Section 1

Resuscitation

Expert reviewers: James P. Andrus and Anand Rajani

Chapter 1

Airway, breathing, and ventilation

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Introduction

While resuscitation concepts and priorities are the same for children and adults, the situation of a pediatric code is quite different. An acute life-threatening medical emergency in a child is usually unexpected and a child can often be resuscitated with the expectation of full recovery. Appropriate airway management is vital since hypoxia is the most common cause of cardiac arrest in children. Pragmatically, the need for varying sized equipment and weight-based dosing can cause confusion, delay, and mistakes.

This section will discuss the anatomic and physiologic differences between the pediatric and adult airway and apply these to principles of airway management. We discuss rapid sequence intubation (RSI) and rescue airway measures as well as special pediatric cases that may present airway management difficulties.

Assessment of respiratory status

A child may be too young to declare shortness of breath. Pediatric vital signs should be compared with age-related normal values. Pulse oximetry is a fifth vital sign and useful in monitoring oxygenation, not ventilation. Capnography is being increasingly used to identify situations of decreased ventilation.

Observation is the most accurate method to identify respiratory distress. Tachypnea is the initial compensatory mechanism for preserving minute ventilation. Chest rise or abdominal excursions also reveal the adequacy of the patient's respirations. Snoring or stridor indicates upper airway obstruction; wheezes indicate lower airway obstruction. Retractions (supraclavicular, subcostal, or abdominal), as well as grunting and nasal flaring can be subtle but significant signs of increased work of breathing. Overall general appearance – posture, level of alertness or responsiveness – and indications from other organ systems such as the central nervous system (CNS) (lethargy, agitation, or other altered mental status) and skin (pallor, cyanosis, or delayed capillary refill) will contribute to recognition of respiratory distress and impending respiratory failure in a child.

The pediatric airway

Anatomy

The pediatric airway is usually a different, rather than a difficult, airway. The differences are most pronounced in infants, and decrease with growth so that the airway in an 8-year-old child is considered similar to an adult's airway (Fig. 1.1). These anatomical differences result in different management techniques (Table 1.1).

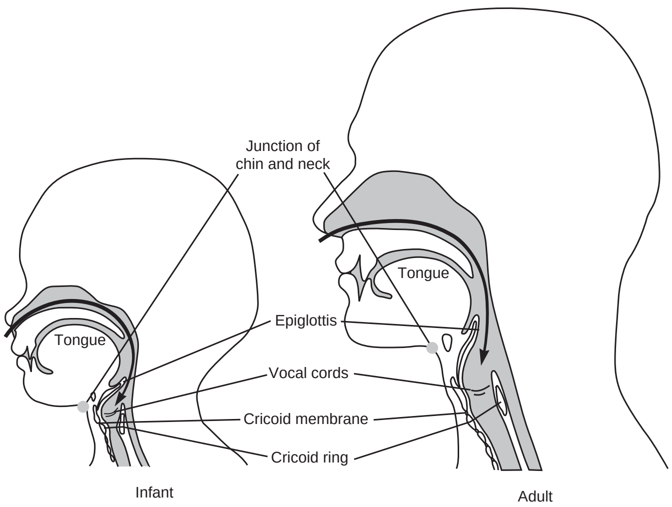

Figure 1.1 Anatomic airway differences between children and adults. Features that are distinct to the child are: higher, more anterior position for the glottic opening in a child (note the relationship of the vocal cords to the chin–neck junction); relatively larger tongue in the infant, which lies between the mouth and glottic opening; relatively larger and more floppy epiglottis in the child; cricoid ring is the narrowest portion of the pediatric airway whereas the vocal cords are in the adult; position and size of the cricothyroid membrane differs between infant and adult; sharper, more difficult angle for blind nasotracheal intubation in the child; larger relative size of the occiput in the infant. (Reproduced with permission from Walls RM, Murphy MF, Luten RC, *et al. Manual of Emergency Airway Management*, 3rd edn. Philadelphia, PA: Lippincott Williams & Wilkins, 2008.)

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Table 1.1. Unique characteristics of pediatric airway anatomy and its consequences in airway management

Pediatric anatomic feature	Airway management significance	Airway management adjustment
Large head, short neck	Neutral cervical spine position/sniffing position difficult to achieve	Shoulder roll or elevation of head
Nares smaller; infants up to 6 months of age are obligate nasal breathers	Small nares cause increased resistance to airflow particularly when narrowed by secretions	Avoid accidental compression of nares with bag-valve mask, which can cause significant respiratory obstruction
Small mouth, large soft tissue structures	Less space for laryngoscope blade and airway visualization	Use of smaller straight laryngoscope blade
Large tongue	Most common cause of airway obstruction is the tongue	Use of chin lift maneuvers and airway adjuncts (nasopharyngeal, oropharyngeal)
Large adenoids	Potential for bleeding and soft tissue obstruction	Blind nasotracheal intubation contraindicated in children <9 years Oropharyngeal airway should not be initially inserted upside down and turned
Anterior and cephalad airway	Acute angle between epiglottis and anterior glottic opening makes nasotracheal intubation difficult	Alignment of different airway axes is often better accomplished with a straight blade than a curved blade
Long floppy epiglottis	Epiglottis can block visualization of the airway	Straight blade, with a narrower tip can be used to lift it out of the way
Cricoid ring is narrowest part of pediatric airway	Failure to get good compliance and seal with uncuffed endotracheal tube	Gently inflated cuffed endotracheal tube can be used to decrease air leak and improve ventilation
Pediatric airway smaller and shorter and delicate	Pediatric airway more prone to obstruction, compression; right main stem intubation and tube dislodgement are more common	Vigilance with tube placement and confirmation, particularly with transfer of child
Chest wall pliability	Children can have increased lung parenchymal damage with few outward signs	Increased index of suspicion for lung injury in the setting of trauma
Diaphragm is the main muscle of breathing	Abdominal trauma and distention can cause or contribute to severe respiratory compromise	Placement of nasogastric and orogastric tubes with airway management as bag-valve mask can cause abdominal distention
Small cricothyroid membrane	Cricothyroidotomy contraindicated in children <8 years of age	Needle cricothyroidotomy can be used as an airway rescue technique

The oropharyngeal soft tissues are proportionately larger and have less tone in children than in adults, resulting in less space for manipulation inside the child's mouth. The tongue is the main cause of airway obstruction in the child. During infancy, the larynx is at the level of C1 and descends to the level of C4–C5 in the adult. This, coupled with the child's more anterior airway, changes the axes needed for alignment of the oropharynx and larynx during direct laryngoscopic intubation (Fig. 1.2). In an infant, the straight laryngoscope blade is better able to align these axes, and is also thinner and fits better into the mouth. The thinner tip of the straight blade also helps to elevate the floppy epiglottis out of the visual field.

The tongue is the main cause of airway obstruction in a child. If unable to use a bag-valve mask (BVM), use naso- and or oropharyngeal airways as adjuncts.

The narrowest portion of the pediatric airway is the cricoid cartilage, while the adult airway narrows at the level of the cords and then widens. Historically, uncuffed endotracheal tubes (ETT) have been recommended in children <8 years of age. Recently, ETT with uninflated or lightly inflated cuffs as well as new cuffed ETTs developed for children are more frequently recommended for pediatric intubation, particularly during resuscitation.

The large infant occiput can cause passive flexion of the cervical spine and subsequent compression of the pharyngeal airway. Consequently, an infant must be kept in the "sniffing position" to maintain cervical spine protection and open the airway (Fig. 1.2B). Overextension of the neck should be avoided to ensure optimal visualization of the cords. Since the child's vocal cords are more antero-caudally angled than in an adult, the vocal cords can be difficult to visualize during intubation if the child's head is not in an anatomical position. The pediatric trachea is smaller in diameter and length, and is more pliable and compressible than the adult airway. The infant's trachea is approximately 5 cm long and grows to 7 cm by 18 months. Failure to take the

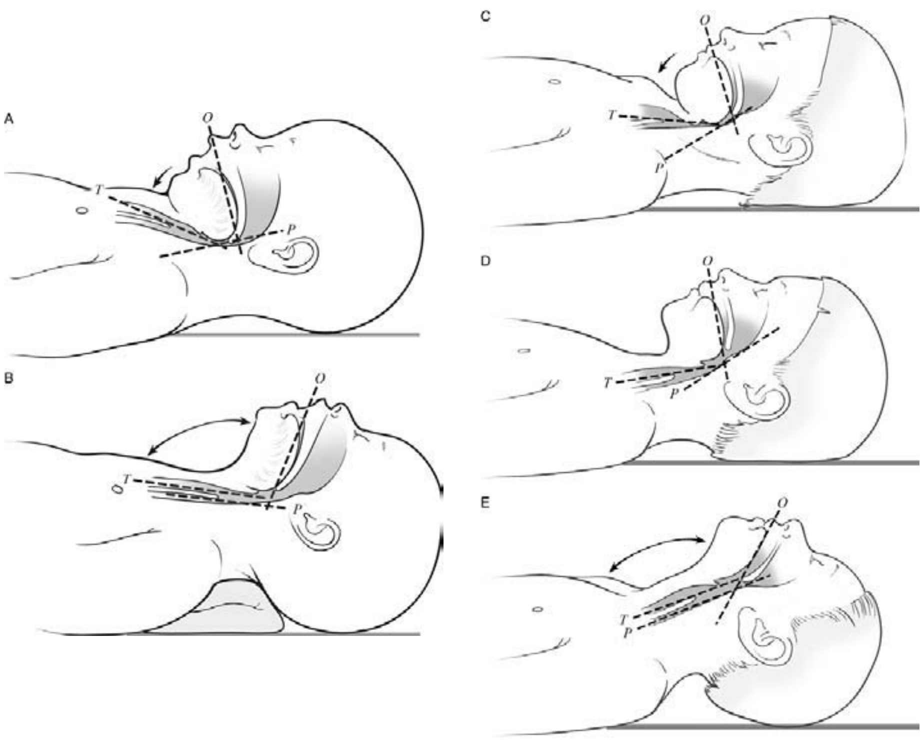

Figure 1.2 Comparison of infant and child positioning for ventilation and endotracheal intubation. (A) Incorrect infant positioning with neck flexion. (B) Correct infant positioning (also known as sniffing position) with oral (O), pharyngeal (P) and tracheal (T) axes aligned. (C) Incorrect child positioning with neck flexion and divergent axes. (D) Improved positioning with increased alignment of the pharyngeal and tracheal axes. (E) Increased extension causes maximal alignment of the axes. (Copyright Chris Gralapp.)

short length of an infant's trachea into account can result in right main-stem intubation, tube dislodgement, or mechanical barotrauma. The angle between the epiglottis and the larynx is more acute than in the adult patient and is difficult to maneuver. Blind nasotracheal intubation is contraindicated in young children because manipulation can cause trauma and bleeding of the oropharyngeal soft tissues. Cricothyroidotomy is contraindicated in children <8 years of age because the cricothyroid membrane is very small, difficult to palpate and incise (Fig. 1.3).

The diaphragm and abdominal wall musculature – the major respiratory muscles in a child – are underdeveloped and fatigue more quickly than in adults. Abdominal trauma or distention can impede these muscles and cause respiratory distress. Crying and BVM can lead to stomach inflation and increases the risk of aspiration while decreasing tidal volume. It is important to place a nasogastric or orogastric tube after definitive airway management.

Physiology

Children have smaller lung volumes and higher oxygen demands than adults. They also deplete their respiratory reserves more quickly than in adults. Hypoxia is poorly tolerated because of their baseline increased metabolic rate and increased cerebral blood flow. Children also have increased oral secretions and vagal tone compared with adults. Historically, this has led to the dictum of pretreatment with atropine to avoid bradycardia with laryngeal manipulation. Recent evidence has questioned this practice and atropine may not be required for all pediatric patients.

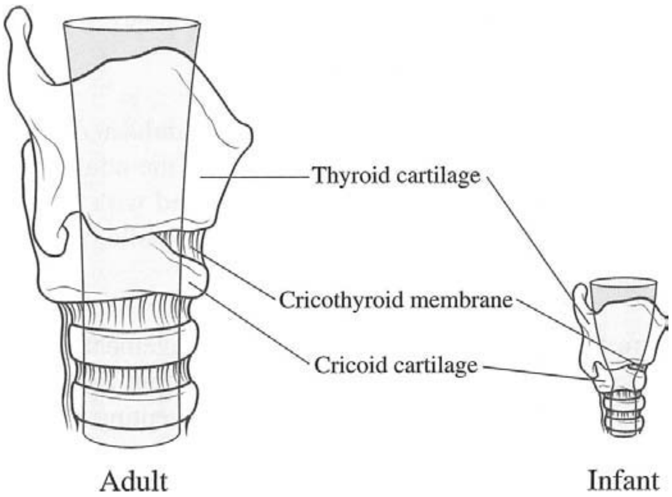

Figure 1.3 Comparison of infant and adult airway shape. The narrowest portion of the pediatric airway is the cricoid ring, whereas in the adult the narrowest portion is the vocal cords. The pediatric airway is funnel shaped but the adult is cylindrical. (Reproduced with permission Walls RM, Murphy MF, Luten RC, *et al. Manual of Emergency Airway Management*, 3rd edn. Philadelphia, PA: Lippincott Williams & Wilkins, 2008.)

Equipment

Medication dosing for children has been fraught with error, and color-coded, length-based resuscitation systems have been demonstrated to decrease medication errors as well as increase response time in emergency situations.

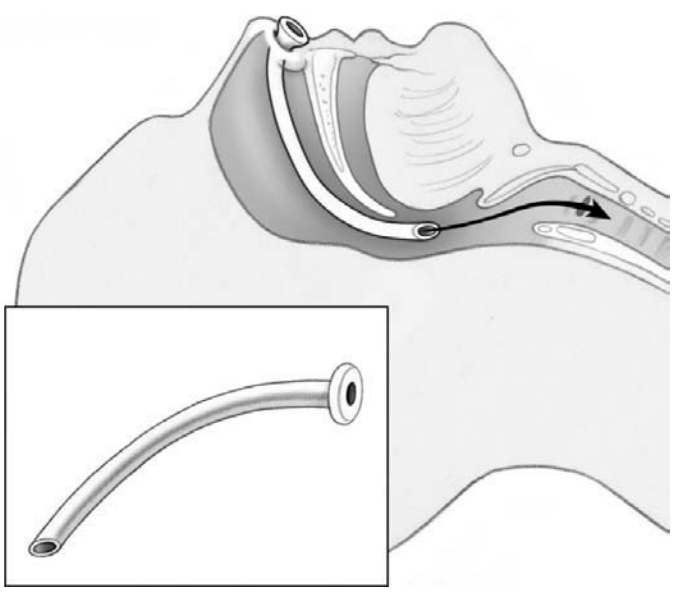

Figure 1.4 Nasopharyngeal airway. (Copyright Chris Gralapp; reproduced with permission from Mahadevan SV, Garmel GM. *An Introduction to Clinical Emergency Medicine*. Cambridge, UK: Cambridge University Press, 2005.)

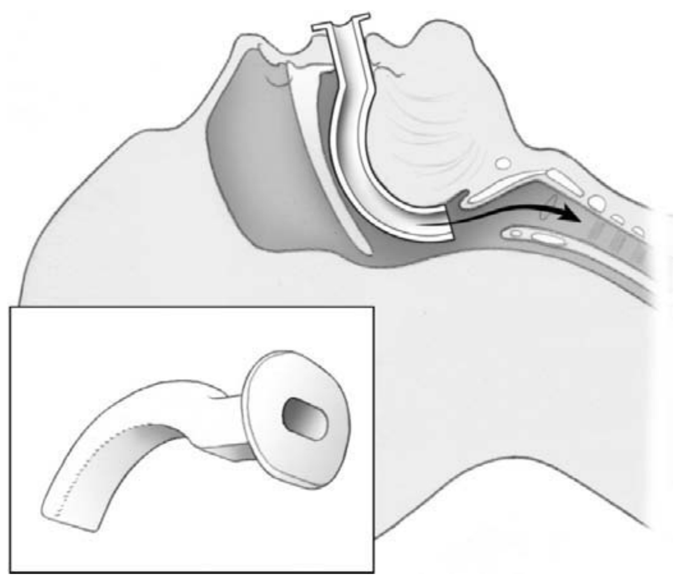

Figure 1.5 Oropharyngeal airway. (Copyright Chris Gralapp; reproduced with permission from Mahadevan and Garmel, 2005.)

Oxygen delivery adjuncts

Nasal cannula

Nasal cannula is acceptable for children who require minimal oxygen supplementation. The concentration of oxygen delivered can be unpredictable, and high flow can be upsetting to young children. A flow rate of <3–5 l/min is usually tolerated. Nasal prongs should be trimmed in small children.

Oxygen face mask

Oxygen flow rates should be set at 10 l/min to deliver 30–60% oxygen concentration and to prevent rebreathing of exhaled gas.

Non-rebreather oxygen mask

The non-rebreather masks are attached to a reservoir bag with an oxygen source. Most systems have a one-way valve to the reservoir bag to prevent exhaled gas from entering the reservoir. The oxygen flow rate should be 6–10 l/min (greater than the child's minute volume) and the reservoir bag must be larger than the patient's tidal volume and should stay inflated. Non-rebreather masks can deliver 60–90% oxygen concentration.

Airway adjuncts

Nasal airway

The nasal airway is for children who are conscious or semiconscious with a partially obstructed airway. An appropriately sized nasopharyngeal airway extends from the tip of the nose to the tragus of the ear, with the outside diameter smaller than the inner diameter of the nostril (Fig. 1.4).

Oral airway

The oral airway is used in unconscious children with airway obstruction. It is contraindicated in conscious children since it can trigger a gag reflex. An appropriately sized oral airway extends from the incisors to just anterior to the angle of the mandible. If the oral airway is too small, the tongue can be pushed into the pharynx, thus increasing airway obstruction. Place the oral airway by depressing the tongue with a tongue blade. (Fig. 1.5).

Ventilation assistance

Bag-valve mask

The BVM consists of a mask, valve, and bag that entrains room air between valve and mask but should be attached to an oxygen reservoir. The masks should be transparent and extend from the bridge of the nose to just under the mouth without compressing the eyes or extending over the edge of the chin. The BVMs used in the ED are usually self-inflating.

Laryngeal mask airways

The laryngeal mask airways can be used as a life-saving bridge to a definitive airway in children who cannot be ventilated effectively with the BVM; however, they do not provide protection from aspiration.

Intubation equipment

The ETT size can be calculated using the following formula:

$$\text{uncuffed tracheal tube size (mm)} = (\text{Age in years} + 16)/4$$

$$\text{cuffed tracheal tube size (mm)} = \text{Age in years} + 16/3$$

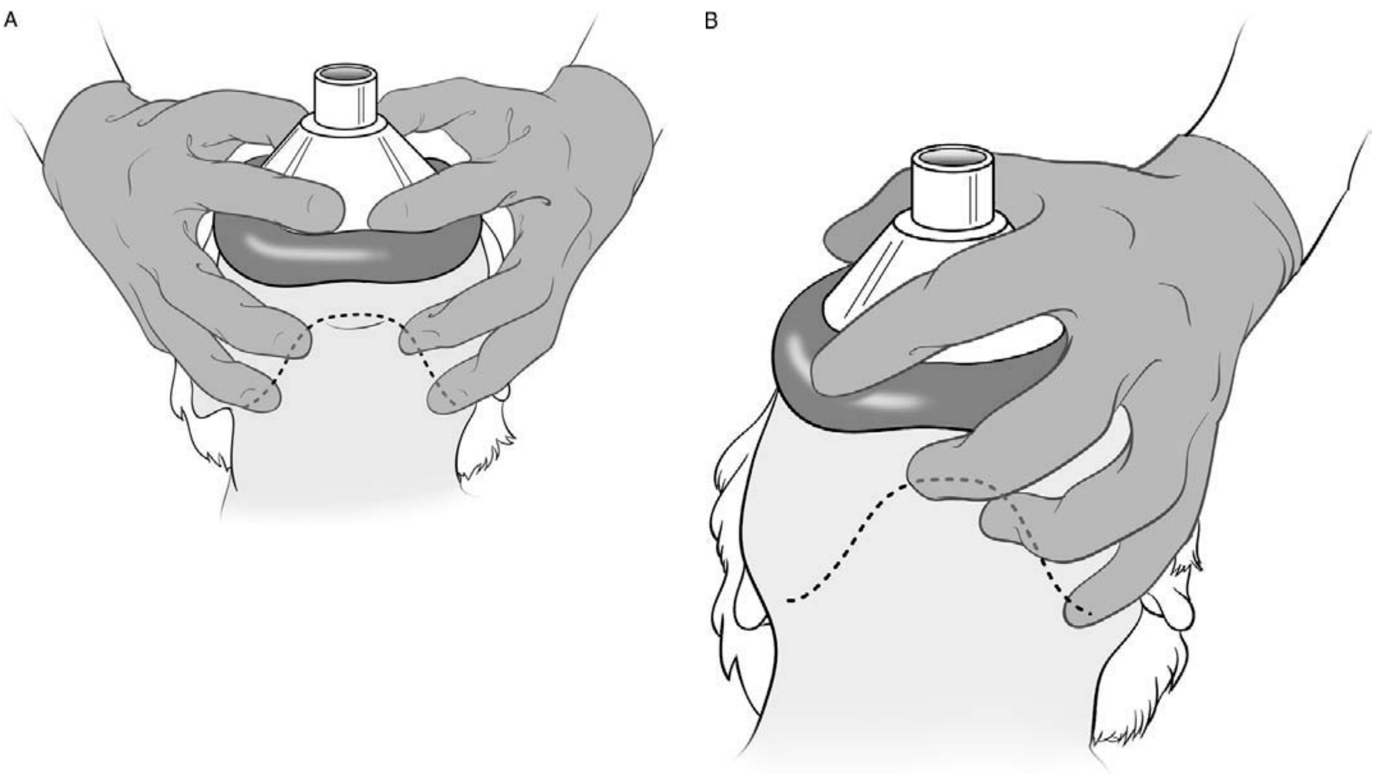

Figure 1.6 The EC technique for use of a bag-valve mask. The thumb and index finger form a "C" shape over the mask, with the third, fourth and fifth digits forming an "E" along the jaw line. (A) Two-handed technique. (B) One-handed technique. (Copyright Chris Gralapp.)

Most ETT have a mark that indicates the length at which the tube should have passed the vocal cords. The appropriate ETT depth of insertion can be calculated by the formula:

$$\text{ETT depth (cm)} = 3 \times \text{ ETT size}$$

Laryngoscope blades

Straight blades are easier to insert in the child's small mouth and can lift the relatively large and floppy epiglottis of infants. However, it can be difficult to retract the large, sometimes slippery tongue with the thinner, straight blade. Although the curved laryngoscope blade is larger and bulkier than the straight blade, it retracts the tongue more easily and may be useful in pediatric populations when the tongue is larger than usual.

Suction devices

Yankauer suction is necessary to clear anticipated and unanticipated blood and secretions.

Breathing and ventilation

If spontaneous ventilation and breathing are not adequate, children need assistance. Well-performed BVM ventilation can be life-saving and can temporize a situation until intubation is possible. The majority of children can be ventilated effectively with BVM, although complications include gastric distention and aspiration.

Because of the relative size of an adult's hand to a child's neck, it can be easy to accidentally cause further obstruction of the airway by applying pressure to the child's neck. The optimal method to hold the mask is to place the index finger on the mask, the middle finger on the chin, and the ring and little finger on the bony angle of the mandible (EC method) (Fig. 1.6).

Self-inflating BVM devices will not deliver oxygen unless squeezed. Tidal volumes set from 5–8 ml/kg in infants and children will mimic spontaneous breathing. Although most BVM devices have a pop-off valve to limit the amount of pressure that can be exerted manually on the child's airway, the potential for iatrogenic bronchoalveolar injury or pneumothorax from overexuberant ventilation exists. If BVM ventilation cannot be achieved, the airway should be repositioned. If jaw thrust or chin lift are not successful in relieving the airway obstruction (Figs. 1.7 and 1.8), an airway adjunct such as an oral and or nasal airway may be key in achieving successful BVM ventilation.

Intubation

The overall goal of emergency airway management is the same for children as for adults: (1) to supply supplementary oxygen, (2) to support ventilation, (3) to provide a secure patent

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Figure 1.7 Head tilt with chin lift. This maneuver should not be used in trauma situations. (Copyright Chris Gralapp; reproduced with permission from Mahadevan SV, Garmel GM. *An Introduction to Clinical Emergency Medicine*. Cambridge, UK: Cambridge University Press, 2005.)

airway, and (4) to prevent aspiration. Definitive airway management, usually achieved by endotracheal intubation, is indicated for airway protection, to decrease the work of breathing, or for respiratory failure.

Positioning

The airway should be optimized by placing the child's head in the sniffing position while maintaining neutral alignment of the cervical spine. Often, a shoulder roll for an infant, or pillow for a child <2 years of age, is helpful for positioning. A chin lift or jaw thrust maneuver combined with bimanual in-line spinal immobilization may be necessary to maintain an unobstructed airway in a trauma victim.

A systematic protocol, RSI, uses sedatives and neuromuscular blocking agents to increase chances of a successful intubation and decrease risks of aspiration, while avoiding elevated intracranial pressure for head injured patients There are 10 steps in RSI.

1. Brief history
2. Preparation
3. Monitoring
4. Preoxygenation
5. Premedication
6. Cricoid pressure ± assisted ventilation
7. Sedation
8. Paralysis
9. Intubation
10. Confirmation of tube placement.

Figure 1.8 Jaw thrust without head tilt. (Copyright Chris Gralapp; reproduced with permission from Mahadevan SV, Garmel GM. *An Introduction to Clinical Emergency Medicine*. Cambridge, UK: Cambridge University Press, 2005.)

Major differences between pediatric and adult RSI occur at the steps of preoxygenation and premedication (Table 1.2). Preoxygenation consists of the patient breathing 100% oxygen spontaneously for 5 min. During this time, all nitrogen should be effectively displaced from the lungs, providing the patient with an oxygen reserve. While the adult patient can tolerate up to 5 min of apnea without developing hypoxia, children can tolerate only 2–3 min before developing hypoxia.

Pharmacy for RSI involves a choice of premedications, sedatives, and paralytics depending on the clinical situation. Areas of historical controversy in pediatric RSI include the use of atropine as a premedication, the use of etomidate as an RSI sedative, and the use of succinylcholine (suxamethonium) as a paralytic agent. The addition of adjunctive agents should be critically considered, since each additional agent adds time and complexity to RSI.

Medications for rapid sequence intubation

Premedications

Anticholinergic drugs

Atropine (0.01–0.02 mg/kg IV; minimum 0.1 mg; maximum 1 mg) has been recommended in the past to prevent bradycardia resulting from vagal stimulation. Recent literature suggests that there is a decreased role for atropine in advanced airway management. Atropine can increase arrhythmias as well as obscure the physician's ability to identify physiologic responses to pain, hypoxia, and shock. Currently, it is recommended to use atropine in children <1 year of age. Any patient

Table 1.2. Rapid sequence intubation: modifications for children

Phase of RSI	Pediatric modification
History and anatomic assessment (AMPLE)	
Preparation	Use length-based system for equipment organization and size determination and medication dosages
Monitoring	Pediatric size EZCap
Preoxygenation	8 vital capacity breaths with high-flow oxygen can be used if 5 min of preoxygenation not available; children will tolerate only 2–3 min of apnea
Premedication	Avoid bradycardia: in general, it is the authors' opinion that premedication can increase the complexity and the time required for RSI, thus defeating its main rationale Atropine 0.01–0.02 mg/kg if a second dose of succinylcholine is given
Assisted ventilation and cricoid pressure	
Sedation	Etomidate 0.3 mg/kg: least cardiovascular effects Ketamine 1–4 mg/kg: contraindicated with increased ICP, but good to maintain blood pressure Thiopental 0.5–4 mg/kg: can cause hypotension
Paralysis	Depolarizing neuromuscular blockade: succinylcholine 1–2 mg/kg Non-depolarizing neuromuscular blockade: rocuronium 0.6–1.2 mg/kg, vecuronium 0.1–0.2 mg/kg
Intubation	
Confirmation of endotracheal tube placement	End-tidal CO_2, O_2 saturation EZCap: purple, unsuccessful; tan, questionable; yellow: successful Historically uncuffed tubes were used to avoid mucosal damage; however, use of cuffed ETT decreases air leak

ICP, intracranial pressure; RSI, rapid sequence intubation.

who receives a second dose of succinylcholine should receive atropine, as should any patient with bradycardia.

Defasciculating agents

The procedure of using 1/10th the dose of a non-depolarizing muscle relaxant 1–3 min before succinylcholine administration to decrease muscle fasciculation is not necessary in children 5 years or younger.

Sedatives

Etomidate (amidate; 0.2–0.3 mg/kg IV) is an imidazole hypnotic agent. It does not cause hypotension or increased intracranial pressure, making it the ideal sedative for the multitrauma patient with or without head trauma. Recent studies have demonstrated that etomidate is safe for children and does not cause clinically significant adrenocorticoid suppression or hypotension. Side effects include clinically insignificant vomiting and myoclonic jerking. Etomidate is not approved by the US Food and Drug Administration (FDA) in children <10 years of age despite the growing amount of data to support its utility and safety in children.

Paralytics

Paralytics are essential in creating the optimal intubation conditions, although clinicians seem to use paralytics less frequently with children than adults. There is a consensus that succinylcholine is the most reliable and rapid paralytic available for RSI.

Succinylcholine (suxamethonium [Anectine, Quelicin]; 1.5–2 mg/kg IV) is the classic depolarizing agent. Its onset is rapid (30–60 s) and its duration is short (5–10 min). Maximum dose should be used to avoid complications associated with repeat dosing. Succinylcholine has been demonstrated in studies to cause bradycardia; however, it is unclear if the etiology of the bradycardia stems from the medication itself or from the vagal response to intubation. Succinylcholine can cause a rise in intracranial pressure (ICP) or intraocular pressure (IOP); however, the clinical significance is controversial.

Complications of succinylcholine use include case reports of asystole, malignant hyperthermia, and hyperkalemia. Succinylcholine can increase serum potassium by approximately 0.5–1.0 mEq/l by two mechanisms. The first is potassium leak with muscle depolarization. Therefore, succinylcholine is contraindicated in patients with potential hyperkalemia, including patients with renal failure or a significant burn or crush injury greater than 48 h old. Succinylcholine can also cause hyperkalemia by receptor stimulation in patients, with upregulation of acetylcholine receptors and subsequent exaggerated release of potassium. This mechanism of hyperkalemia could occur in patients with spinal cord injury and neuromuscular diseases with wasting, such as muscular dystrophy.

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Rocuronium (Zemuron; 1.0 to 1.2 mg/kg IV) is a non-depolarizing neuromuscular blocker with the shortest onset of all the non-depolarizing agents. The onset of rocuronium is comparable to succinylcholine (60–90 s), with a duration of action of 30–45 min. It is an effective agent for RSI when succinylcholine is contraindicated. Its actions can also be potentially reversed although the reversal agent is not yet FDA approved. Disadvantages are its longer duration.

Intubation

Children with any kind of upper respiratory infection or with repeated attempts at intubation may require an ETT of smaller diameter than expected. Any single intubation attempt should last no longer than 30 s in order to prevent hypoxemia. The steps of RSI and modifications for children are shown in Table 1.2.

Preparation is key to the success of intubation. All equipment should be laid out with smaller and larger half sizes. (The physician should have a secondary plan in the case of a difficult airway.) The ETT cuff should be checked with a syringe attached and stylet in place. End-tidal carbon dioxide and Yankauer suction should be available. The BVM should be connected to oxygen and providing 100% blow by oxygen. The child should be preoxygenated. The RSI medications should be given by the nurse with simultaneous cricoid pressure placed by the intubating practitioner. At the time of medication onset, the laryngoscope should be inserted on the right side of the mouth and then moved to the midline. While the straight blade is usually inserted into the vallecula, it can also be used to lift the epiglottis out of the way. Suctioning and adjustment of position should be used to get a view of the vocal cords (often if just tissue is in the field of view, the laryngoscope is too deep). Adjunct personnel can take over cricoid pressure when the intubating physician indicates that the cords can be seen, then hand over the ETT. The ETT should be advanced just beyond the vocal cords and the cuff should be inflated.

Visualization of the ETT passing through the vocal cords and confirmation of proper placement by auscultation over the lung fields and epigastrium are the initial confirmation signs of successful endotracheal intubation. Disposable capnographic devices and end-tidal carbon dioxide monitors are becoming standard to confirm endotracheal intubation.

Airway rescue procedures

If RSI is initiated and the patient cannot be endotracheally intubated, oxygenation and ventilation must be performed immediately until the airway is secured by other means. Most patients can be ventilated with BVM until the neuromuscular blocker has worn off. However, a nasogastric tube should be placed to decompress the stomach and avoid gastric distention and regurgitation.

The Laryngeal Mask Airway (LMA) is an alternative to BVM that effectively seals off the hypopharynx from the airway until a definitive airway can be obtained. The LMA is a tube with an inflatable silicon cuff on the distal end (Fig. 1.9). The insertion procedure is illustrated in Figs. 1.10 and 1.11):

1. The appropriately sized cuff is fully deflated.
2. The LMA is blindly inserted into the mouth with opening facing anteriorly.
3. The LMA should be inserted by sliding the mask along the hard palate until resistance is encountered at the level of the upper esophageal sphincter. The mask is then inflated (the tube often moves outward). The blackline along the tubing should be midline and against the lip. The LMA should be secured with tape.

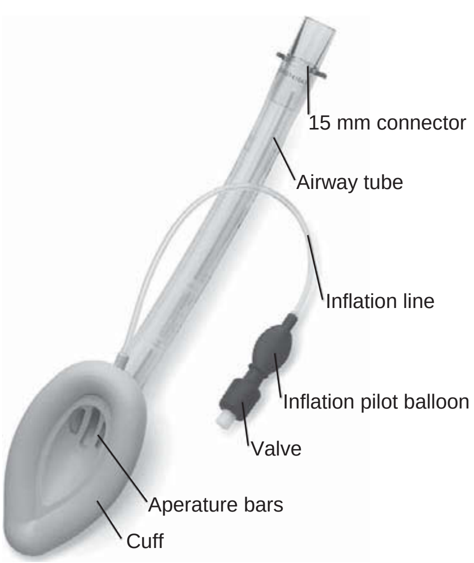

Figure 1.9 The Laryngeal Mask Airway. The mask has a soft cuff that is deflated before insertion. (Courtesy of LMA North America, Inc.)

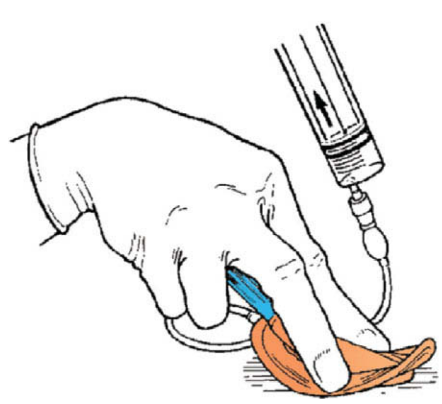

Figure 1.10 Prior to insertion of the Laryngeal Mask Airway, the cuff should be tightly deflated so that it forms a smooth wedge shape without any wrinkles. This can be accomplished by compressing the mask top between finger and thumb to achieve the correct shape. Alternatively, the mask can be properly deflated by using two index fingers and placing the mask against a solid surface. (Courtesy of LMA North America, Inc.)

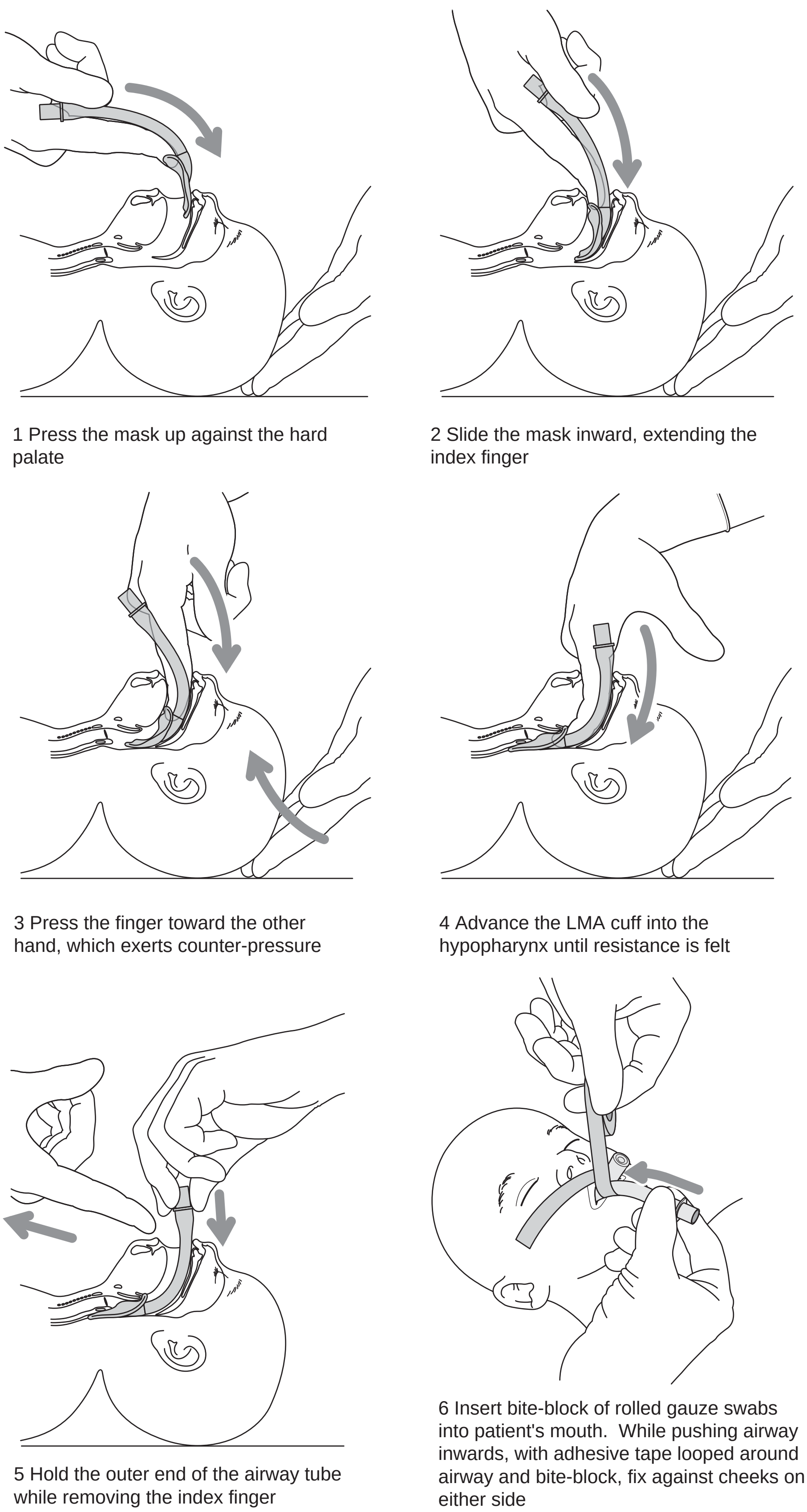

Figure 1.11 Insertion procedure for the Laryngeal Mask Airway (LMA). A size 1½ should be used for an infant approximately 5–10 kg. The cuff should be inserted with the smooth, portion opposed to the roof of the mouth. After correct insertion, the tip of the LMA is positioned in the esophagus. The LMA opening is at the glottis. Inflation of the cuff helps to secure the tube in the proper position so that air passes through the tube into the trachea. (Courtesy of LMA North America, Inc.)