F	30F
Bag/valve device	Infant	Infant	Child	Child	Child	Child	Child/adult	Adult
Oxygen mask	Newborn	Newborn	Pediatric	Pediatric	Pediatric	Pediatric	Adult	Adult
Vascular access	22-24/23-25	22-24/23-25	20-22/23-25	18-22/21-23	18-22/21-23	18-20/21-23	18-20/21-22	16-20/18-21
Catheter/butterfly	Intraosseous	Intraosseous	Intraosseous	Intraosseous	Intraosseous	Intraosseous		
Nasogastric tube	5-8F	5-8F	8-10F	10F	10-12F	12-14F	14-18F	18F

(continued)

TABLE 25.1 Equipment Selection (*continued*)

	Pink[a]	Red	Purple	Yellow	White	Blue	Orange	Green
Length (cm)-Based Pediatric Equipment Chart								
Urinary catheter	5-8F	5-8F	8-10F	10F	10-12F	10-12F	12F	12F
Chest tube	10-12F	10-12F	16-20F	20-24F	20-24F	24-32F	24-32F	32-40F
Blood pressure cuff	Newborn/ infant	Newborn/ infant	Infant/child	Child	Child	Child	Child/adult	Adult
LMA[b]	1.5	1.5	2	2	2	2-2.5	2.5	3

Directions for use: (1) measure patient length with centimeter tape or with a Broselow tape; (2) using measured length in centimeters or Broselow tape measurement, access appropriate equipment column; (3) column for ETTs, oral and nasopharyngeal airways, and LMAs; always select one size smaller and one size larger than recommended size.

ETT, endotracheal tube; LMA, laryngeal mask airway.

[a]*For infants smaller than the pink zone, but not preterm, use the same equipment as the pink zone.*

[b]*Based on manufacturer's weight-based guidelines:*

Mask Size	Patient Size (kg)
1	≤5
1.5	5-10
2	10-20
2.5	20-30
3	>30

Modified from Luten RC, Wears RL, Broselow J, et al. Managing the unique size related issues of pediatric resuscitation: reducing cognitive load with resuscitation aids. Acad Emerg Med. 1992;21:900–904.

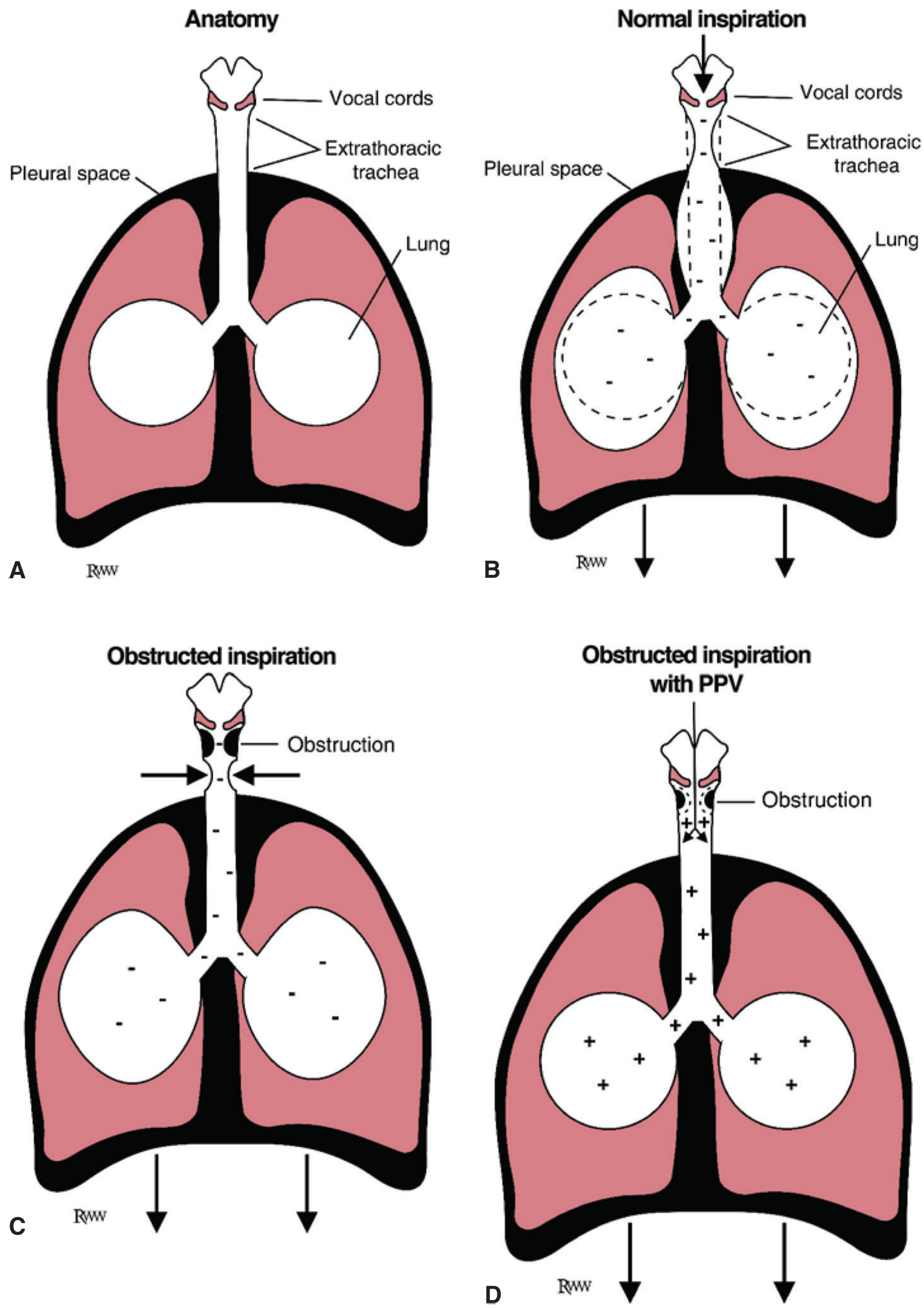

Figure 25.1: **Intra- and extrathoracic trachea and the dynamic changes that occur in the presence of upper airway obstruction. A:** Normal anatomy. **B:** The changes that occur with normal inspiration; that is, dynamic collapsing of the upper airway associated with the negative pressure of inspiration on the extrathoracic trachea. **C:** Exaggeration of the collapse secondary to superimposed obstruction at the subglottic area. **D:** Positive-pressure ventilation (PPV) stents the collapse/obstruction versus the patient's own inspiratory efforts, which increase the obstruction. (Redrawn from Cote CJ, Ryan JF, Todres ID, et al, eds. *A Practice of Anesthesia for Infants and Children.* 2nd ed. WB Saunders; 1993, with permission.)

TABLE 25.2 Anatomic Differences Between Adults and Children

Anatomy	Clinical Significance
Large intraoral tongue occupying relatively large portion of the oral cavity and proportionally larger epiglottis	Straight blade preferred over curved to push distensible anatomy out of the way to visualize the larynx and elevate the epiglottis
High tracheal opening: C-1 in infancy vs C-3 to C-4 at age 7, C-5 to C-6 in the adult	High anterior airway position of the glottic opening compared with that in adults
Large occiput that may cause flexion of the airway, large tongue that easily collapses against the posterior pharynx	Sniffing position is preferred. The larger occiput actually elevates the head into the sniffing position in most infants and children. A towel may be required under shoulders to elevate torso relative to head in small infants
Cricoid ring is functionally the narrowest portion of the trachea as compared with the vocal cords in the adult.	Uncuffed tubes provide adequate seal because they fit snugly at the level of the cricoid ring. Correct tube size is essential because variable expansion cuffed tubes are not used. If using a cuffed tube, careful monitoring of cuff inflation pressure is essential.
Consistent anatomic variations with age with fewer abnormal variations related to body habitus, arthritis, chronic disease	Younger than 2 y, high anterior; 2-8 y, transition; and older than 8 y, small adult
Large tonsils and adenoids may bleed; more acute angle between epiglottis and laryngeal opening results in nasotracheal intubation attempt failures	Blind nasotracheal intubation not indicated in children; nasotracheal intubation failure
Small cricothyroid membrane landmark, surgical cricothyrotomy impossible in infants and small children	Needle cricothyrotomy recommended, and the landmark is the anterior surface of the trachea, not the cricoid membrane.

5. Blind nasotracheal intubation is relatively contraindicated in children younger than 10 years of age. Children have large tonsils and adenoids, which may bleed significantly when traumatized, and the angle between the epiglottis and the laryngeal opening is more acute than that in the adult, making successful cannulation of the trachea difficult. Children also possess a small cricothyroid membrane, and in children younger than 3 to 4 years, it is virtually nonexistent. For this reason, needle cricothyrotomy may be difficult, and surgical cricothyrotomy is virtually impossible and contraindicated in infants and small children up to 10 years of age.
6. Although younger children possess a relatively high, anterior airway with the attendant difficulties in visualization of the glottic aperture, this anatomic pattern is consistent in all children, so this difficulty can be anticipated. The adult airway is subject to more variation and age-related disorders, leading to a difficult airway (eg, rheumatoid arthritis, obesity). Children are predictably "different," not "difficult." **Figure 25.2** demonstrates anatomic differences specific to children.

Physiologic Issues

There are two important physiologic differences between children and adults that impact airway management (**Box 25.1**). Children have a basal oxygen consumption that is approximately twice that of adults. Coupled with a proportionally smaller functional residual capacity (FRC) to body weight ratio, these factors result in more rapid desaturation in children compared with adults, given an equivalent duration of preoxygenation. Rapid desaturation is most pronounced in children < 24 months old. The clinician must anticipate and communicate this possibility to the staff and be prepared to provide supplemental oxygen by BMV if the patient's oxygen saturation drops below 90%.

Drug Dosage and Selection

The dose of succinylcholine (SCh) in children is different from that in adults. SCh is rapidly metabolized by plasma esterases and distributed to extracellular water. Children have a larger volume of extracellular

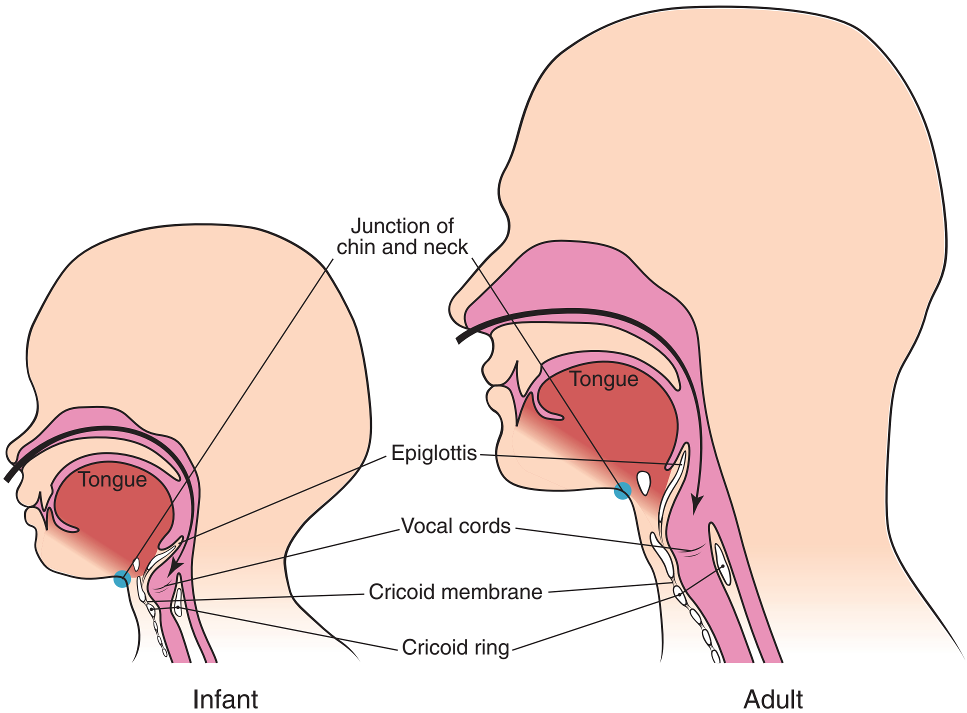

Figure 25.2: The anatomic differences specific to children are (1) higher, more anterior position of the glottic opening (note the relationship of the vocal cords to the chin/neck junction); (2) relatively larger tongue in the infant, which lies between the mouth and glottic opening; (3) relatively larger and more floppy epiglottis in the child; (4) the cricoid ring is the narrowest portion of the pediatric airway versus the vocal cords in the adult; (5) position and size of the cricothyroid membrane in the infant; (6) sharper, more difficult angle for blind nasotracheal intubation; and (7) larger relative size of the occiput in the infant.

BOX 25.1 Physiologic Differences

Physiologic Difference	Significance
Basal O_2 consumption is twice adult values (>6 mL/kg/min); proportionally smaller functional residual capacity as compared with adults	Shortened period of protection from hypoxia for equivalent preoxygenation time as compared with adults. Infants and small children often require bag-mask ventilation while maintaining cricoid pressure to avoid hypoxia.

fluid water relative to adults: at birth, 45%; at age 2 months, ~ 30%; at age 6 years, 20%; and at adulthood, 16% to 18%. The recommended dose of SCh, therefore, is higher on a per kilogram basis in children than in adults (2 vs 1.5 mg/kg). All drug dosage determinations are most appropriately and safely done using resuscitation aids such as the Broselow-Luten system previously described.

In 1993, the U.S. Food and Drug Administration (FDA), in conjunction with pharmaceutical companies, revised the package labeling for SCh in the wake of reports of hyperkalemic cardiac arrest following the administration of SCh to patients with previously undiagnosed neuromuscular disease. Initially, it stated that SCh was contraindicated for elective anesthesia in pediatric patients because of this concern, although the wording was subsequently altered to embrace a risk-benefit analysis when deciding to use SCh in children. However, both the initial advisory warning and the revised warning continue to recommend SCh for emergency or full-stomach intubation in children. Pediatric drug doses are provided in **Table 25.3**.

Equipment Selection

Table 25.1 references length-based recommendations for emergency equipment in pediatric patients. Appropriately sized equipment can be chosen with a centimeter length measurement or with a Broselow tape.

TABLE 25.3 Drugs—Pediatric Considerations

Drug	Dosage	Pediatric-Specific Comments
Premedications		
Atropine	0.02 mg/kg	An option <1 y of age
Induction Agents		
Midazolam	0.3 mg/kg IV	Use 0.1 mg/kg if hypotensive
Etomidate	0.3 mg/kg IV	
Ketamine	2 mg/kg IV, 4 mg/kg IM	
Propofol	2-3 mg/kg IV	
Paralytics		
Succinylcholine	2 mg/kg IV	Have atropine drawn up and ready
Vecuronium	0.2 mg/kg IV	May increase to 0.3 mg/kg of vecuronium for RSI (0.1 mg/kg for maintenance of paralysis)
Rocuronium	1.0 mg/kg IV	For RSI

IM, intramuscularly; IV, intravenous; RSI, rapid sequence intubation.

***A word of caution with respect to the storage of airway management equipment for children*:** Despite best efforts (eg, equipment lists or periodic checks), it is not uncommon for newborn equipment to be mixed in with or placed in proximity to the smallest pediatric equipment. This practice may lead to newborn equipment being used in older children for whom it may not be intended. Examples include the no. 0 laryngoscope blade, which is too short to allow visualization of the airway; the 250-mL newborn BMV, which provides inadequate ventilation volumes; and various other equipment, such as oral airways that can cause airway obstruction if too small (see **Table 25.4**).

Endotracheal Tubes

The correct endotracheal tube (ETT) size for the patient can be determined by a length measurement and by referring to the equipment selection chart. The formula (16 + age in years)/4 is also a reasonably accurate method of determining the correct uncuffed tube size. However, the formula cannot be used in children younger than 1 year and is useful only if an accurate age is known,

TABLE 25.4 Dangerous Equipment

Equipment	Problem
No. 0 or no. 00 laryngoscope ETT blades	Valuable time can be lost trying to visualize the glottic opening if mistaken for a no. 1 blade.
Curved no. 1 laryngoscope blades	Straight blades are preferred because of the following: The epiglottis is picked up directly, not indirectly, by compressing the hyoepiglottic ligament in the vallecula. The tongue and mandibular anatomy are more easily elevated from the field of vision.
250-mL BMV	Cannot generate adequate tidal volumes
Cuffed ETTs <5.0 mm	If leak pressures are not monitored, ischemia of the tracheal mucosa may develop with the potential for scarring and stenosis.
Oral airways <50 mm	Unless appropriate size oral airways are used, they may act to increase, rather than relieve, obstruction.
Any *other* equipment too small	Sizing is critical to function!

Note: Only appropriate size is functional. Frequently, very small sizes are placed in the pediatric area without attention to appropriateness of size. This can greatly contribute to a failed airway outcome.

BMV, bag-mask ventilation; ETT, endotracheal tube.

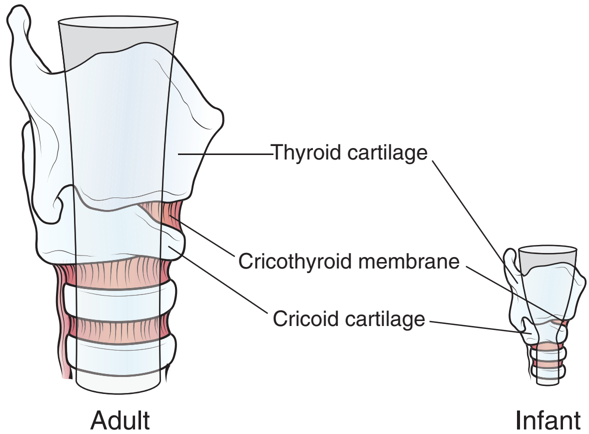

Figure 25.3: Airway shape. Note the position of the narrowest portion of the pediatric airway, which is at the cricoid ring, creating a funnel shape, versus the cylindrical shape seen in the adult, where the vocal cords form the narrowest portion. This is the rationale for using the uncuffed tube in the child; it fits snugly, unlike the cuffed tube used in the adult, which is inflated once the tube passes the cords to produce a snug fit. (Modified with permission from Cote CJ, Todres ID. The pediatric airway. In: Cote CJ, Ryan JF, Todres ID, et al, eds. *A Practice of Anesthesia for Infants and Children.* 2nd ed. WB Saunders; 1993.)

although this cannot always be determined in an emergency. Either cuffed or uncuffed ETTs are acceptable in the younger pediatric age groups (**Fig. 25.3**). The admonition to avoid cuffed tubes in young infants is historical, and in the past, there was an unacceptably high rate of subglottic stenosis resulting from failure to carefully monitor cuff pressures. Newer ETTs make it easier to monitor cuff pressures and can be safely used in infants and small children, provided clinicians recognize the following fact: A cuffed tube adds 0.5 mm to the internal diameter (ID), so a smaller than predicted (by 0.5 mm) tube may be required. The cuffed tube should be inserted with the cuff deflated initially and inflated with the minimum volume of air needed for an adequate seal.

When intubating a young child, there is a tendency to insert the ETT too far, usually into the right mainstem bronchus. Various formulas can be used to determine the correct insertion distance (eg, tube size times 3; age/2 + 10). For example, a 3.5-mm ID tube should be inserted $3.5 \times 3 = 10.5$ cm at the lip. Alternatively, a length-based chart can be used. We recommend placing a piece of tape on the tube at the appropriate lip-to-tip centimeter line, which serves as a constant visual reminder of the correct position of the tip of the ETT in the intubated patient.

Tube-Securing Devices

Once an ETT has been successfully placed, take care to appropriately secure the tube at the mouth to prevent inadvertent dislodgement and extubation. Head and neck movement, particularly extension that translates into movement of the tube up and potentially out of the trachea, should be minimized. A cervical collar placed after intubation prevents flexion and extension and can therefore help prevent ETT dislodgement (**Fig. 25.4**). The ETT is traditionally secured by taping the tube to the cheek, although various commercial devices are also available.

Oxygen Masks

The simple rebreather mask used for most patients provides a maximum of 35% to 60% oxygen and requires a flow rate of 6 to 10 L/min. A non-rebreather mask can provide ~ 70% oxygen in children if a flow rate of 10 to 15 L/min is used. For emergency airway management, and particularly for preoxygenation for rapid sequence intubation (RSI), the pediatric non-rebreather mask is preferable. Adult non-rebreather masks can be used for older children but are too large to be used for infants and small children and will entrain significant amounts of room air. Apneic oxygenation (see Chapter 8) should be considered in children (at a rate of 1 L / min per year of age) as a low-risk maneuver to prolong safe apnea time. Recent evidence suggests that, in adults, turning the oxygen flow rate to the "flush" rate of 40 to 70 L/min (varies depending on the wall source) increases FIO_2 (>90%) and end-tidal oxygen measurements. This has not been studied rigorously in children but may be reasonable to try if preoxygenation is difficult. Additionally, properly configured bag-mask systems (ie, those that function

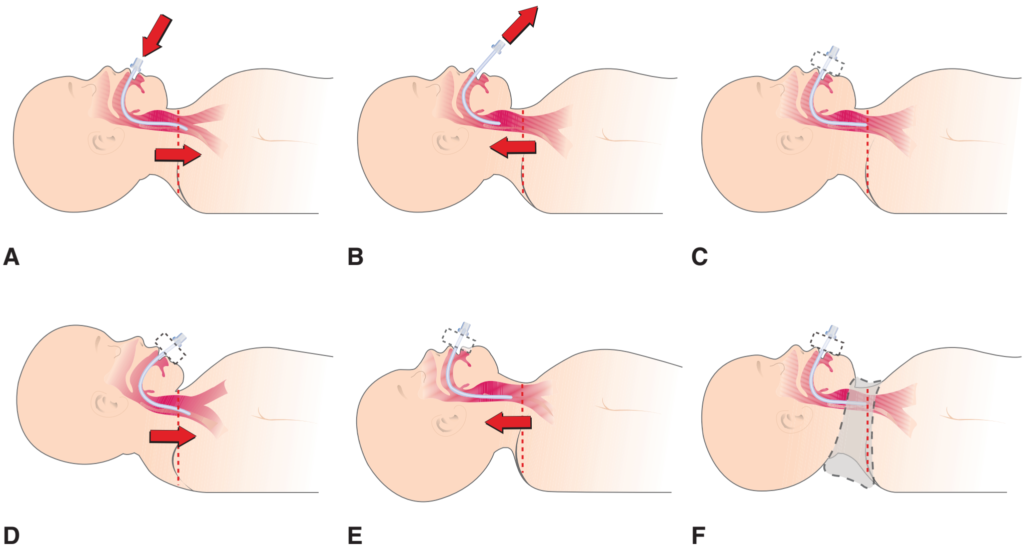

Figure 25.4: Securing the endotracheal tube. A: Unsecured tube sliding in/down. **B:** Unsecured tube sliding out/up. **C:** Tube secured to prevent in/out, up/down movement. **D:** Secured tube moving down and in as head flexes. **E:** Secured tube moving up/out as head extends. **F:** Neck movement prevented by cervical collar, thus preventing tube movement in the trachea.

as one-way inspiratory and expiratory valves and small dead space) are capable of delivering oxygen concentrations >90%, if correctly used. On inspiration, the spontaneously breathing patient opens the duck-billed inspiratory valve, and on expiration the expired volume with carbon dioxide (CO_2) pinches the duckbill valve closed and is vented through the expiratory valve into the atmosphere. One must be confident that the patient can generate sufficient negative inspiratory force to open the valve and draw a volume from bag; otherwise, bag assist is required. Adult-type units tend not to be used in infants and small children because of dead space considerations and size-related awkwardness, leading some to prefer pediatric non-rebreather BMV masks.

Oral Airways

Oral airways should be used only in children who are unconscious. In the conscious or semiconscious child, these airways can precipitate vomiting. Oral airways can be selected based on the Broselow tape measurement or can be approximated by selecting an oral airway that fits the distance from the angle of the mouth to the tragus of the ear.

Nasopharyngeal Airways

Nasopharyngeal airways are helpful in the obtunded but responsive child. The correctly sized nasopharyngeal airway is the largest one that comfortably fits in the naris but does not produce blanching of the nasal skin. The correct length is from the tip of the nose to the tragus of the ear and usually corresponds to the nasopharyngeal airway with the correct diameter. Care must be taken to suction these airways regularly to avoid blockage.

Nasogastric Tubes

BMV may lead to insufflation of the stomach, hindering full diaphragmatic excursion and preventing effective ventilation. Place a nasogastric (NG) tube soon after intubation to decompress the stomach in any patient who has undergone BMV and who requires ongoing mechanical ventilation after intubation. Often, in such patients, the abdomen is distended or tense, making the problem obvious, but other times it is difficult to identify the difference between this and the normally protuberant abdomen of the young child. Difficulty in ventilation that is felt to be related to reduced compliance should prompt the placement of an NG tube. Length-based systems identify the appropriate NG tube size.

BMV Equipment

For emergency airway management, the self-inflating bag is preferred by most over the anesthesia ventilation bag. These bag-mask units should have an oxygen reservoir so that at 10 to 15 L

TABLE 25.5 Alternatives for Airway Support

Bag-mask ventilation	May be the most reliable temporizing measure in children. Equipment selection, adjuncts, and good technique are essential.
Orotracheal intubation (usually with rapid sequence intubation)	Still the procedure of choice for emergent airway in potential cervical spine injury and most other circumstances
Needle cricothyrotomy	Recommended as last resort in infants and children, but data lacking
Laryngeal mask	Viable alternative
Blind nasotracheal intubation	Not indicated for children younger than 10 y
GlideScope	Well studied in adults, a potential alternative in children

of oxygen flow, one can provide an FIO_2 of 90% to 95%. The smallest bag that should be used is 450 mL. Neonatal bags that are smaller (250 mL) do not provide effective tidal volume even for small infants. Many of the pediatric BMV devices have a positive-pressure relief (pop-off) valve. The pop-off valve may be set by the manufacturer to open anywhere between 20 and 45 cm H_2O pressure (centimeters of water pressure [CWP]), depending on whether the bag unit is intended for infants or small children (respectively), and is used to prevent barotrauma. The clinical scenarios encountered in emergency airway management often require higher peak airway pressures, so the bag should be configured without a pop-off valve or with a pop-off valve that can be closed. It is a good practice to store the BMV device with the pop-off valve closed so that initial attempts to ventilate the patient can achieve sufficient peak airway pressure to achieve ventilation. Chapter 26 discusses this issue in more detail and offers suggestions to prevent its occurrence.

End-Tidal CO_2 Detectors

Colorimetric end-tidal CO_2 ($ETCO_2$) detectors are as useful in children as in adults. A pediatric size exists for children weighing <15 kg, whereas the adult model should be used for children weighing >15 kg. If an adult-sized $ETCO_2$ device is used inappropriately for a small child, there may be insufficient CO_2 volumes to cause the detector to change color, resulting in a false-negative reading and removal of a correctly placed tube. Conversely, the resistance in a pediatric $ETCO_2$ detector may be sufficiently high to make ventilation difficult in a larger child.

Airway Alternatives

Orotracheal intubation is the procedure of choice for pediatric emergency airway management, including those patients with potential cervical spine injury where RSI with in-line manual stabilization is preferred. Nasotracheal intubation is relatively contraindicated in children **(Table 25.5)**.

Cricothyrotomy is the preferred emergency surgical airway in adults. The cricothyroid membrane develops in early childhood but is not of sufficient size to make it a viable rescue airway option until 10 years of age. "Needle cricothyrotomy" in children younger than 10 years is the term used when one accesses the airway in a percutaneous manner in young children, even though it is recognized that the point of entry into the airway is often the trachea as opposed to the cricothyroid space.

Other devices that may be of use in difficult airway management in young children are laryngeal mask airways (LMAs) and the GlideScope. LMAs are made for even newborns and young infants and may be useful as a temporizing measure when direct laryngoscopy proves difficult. The GlideScope is supplied in sizes appropriate for pediatric patients, although the penetration of this technology to all clinical settings has not occurred. These and other adjuncts are discussed in Chapter 26.

INITIATION OF MECHANICAL VENTILATION

In emergency pediatrics, two modes of ventilation are used. Pressure-controlled ventilation is the mode used for newborns and small infants, whereas volume-controlled ventilation is used for older children and adults. One can arbitrarily set 10 kg as the weight below which pressure-limited ventilators should be used, although volume-limited ventilators have been used effectively in smaller children. The younger the child is, the more rapid the ventilatory rate. The initial ventilatory rate in infants is typically set between 20 and 25 breaths per minute. Inspiratory:expiratory ratios are set at 1:2, and the typical peak inspiratory pressure at initiation of ventilation is between 15 and 20 CWP. These initial settings in a pressure-controlled ventilation mode will usually give a tidal volume of 8 to 12 mL/kg. These initial settings are adjusted according to subsequent clinical evaluation and chest rise. Positive end-expiratory pressure should also be set at 3 to 5 cm of water and FIO_2 at 1.0. The Broselow-Luten length-based system also provides guidance for approximate starting tidal volumes, ventilator rates, and inspiratory times.

Once initial settings have been established, it is critical that the patient be quickly reevaluated and adjustments made, particularly as pulmonary compliance, airways resistance, and leak volumes change with time, precluding adequate ventilation with the initial settings of pressure-controlled ventilation. Clinical evaluation of ventilatory adequacy is more important than formulae to ensure adequate ventilation. Once adjustments are made and the patient appears clinically to be ventilated and oxygenating, blood gas determinations, or continuous pulse oximetry and $ETCO_2$ monitoring, should be used for confirmation and to guide additional adjustments (**Table 25.6** and **Box 25.2**).

TABLE 25.6 Initiation of Mechanical Ventilation

I. Initial Settings		
Ventilator type	Pressure limited	Volume limited
Respiratory rate	20-25/min	12-20/min, by age
Positive end-expiratory pressure (cm H_2O)	3-5	3-5
FIO_2	1.0 (100%)	1.0 (100%)
Inspiratory time	≥0.6 sec	≥0.6 sec
Inspiratory/expiratory ratio	1:2	1:2
Pressure/volume settings	For pressure ventilation, start with peak inspiratory pressure (PIP) of 15-20 cm H_2O. Assess chest rise and adjust to higher pressures as needed. For volume ventilation, start with tidal volumes of 8-12 mL/kg. Start at lower volumes and increase to a PIP of 20-30 cm H_2O. *These are initial setting guidelines only. Assess chest rise and adjust accordingly.*	
II. Evaluate Clinically and Make Adjustments	Most patients will be ventilated with volume-cycled ventilators. Poor chest rise, poor color, and decreased breath sounds require *higher* tidal volume. Check for pneumothorax or blocked tube. Ensure that tube size and position are optimal and leaks are not present. For patients ventilated with pressure-cycled ventilators, these findings may indicate the need to increase the PIP	
III. Laboratory Information	Arterial blood gas should be performed ~ 10-15 min after settings are stabilized. Additional samples may be necessary after each ventilator adjustment, unless ventilatory status is monitored by $ETCO_2$ and SPO_2.	

BOX 25.2 Emergency Pediatric Airway Management—Practical Considerations

Anatomic

- Anticipate high anterior glottic opening
- Do not hyperextend the neck
- Uncuffed tubes are used in children younger than 8 y
- Use straight blades in young children

Physiologic

- Anticipate desaturation

Drug Dosage and Equipment Selection

- Use length-based system. Do *not* use memory or do calculations
- Nasogastric tube is an important airway adjunct in infants
- Stock pediatric non-rebreather masks

Airway Alternatives for Failed or Difficult Airway

- Surgical cricothyrotomy—contraindicated until age 10 y
- Blind nasotracheal intubation—contraindicated until age 10 y
- Combitube—only if >4 ft tall
- Needle cricothyrotomy—acceptable

TIPS AND PEARLS

RSI Techniques for Children

The procedure of RSI in children is essentially the same as in adults, with a few important differences outlined as follows:

- Preparation
  - Use resuscitation aids that address age- and size-related issues in drug dosing and equipment selection (eg, Broselow-Luten tape).
- Preoxygenation
  - Be meticulous. Children desaturate more rapidly than adults do.
  - Consider apneic oxygenation as an adjunct to maximize safe apnea time.
- Physiologic optimization
  - Weight-based isotonic fluid boluses or blood for hypotension. Maximize preoxygenation efforts. Consider atropine for infants <1 year of age.
- Paralysis with induction
  - Induction agent selection as for adult: dose by length or weight.
  - SCh 2 mg/kg IV or rocuronium 1 mg/kg.
  - Anticipate desaturation; bag ventilate if oxygen saturation (Sp_{O_2}) is <90%.
- Positioning with protection
  - Optional: apply Sellick maneuver.
- Placement with proof
  - Confirm tube placement with $ETCO_2$ as for adult.
- Postintubation management

In almost all cases, children who are intubated and mechanically ventilated should be sedated and paralyzed in the emergency department to prevent deleterious rises in intracranial or intrathoracic pressures and inadvertent ETT dislodgement.

EVIDENCE

Is lack of experience in managing pediatric airways a major problem for Emergency Providers?

Since the inception of Emergency Medicine as a specialty, there has been a concern over the amount of training emergency medicine residents received in pediatrics. Exposure to critically ill children is less common than exposure to critically ill adults in most training programs.[1,2,3] Introduction of the pneumococcal and *Haemophilus influenzae* vaccines, the change in sleep position that has reduced sudden infant death syndrome deaths, and the overall improvement in pediatric care have further reduced ED visits for acute respiratory events. A recent article from a large children's hospital with >90 000 ED visits a year demonstrated insufficient exposure to critical procedures, especially intubations.[4] Informal surveys from the *Difficult Airway Course: Emergency* reveal that the emergency physician's experience and comfort with pediatric airways is a source of concern to many practitioners. It is hoped that the focused education and training in the airway course, and other high-quality simulation programs, can bolster comfort levels.[5]

What are the particular barriers to successful airway management in children?

Time delay and cognitive errors are more common with pediatric emergency airway management.[6] Pediatric emergencies are complicated by the fact that children vary in size, creating logistical difficulties, especially with respect to drug dosing and equipment selection. This mental burden (or "cognitive load") can be reduced by the use of resuscitation aids, which save time and reduce errors. The literature suggests that resuscitation aids can mitigate the effect of these variables on the mental burden in the resuscitative process.[7] Simulated emergency patient encounters have confirmed that the Broselow-Luten color-coded emergency system reduces time delay and errors by eliminating the cognitive burden associated with these situations.[8]

To the extent that the process can be simplified (eg, limiting the number of recommended medications, reducing the complexity and number of decisions required), time is freed up for critical thinking that can then be dedicated to the priorities of airway management. The management of children in extremis is inherently stressful, and, as such, RSI should be kept simple and uncomplicated to reduce this stress.

Should atropine be used for RSI in children?

The evidence does not support the universal use of atropine in children; however, it is an issue that is difficult to definitively resolve based on current literature. Traditionally, atropine has been used to prevent the bradycardia associated with a single dose of SCh in children, a rare but serious event. A few recent studies failed to show a difference in response to SCh with or without atropine in children,[9,10] with similar numbers in the atropine- and noratropine-treated groups developing transient, self-limited decreases in heart rate. The absence of evidence of benefit, however, should not be construed as "proof" when dealing with uncommon events. Atropine also has significant but rare side effects, including paradoxical bradycardia if incorrectly dosed.[11] Atropine may have a role when manipulating the airway of infants younger than 1 year because of their high vagal tone, coupled with a relatively greater dependency on heart rate for cardiac output.[12] However, most bradycardic episodes are because of hypoxia or are a transient, vagally mediated reflex response that resolves spontaneously. It is better to treat the hypoxia or the reflex if it occurs. To keep the process of RSI in children as simple as possible, we are not recommending the routine use of atropine. In special circumstances, such as with infants younger than 1 year (3, 4, and 5 kg, and pink or red zones on the Broselow-Luten tape and airway card), atropine can be considered optional.

SCh versus rocuronium as a paralytic in children—which is the preferred agent?

In the 1990s, the FDA warned against the use of SCh in children following case reports of hyperkalemic cardiac arrest following the administration of SCh to patients with undiagnosed neuromuscular disease. The pediatric anesthesia community at that time challenged the FDA decision based on the risk versus benefit in patients requiring emergency intubation, leading to a modification of their position to a "caution." There is no body of evidence that specifically addresses the relative risks and benefits of SCh versus rocuronium in children to guide recommendations. Currently, SCh remains the agent of choice for emergency full-stomach intubations, although both rocuronium and SCh should be considered viable options for emergency airway management of the pediatric patient based on provider preference.[13,14]

Are cuffed ETTs contraindicated in pediatric emergency airway management?

The issue of whether cuffed ETTs are safe or required in children younger than 8 to 10 years has been debated for some time because of the anatomic and functional seal afforded by the subglottic area. Two studies have addressed this issue.[15,16] Deakers et al. studied 282 patients intubated in the operating room, emergency department, or ICU.[15] In their observational prospective, nonrandomized study, they found no difference in postextubation stridor, the need for reintubation, or long-term upper airway complications. Khine et al. compared the incidence of postextubation croup, inadequate ventilation, anesthetic gases leaking into the environment, and the requirement for a tube change resulting from air leak.[16] In this study of children younger than 8 years, the authors found no difference in croup, more attempts at intubation with uncuffed tubes, less gas flow required with cuffed tubes, or less gas leakage into the environment. Additionally, any large air leak in an uncuffed tube may require tube removal and replacement, which may not be the case with a cuffed ETT, where there is more "margin for error" in sizing afforded by the cuff. Even though it may seem that the use of cuffed tubes in younger children does not result in any postextubation sequelae, it must be made clear that these studies monitored cuff inflation pressures, a practice that is uncommonly performed in emergency intubations. For this reason, it seems reasonable to recommend the use of uncuffed ETTs to avoid excessive tracheal mucosal pressure with the potential sequelae of scarring and stenosis. However, for some patients in whom high mean airway pressures are expected, such as those with acute respiratory diseases and asthma, the placement of a cuffed tube with the cuff initially deflated, and inflated if necessary, may be appropriate. The most recent Pediatric Advanced Life Support standards recommend cuffed tubes, but with the qualifier *only if leak pressures are monitored*.[17]

Why do children desaturate more quickly than adults with comparable degrees of preoxygenation?

An infant uses 6 mL of oxygen/kg/min as compared with the adult who uses 3 mL/kg/min. The FRC reduction in an apneic child is far greater than in the apneic adult owing to differences in the elastic forces of the chest wall and the lung. In children, the chest wall is more compliant, and the lung elastic recoil is less than in adults. An analysis of these forces reveals that if they are brought into equilibrium as in the apneic patient, a value of FRC around 10% of total lung capacity is predicted instead of the observed value of slightly <40%. These same factors also reduce the FRC in the spontaneously breathing patient, albeit to a lesser degree. FRC is further reduced with the induction of anesthesia and by supine positioning. The clinical implication of the decreased effective FRC combined with increased oxygen consumption is that the preoxygenated, paralyzed infant has a disproportionately smaller reservoir of intrapulmonary oxygen to draw on as compared with the adult. Pulmonary pathology in critically ill patients may further reduce the ability to effectively preoxygenate. It is therefore critical that these factors be considered when preoxygenating a pediatric patient. BMV with cricoid pressure may be required to maintain oxygen saturation above 90% during RSI, especially if multiple attempts are required or the child has a disorder that compromises the ability to preoxygenate.[18,19]

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