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Accidental injury is the number one cause of death and disability in all children between 1 and 18 years of age. In 2002, trauma accounted for 33-39% of mortality in children aged 1-14 years.[1]

Airway management is paramount in the management of the trauma patient and especially in the case of the pediatric trauma patient. A known pitfall in trauma management—under-resuscitation and subsequent hypoxia— is the most common cause of cardiac arrest in the child.[2-4] Early identification and aggressive management of pediatric airway difficulties may affect the child's outcome.

This article reviews the anatomic and physiologic differences between pediatric and adult airways and the critical aspects of management.

—The Editor

Managing the Airway of the Pediatric Trauma Patient: Meeting the Challenge

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Introduction

Although children do have an increased susceptibility to respiratory compromise (*Table 1*), appropriate and timely airway management can profoundly influence mortality and morbidity and lead to a good outcome. Acute trauma may result in airway obstruction in the case of orofacial trauma or altered level of consciousness. Decreased oxygenation occurs in pulmonary injuries such as pneumothorax, hemothorax, chest wall injuries, pulmonary contusions, and aspiration. Ventilation can be compromised by airway obstruction, diaphragmatic injury, or central nervous system (CNS) depression. One of the main causes of early death in pediatric trauma is airway compromise often secondary to inadequate airway management.[2-4] Many trauma-associated deaths are preventable if appropriate, prompt care is provided at initial presentation.[5] Once respiratory arrest leads to pulseless cardiac arrest, survival as well as neurologic

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outcome is dismal.[2]

The pediatric airway presents a special challenge to many clinicians. Although airway management priorities in trauma are the same for children and adults, the pediatric airway has several unique features that emergency department (ED) physicians must understand to manage a pediatric trauma patient optimally.

This article does not extensively review basic airway management in trauma. Rather, the anatomic and physiologic differences between pediatric and adult airways as well as how and when these differences translate into differences in management are highlighted.

The Pediatric Airway: Anatomy

Overall, the pediatric airway is anatomically different than the adult airway. It has a different shape, is more pliable, and is smaller in diameter and length than the adult airway (*Figure 1*). These anatomic differences are most pronounced in infants and evolve with the child's growth. Generally, by the age of 8 years, the airway is considered to have the characteristics of the adult airway.[6]

Unique features in the child (*Table 2*) include a mouth that is smaller and oropharyngeal soft tissues, tongue, and tonsils that are proportionately larger than in the adult. The tongue is the main cause of airway obstruction in the child and may make visualization of the larynx difficult. In infants and children, the larynx is more cephalad and anterior than in adults.[7] The larynx or glottic opening of the trachea is at the level of C1 during infancy, transitioning to the level of C4-C5 in the adult.[8] Therefore, alignment of the oropharynx and larynx usually requires a straight laryngoscope blade. The thinner tip of the straight laryngoscope blade also helps elevate the floppy epiglottis out of the visual field. In children, the angle between the epiglottis and the larynx is more acute than in the adult, thus making blind nasotracheal intubation contraindicated in the young child; this angle is difficult to maneuver and blind manipulation can cause trauma and bleeding of the adenoids. The pediatric epiglottis is long, narrow, and floppy. A child's vocal cords have a slightly more anterocaudal angle than in an adult, therefore, if a child's head is not in the normal supine anatomical position, the vocal cords are more difficult to visualize during intubation. While an adult airway narrows after the cricoid cartilage, the narrowest portion of a pediatric airway is the cricoid cartilage. Historically, uncuffed endotracheal tubes (ETTs) have been recommended in children younger than 8 years because of concern about tissue necrosis from an improperly inflated balloon. New cuffed ETTs, which are safe in young children, have been developed, are widely available, and are becoming the preferred choice for intubation.[9] The rationale for using these cuffed ETTs is to increase effective ventilation by decreasing air-leak, a critical issue in children who require increased ventilatory pressures (e.g., children with acute respiratory distress syndrome).[2] A child's anatomically funnel-shaped larynx allows secretions to accumulate in the retropharyngeal area and increases the frequency of airway obstruction in children.[10]

In an infant, the relatively large occiput causes passive flexion of the cervical spine, as well as buckling of the pharyngeal airway.[2] To maintain cervical spine protection and an open airway, the patient must be kept in the 'sniffing position'. In this position, the external auditory meatus is aligned with the anterior border of the shoulder (*Figure 2*).

A pediatric trachea is smaller in diameter and length (5 cm long and grows to 7 cm by 18 months of age)[11] and is more pliable and compressible than the adult airway. Failure to appreciate this short length may result in right main stem bronchus intubation, inadequate ventilation, accidental tube dislodgement, and/or mechanical barotrauma.[11] The cricothyroid membrane is very small and difficult to palpate and to incise, therefore, cricothyroidotomy is contraindicated in children younger than 8 years.

Infants are obligate nasal breathers up to 6 months of age.[6] Infant nares are proportionately smaller than in adults and when occluded with mucous or secretions, they may cause significant airflow obstruction. This condition can be exacerbated by compressing the infant's nares with a face mask.[6]

The pediatric chest is more pliable than the adult chest. Even in the setting of significant blunt thoracic trauma, a child may have severe pulmonary contusions with no outward indication of severe trauma.[14] The high incidence of tension pneumothorax may be due to the increased pliability of the pediatric chest. The diaphragm and the abdominal wall musculature are relatively immature and weak despite being the major respiratory muscles in the child. Serious abdominal trauma or abdominal distention from bleeding or perforation can severely compromise a child's ventilatory status.

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Table 1. Reasons for Increased Pediatric Susceptibility to Respiratory Emergencies

PEDIATRIC CHARACTERISTIC	REASON FOR INCREASED SUSCEPTIBILITY TO RESPIRATORY EMERGENCIES
Higher metabolic requirements	Less tolerant of hypoxia and shock
Smaller airway diameter	Increased airflow resistance
Collapsible airways	Easily occluded
Compliant chest wall	May have significant lung injury and decreased air exchange despite relatively few external signs of trauma
Underdeveloped respiratory muscles	Diaphragm (the major muscle of respiration) fatigues relatively easy
Behavioral immaturity	Inability to verbalize respiratory distress or cooperate with intervention

Adapted from Mahadevan S, et al. *Principles of Emergency Medicine*. 1st. ed. Cambridge, UK; Cambridge University Press;2005.

Figure 1. Comparison of Pediatric and Adult Airway

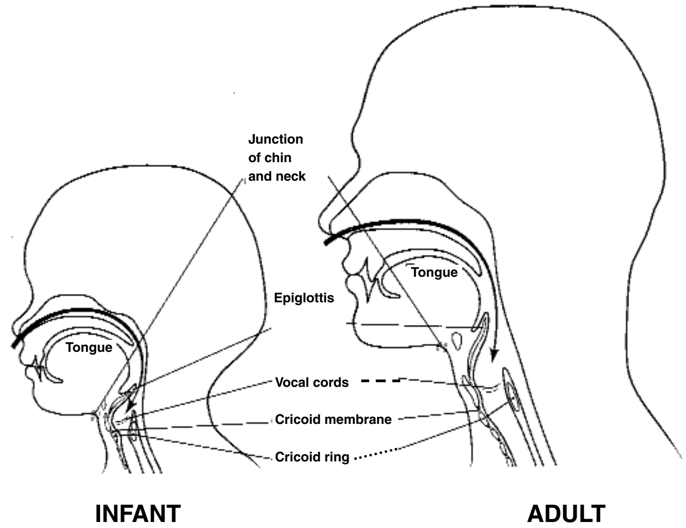

Figure 1. The anatomic differences particular to children are these: 1) Higher, more anterior position for the glottic opening. (Note the relationship of the vocal cords to the chin/neck junction.) 2) Relatively larger tongue in the infant, which lies between the mouth and glottic opening. 3) Relatively larger and more floppy epiglottis in the child. 4) 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. 7) Larger relative size of the occiput in the infant.

Reprinted with permission from: Wall RM. *Manual of Emergency Airway Management.* Philadelphia:Lippincott Williams & Wilkins;2000:145.

The Pediatric Airway: Physiology

Children have great compensatory mechanisms, and their vital signs may remain normal even with a severe physiologic compromise. Likewise, changes in vital signs may be subtle and misleading and may result in inadequate assessment of respiratory status, leading to inadequate resuscitation and precipitous deterioration of the pediatric trauma patient.

The major cause of traumatic death in children is respiratory failure.[2-4] Given the increased metabolic rate of children, hypoxia is poorly tolerated. Normal cerebral blood flow increases proportionately to nearly twice that of adult levels by the age of 5 years, and then decreases,[2] a partial reason for children's severe susceptibility to cerebral hypoxia. Children and infants in particular have smaller lung volumes and higher oxygen demands than adults. Therefore, they consume their respiratory reserves more quickly than in adults.

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 life-threatening bradycardia with laryngeal manipulation. Although a recent study documented that pretreatment with atropine may not prevent bradycardia in all cases, and thus may not be required for all pediatric patients,[8] it is still the standard of care.

Pediatric Airway Management Goals

The overall goals of airway management in the trauma patient are to: 1) provide a secure patent airway, 2) supply supplementary oxygen, 3) support ventilation, and 4) prevent aspiration. These goals are the same for the pediatric and the adult patient.

Assessment of the Pediatric Respiratory Status

Accurate assessment of the pediatric respiratory status is of the utmost importance. Failure to recognize and respond to pediatric respiratory distress can precipitously lead to cardiopulmonary arrest. Pediatric vital signs must be compared with age-related normal values. Pulse oximetry is a useful adjunct for monitoring a child's respiratory status.

Tachypnea is the initial compensatory mechanism for preserving minute volume.[2] Observation of a child's respiratory effort is the most accurate method to identify respiratory distress. Tidal volume assessed by chest rise or abdominal excursion can reveal the adequacy of the trauma patient's respirations. Respiratory noises (e.g., snoring or stridor indicating upper airway obstruction; wheezes indicating lower airway obstruction; and grunting, ominous for severe respiratory distress) are indications of work of breathing and airway obstruction.

The pediatric brain has high oxygen consumption, and hypoxia may result in an altered mental status. Thus, evaluation of overall general appearance (e.g., posture, level of alertness, or responsiveness) and other organ systems such as CNS (e.g., lethargy, agitation, or other altered mental status) and skin (e.g.,

Table 2. Unique Characteristics of Pediatric Airway Anatomy and Their Consequences on Airway Management

PEDIATRIC ANATOMIC FEATURE	AIRWAY MANAGEMENT SIGNIFICANCE
Large head, short neck	1. Neutral C-spine position/sniffing position difficult to achieve 2. Increased incidence of head trauma
Small mouth	1. Small mouth in conjunction with large soft tissue structures leaves less space for laryngoscope blade and subsequent airway visualization 2. Smaller straight laryngoscope blade can fit better into the child's mouth and lift soft tissues out of the way
Large tongue	1. Most common cause of airway obstruction
Large adenoids	1. Blind nasotracheal intubation contraindicated in children < 9 years secondary to large adenoids and potential to bleed 2. Oropharyngeal airway should not be inserted upside down and turned
Anterior and cephalad airway	1. Acute angle between epiglottis and anterior glottic opening makes nasotracheal intubation difficult 2. Alignment of different airway axes is often better accomplished with a straight blade than a curved blade
Long floppy epiglottis	1. Epiglottis can block visualization of the airway. A straight blade, with a narrower tip can be used to lift it out of the way.
Cricoid ring is narrowest part of the pediatric airway	1.Historically, uncuffed ETTs were recommended secondary to possible tissue necrosis from inflated balloon. 2. New data support the use of new cuffed ETTs, which decrease air leak and improve ventilation
Pediatric airway smaller, shorter, and delicate	1. Pediatric airway more prone to obstruction, compression 2. Right main stem intubation, and tube dislodgement are more common
Nares smaller; Infants up to 6 months of age are obligate nasal breathers	1. Small nares cause increased resistance to airflow especially when narrowed by secretions. 2. Compression of nares, can cause significant respiratory obstruction
Chest wall pliability	1. Children can have increased lung parenchymal damage with few outward signs.
Diaphragm is the main muscle of breathing	1. Abdominal trauma and distention can cause or contribute to severe respiratory compromise
Small cricothyroid membrane	1. Cricothyroidotomy contraindicated in children younger than 8 years

pallor, cyanosis, or delayed capillary refill) also will aid the recognition of respiratory distress and impending respiratory failure in a child.[2]

Management of the Pediatric Airway

Positioning. In a spontaneously breathing child, the airway should be optimized by placing the child's head in the sniffing position while maintaining neutral alignment of the cervical spine (*Figure 2*). Often a shoulder roll in an infant is recommended to help in obtaining a sniffing position. Due to the prominence of the tongue, the chin lift or jaw thrust maneuver combined with bimanual inline spinal immobilization may be necessary to maintain an unobstructed airway. The mouth and oropharynx should be cleared of secretions or debris, and supplemental oxygen should be administered. If the child's airway or ventilation is compromised, then mechanical methods may be necessary. Before attempts to mechanically establish an airway, the child should be pre-oxygenated.

Airway Adjuncts. Positioning alone may not be enough to keep the tongue from obstructing the airway. The nasal and oral airways are common airway adjuncts used in children.

Oral Airway. The oral airway is contraindicated for use in children who are conscious because it can trigger the gag reflex; but in an unconscious patient it may relieve upper airway obstruction. The appropriate oral airway will extend from the level of the incisors in the child's mouth to just anterior to the angle of the mandible. Placement of the oral airway by depressing the tongue with a tongue blade is recommended. The practice of inserting the oral airway backward and rotating it into position is not recommended for pediatric patients. Trauma with resultant hemorrhage into soft tissues may occur. Note that if the oral airway is too small, the tongue may be pushed into the pharynx causing increased airway obstruction. Proper positioning should result in improved and easier ventilation.

Ventilation and Breathing. If spontaneous ventilation and breathing are not adequate, children with trauma must have ventilatory assistance. Bag valve mask (BVM) ventilation can be successful; however, BVM ventilation may contribute to gastric distention with air and potential regurgitation and aspiration.[10]

Bag Valve Mask. Usual spontaneous tidal volumes vary from 5 to 8 mL/kg in infants and children.[2] Although most BVM devices are designed to limit the amount of pressure that can be exerted manually on the child's airway, the physician must minimize the potential for iatrogenic bronchoalveolar injury or development of a pneumothorax. Remember that self-inflating BVM devices will not deliver oxygen unless squeezed.[2] Putting this type of BVM device over the face of a spontaneously breathing child without squeezing the bag will result in a lack of oxygen delivery to the child.

If airway obstruction occurs and BVM ventilation cannot be achieved, the airway should be re-positioned. Jaw thrust or chin lift may be used, but chin tilt should be avoided in the setting of a suspected cervical spine injury. If repositioning does not succeed, an airway adjunct may be needed. Due to the relative size of an

Figure 2. Positioning of the Child for Ventilation

A

B

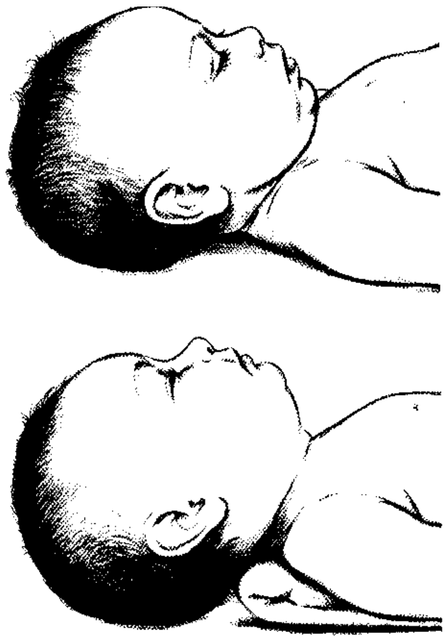

Figure 2. Positioning fo the Child for Ventilation.
A: Incorrect position with neck flexion. **B**: Correct position for infant. Note that the external ear canal is anterior to the shoulder.

Adapted with permission: Cote CJ, et al. *A Practice of Anesthesia for Infants and Children*. Philadelphia: WB Saunders;1993.

adult's hand to a child's neck, it is easy for a practitioner to accidentally apply additional pressure to the child's neck and cause further obstruction of the airway. The optimal placement of the hand is to apply the index finger to the mask, the middle finger to the mentum, and the ring and little finger to the bony angle of the mandible.[7]

Equipment. Equipment size changes with age. The ED physician caring for a child with trauma must have immediate access and knowledge of the appropriate sized equipment to use, as well as a systematic organization of this equipment. Length-based resuscitation methods provide accurately sized equipment and medication doses, and the most common form used is the Broselow tape. The Broselow tape should be measured with the red arrow at the patient's head and the color-coded section at the patient's heel. Color-coded carts and resuscitation supplies that correspond to the Broselow tape color-coded system have been shown to be more efficient than previous standard organization systems.[15]

A recent small study looked at common problems with the Broselow tape. The most common problem stemmed from holding the tape in the wrong direction: Specifically, the wrong end was put at the top of the patient's head. In several cases, clinicians had difficulty using the Broselow tape to determine the correct medication and equipment size to use. The older version of the Broselow tape had two white-colored sections, one of which was at the top and was not an actual dosing zone. The newest version has corrected this by making the zone closest to the head gray in color.[16]

ETT size can be estimated by comparing the diameter of the ETT to the size of the nail on the child's fifth finger, or calculated by the formulas:

Uncuffed ETT size: (Age in years)/4 +4

Cuffed ETT size: (Age in years)/4 +3

Most ETTs have a mark at the end of the tube that indicates the point of the tube that should be just past the vocal cords. The appropriate ETT depth of insertion in centimeters can be calculated by the formula: ETT depth cm = 3 × ETT size.

Laryngoscope Blades. Straight blades are easier to insert in the child's mouth, but the thinness of the straight blade can make moving and retracting a large tongue difficult. The curved laryngoscope blade is larger and bulkier than the straight blade, but it retracts the tongue more easily and may be useful in certain pediatric populations when the tongue is larger or bulkier than usual.

Endotracheal Intubation

Endotracheal intubation is performed to achieve definitive airway management. It is indicated in acute respiratory failure, as well as for airway protection, to decrease the work of breathing and for some therapeutic interventions (e.g., closed head injury with increased intracranial pressure). (*See Table 3.*) Almost half of endotracheal intubations in children are for trauma, with head injury being the single most common indication for intubation in children (25% of cases).[17-18]

Rapid sequence intubation (RSI) is the use of a systematic protocol involving sedatives and neuromuscular blocking agents to increase chances of a successful intubation, decrease risks of aspiration, and to avoid increases in intracranial pressure for head injured patients. Numerous studies have demonstrated that intubation without paralysis and with or without a sedative has a lower success rate in children and adults, as well as a higher complication rate than RSI.[17,19,20]

The ten steps of RSI include 1) a brief history, 2) preparation, 3) monitoring, 4) preoxygenation, 5) premedication, 6) assisted ventilation and cricoid pressure, 7) sedation, 8) paralysis, 9) intubation, and 10) confirmation of tube placement.[21] (*See Table 4.*)

Major differences between pediatric and adult RSI include the steps of preoxygenation and RSI pharmacy. Preoxygenation with the patient breathing 100% oxygen spontaneously for 5 minutes will 'washout' all the nitrogen in the lungs, providing the patient with an oxygen reserve. An adult patient can tolerate up to 5 minutes of apnea without developing hypoxia. A child has smaller lungs and higher metabolic needs than an adult; often times children can tolerate only 2-3 minutes of apnea before developing hypoxia.[18]

RSI pharmacy involves a choice of different pre-medications, sedative agents, and paralytic agents depending upon the clinical scenario. Important considerations are the presence of increased intracranial pressure and hypotension. Areas of controversy in pediatric RSI include the use of pre-medications, the use of etomidate as an RSI sedative, and the use of succinylcholine as a paralytic agent.

Premedications

RSI premedications include pharmacologic agents that are intended to blunt the cardiovascular stimulation of intubation; decrease intracranial pressure; decrease bradycardia, which can be caused by succinylcholine; decrease airway secretions; and prevent muscular fasciculations caused by depolarizing neuromuscular blocking agents. Succinylcholine has been demonstrated in studies to cause bradycardia, and atropine has been shown to effectively block it. However, it is unclear if the etiology of the bradycardia stems from the medication itself or from the vagal response to intubation.[21,22]

Lidocaine is used widely to mitigate increased intracranial pressure in head injured patients. However, its use is controversial with little or conflicting evidence as to its effects on intracranial pressure.[18,20,23] Although lidocaine also can cause complications of hypotension and dysrhythmia, it is customarily given as pretreatment for RSI in the setting of head injury.

Opiate analgesic agents (e.g., fentanyl) have been advocated to reduce adverse hemodynamic and intracranial pressure effects of intubation,[24] although the data for this use are scant. Opiates can cause hypotension in trauma patients. In addition, fentanyl, in particular, may be associated with chest wall rigidity, especially when given as a bolus.

Anticholinergics. Atropine (0.01-0.02 mg/kg IV min 0.1 mg; max 1 mg) has been recommended to prevent bradycardia resulting from vagal stimulation. Currently, it is recommended that atropine be used universally in children younger than 1 year to minimize the chance of bradycardia in response to laryngoscopy.[2] In children older than 1 year, atropine should be given only if succinylcholine also is being used. In adolescents and adults who receive a second dose of succinylcholine and in any patient with bradycardia, atropine should be given 1-2 minutes prior to intubation.[2] There is currently more discussion about the validity of the use of atropine.[25-27] However, there have been no definitive studies to support discontinuation of atropine with succinylcholine in children.

Defasciculating Agents. The use of one-tenth the dose of a nondepolarizing muscle relaxant 1-3 minutes before succinylcholine administration will decrease muscular fasciculations. This is not necessary in children 5 years or younger.[20] However, even in older patients administration of a defasciculation agent adds time and complexity to the RSI, and may not be clinically indicated in the management of an acute traumatic airway.[25]

Sedative Agents. Etomidate (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 hypnotic agent for the multitrauma patient with or without potential head trauma. Previously, the use of etomidate has been tempered because it causes adrenal suppression, even after a single dose. However, the clinical significance of this adrenal suppression is unknown.[28] In a recent study, it was found to be safe for pediatric patients with no clinically important adrenocorticoid suppression and a low incidence of clinically important hypotension.[29] Side effects include vomiting and myoclonic jerking, which are not usually clinically significant. The National Emergency Airway Registry (NEAR), a multicenter, prospective emergency medicine led registry, documented etomidate use in 42% of RSI procedures.[18] However, despite the growing amount of data to support the utility and safety of etomidate in children, it currently is not FDA approved in the pediatric population.

Table 3. Indications for Endotracheal Intubation

ACUTE RESPIRATORY FAILURE
PO_2 <60 or Low SaO_2
PCO_2 > 50
Apnea
Hypoventilation
AIRWAY PROTECTION
Neurologic dysfunction (seizure, coma)
Loss of protective airway reflexes
Copious secretions, blood
Upper airway obstruction, airway edema or trauma
DECREASED WORK OF BREATHING
Hemodynamic instability
Metabolic acidosis
SPECIAL SITUATIONS/THERAPEUTIC INTERVENTION
Management of ICP
Conduction of necessary diagnostic tests (e.g. CT head)

Paralytic Agents. Paralytic agents are a critical component of RSI. In one prospective study, intubation occurred successfully in 99% of adult patients with paralysis and in 82% without paralysis.[19] In children, intubation was successful 78% of the time with paralysis and only 44% of the time when only a sedative was used.[17] Although paralytic agents are essential to creating the optimal conditions for intubation, the potential complications of neuromuscular paralysis and inability to secure the airway must be seriously considered. Clinicians seem to use paralytic agents less frequently in children. In one study, paralytic agents were used for only 40% for pediatric intubations in children younger than 1 year.[18]

Paralytic agents are categorized into depolarizing and nondepolarizing agents. Depolarizing agents initially depolarize the motor endplate by acting at the acetylcholine receptor and induce contraction, manifested by fasciculations. Succinylcholine is the only depolarizing agent clinically available. The acetylcholine receptor is blocked, and binding is prevented until the succinylcholine is degraded by acetylcholinesterase. Nondepolarizing agents competitively inhibit the acetylcholine receptor. These agents are then degraded in the liver.

Succinylcholine (1.0-2 mg/kg IV) is the classic depolarizing agent. Its onset is rapid (30-60 seconds), and its duration is short (5-10 minutes). Succinylcholine may cause a rise in intracranial pressure or intraocular pressure, as well as an increase in airway secretions. These increased pressures caused by succinylcholine

Table 4. Rapid Sequence Intubation Modifications for Children

PHASE OF RSI	PEDIATRIC MODIFICATION
History and anatomic assessment (AMPLE)	
Preparation	Use length-based system for equipment organization, size determination, and medication dosages
Monitoring	Pediatric size EZ cap
Preoxygenation	1. 8 vital capacity breaths with high flow oxygen can be used if 5 minutes of preoxygenation not available. 2. Although adults may tolerate 4-5 minutes of apnea before hypoxia develops, children may tolerate only 2-3 minutes of apnea.
Premedication	1. Avoid bradycardia: - Atropine (0.01-0.02 mg/kg IV; min 0.1 mg; max 1 mg) 2. Avoid increased ICP: - Lidocaine
Assisted ventilation and cricoid pressure	
Sedation	1. Etomidate 0.3 mg/kg - Least cardiovascular effects 2. Ketamine 1-4 mg/kg - Contraindicated with increased ICP, but good to maintain blood pressure 3. Midazolam 0.05-0.1mg/kg* 4. Thiopental 0.5-4 mg/kg* * Can cause hypotension
Paralysis	1. Depolarizing neuromuscular blockage - Succinylcholine 1-2 mg/kg 2. Non-depolarizing neuromuscular blockade - Rocuronium 0.6 -1.2 mg/kg - Vecuronium 0.1-0.2 mg/kg
Intubation	
Confirmation of endotracheal tube placement	1. End-tidal CO_2, 2. O_2 saturation 3. EASY_CAP: - Purple: Unsuccessful - Tan: Questionable intubation - Yellow: Successful

are probably modest, and the clinical significance is controversial.[25,27] Complications of succinylcholine use include case reports of asystole, malignant hyperthermia, and hyperkalemia.[21,30]

Succinylcholine may induce an increase in serum potassium levels of approximately 0.5-1.0mEq/l.[30] This increase can be caused by two mechanisms. The first results from depolarization of the muscle and potassium leak. Although the significance of the increase in potassium level secondary to this mechanism may be less clinically important than previously documented, the effect is real.[31,33] The use of succinylcholine is contraindicated in patients who could have hyperkalemia (including patients with renal failure) or a significant burn or crush injury greater than 48 hours old. Succinylcholine also may cause hyperkalemia by receptor stimulation in patients with up-regulation 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 (e.g., muscular dystrophy).[31-39]

Rocuronium (0.6 to 1.2 mg/kg IV) is a nondepolarizing neuromuscular blocker. It has the shortest onset of all the nondepolarizing agents. The onset of rocuronium is almost comparable to succinylcholine (60-90 seconds) with a duration of action of 30-45 minutes. Meta-analysis showed that although rocuronium was inferior to succinylcholine in providing excellent intubating conditions, it was comparable to succinylcholine in inducing clinically acceptable intubating conditions.[34] A recent report looked at the use of rocuronium and found it to be safe compared with vecuronium and an effective agent for RSI when succinylcholine was contraindicated.[35,36]

Currently, there is controversy over whether to use succinylcholine, a depolarizing neuromuscular blocker, as the main paralytic agent in children.[25] However, despite the complications described in the literature, there is also a consensus that succinylcholine is the most reliable and rapid paralytic agent available for RSI. In patients in whom the use of succinylcholine may be unsafe (e.g., personal or familial history of malignant hypertension, skeletal muscle myopathies, extensive denervation of skeletal muscle or upper motor neuron injury), rocuronium is a documented safe alternative.

Cricoid Pressure

Cricoid pressure improves visualization of the vocal cords because the larynx will be displaced posteriorly; it also decreases the risk of aspiration. Cricoid pressure should be initiated as soon as sedation is started. Cricoid pressure prevents passive aspiration.[2, 37] If active vomiting occurs, cricoid pressure is to be lifted and the patient rolled to the side because esophageal perforation can occur.[38]

Intubation

Because the radius of the airway is inversely proportional to the resistance of flow, even a small amount of airway edema will result in a significantly increased resistance to flow causing increased work of breathing and possibly signs of respiratory distress in the pediatric patient. A child with any kind of upper res-

Table 5. Appropriate-Sized LMA Based Upon Patient Weight

WEIGHT (KG)	LMA SIZE
<5	1.0
5-10	1.5
10-20	2.0
20-35	2.5
35-55	3.0*
>55	4.0

* An ETT can be inserted into all LMAs, but removal of the LMA and extubation is tricky, often requiring destruction of the LMA. Separate intubating LMAs, designed for intubation through the LMA and subsequent removal of the LMA, exist for size 3.0 and above.

Adapted from Infosino A. Pediatric upper airway and congenital anomalies. *Anesthesiol Clin North Am* 2002;20(4):747-766.

piratory infection or repeated attempts at intubation may have an additional degree of restriction on the airway.

Any single intubation attempt should last no longer than 30 seconds to prevent profound hypoxemia.[2] Children, and especially infants, have smaller lung volumes and higher oxygen demands than adults, therefore, they consume their respiratory reserves more quickly than in adults.

Confirmation of Intubation

Disposable capnographic devices, (e.g., Easy-Cap) and end-tidal carbon dioxide monitors are mandatory adjuncts to evaluate endotracheal intubation. Visualization of the ETT being passed through the vocal cords, confirmation of proper placement by auscultation over the lung fields and the epigastric area, and vapor in the ETT are the initial nondefinitive confirmations of successful endotracheal intubation.; secondary confirmation is necessary.

Although Pediatric Advanced Life Support (PALS) guidelines do not recommend other confirmation devices in infants and children, devices such as the self-inflating rubber bulb have been found to be highly sensitive and specific for detection of esophageal intubation in adults. Two recent studies showed that the bulbs have high sensitivity and specificity in the pediatric patient population.[39,40]

Rescue Procedures

If RSI is started and the patient cannot be endotracheally intubated, the airway must be secured by other means. Most patients can be ventilated with BVM devices until the neuromuscular blockade has worn off. However, care must be taken not to inflate the stomach; a nasogastric tube should be placed to decompress the stomach.

Blind nasotracheal intubation should not be performed in children younger than 9 years.[20] It requires blind passage around a relatively acute angle in the naropharynx toward the anterosuperiorly located glottis, making intubation by this route difficult. The added potential for penetrating the cranial vault or damaging the more prominent nasopharyngeal adenoidal soft tissues, which results in hemorrhage, makes this procedure ill advised in a child. Additionally, it is a rare child who can cooperate with a nasotracheal intubation.

Awake intubations are performed on patients who potentially may be difficult to intubate and ventilate.[24] This procedure may be difficult in the pediatric patient due to behavioral and developmental inability to cooperate.

The laryngeal mask airway (LMA) can be an alternative means of securing the airway until a definitive airway can be obtained.[20,24,41-44] The LMA is a tube with a silicon cuffed mask-like portion on the distal end. It is inserted into the pharynx until resistance is encountered due to the hypopharynx. The mask is then inflated, sealing off the hypopharynx from the airway. The distal portion of the LMA is ideally situated above the airway, allowing ventilation and oxygenation to be performed. While the LMA does not optimally control the airway, it may be more protective than the BVM.[2,45] There is increasing literature, mostly in the form of case reports, documenting airway management success with LMA in children with abnormal anatomy in whom endotracheal intubation was difficult or impossible.[21] Intubation is possible through LMAs. Table 5 lists the LMA size based upon the child's weight.

Needle cricothyroidotomy with jet insufflation is an appropriate temporizing technique when airway access and control cannot be accomplished by BVM or orotracheal intubation in children younger than 8 years. The procedure consists of inserting a 12-14 gauge catheter through the cricothyroid membrane. The catheter is connected to a high pressure oxygen source (50 psi) and a one second burst of high pressure oxygen is given, followed by a 3-4 second period to allow for exhalation. Care must be taken to hold onto the catheter so that it stays in position. The catheter also may kink secondary to the high pressures; nonkinking catheters with metal spirals are availble. If the patient cannot spontaneously exhale, then jet insufflation is contraindicated. Chest movement should be used as a visible indicator of adequate ventilation. This procedure provides oxygenation but does not provide adequate ventilation, and progressive hypercarbia may occur. Complications include tension pneumothorax.

Emergency cricothyroidotomy is the airway of last resort in an adult with difficult airway. It is used often in patients with extensive facial and upper-airway injury. Cricothyroidotomy is difficult in children and contraindicated for an infant or small child. It only can be performed in an older child in whom the cricothyroid membrane is easily palpable, usually by the age of 8-10 years.[21] There are no data specifically on the complication rates in the pediatric population. But the overall complication rate of cricothyrotomy depends upon technique. In one recent small study, there were no reports of complications associated with the rapid four-step technique when performed in the ED; nonrapid four-step cricothyrotomies in the ED had an associated complication rate of 25%.[46]

Other alternative airways in children have similar indications and procedures as in adults. Retrograde intubation has been described in adults and is a rapid and safe technique; the only true contraindication is a patient who cannot be adequately oxygenated or ventilated.[24,47] The cricothyroid membrane is identified and pierced with an 18-gauge needle aimed cephalad. When air is aspirated, a guidewire is threaded through the needle until the proximal end emerges in the mouth.[21,24] The needle is removed, and a plastic sheath is passed over the wire until resistance is met. Then, the ETT is advanced over the wire, and the wire and sheath are removed from the mouth.[24] In children, a 20-gauge IV catheter with a 0.0021-inch J wire is adequate.[21] Retrograde intubation sets are available, however, an 18-gauge or larger needle and 80 cm J tipped guidewire can be used.[24] If using a central line kit, care must be taken that the J wire is of adequate length.

Lighted stylet, bullard larygoscope, ETT introducer, and fiber optic laryngoscope are all alternative airway techniques that may be used in a child with a difficult airway.[24]

Special Circumstances

Head Trauma. Closed head injury is the most common type of injury seen in pediatric trauma, and consummate airway management is necessary to optimize functional outcome.[5] The outcome of head trauma in children is better than in adults, but the outcome in children younger than 3 years is worse than that of a similar injury in an older child.[14] This difference is probably because young children are particularly susceptible to the effects of secondary brain injury that may be produced by hypovolemia and hypoxia. Maintaining oxygenation and preventing hypercarbia are critical in managing the pediatric head-injured trauma patient.

Cervical Spine Injury. Although the overall incidence of cervical spine injury is low, weak neck muscles, a higher fulcrum (C2-C3), and poor protective reflexes in children contribute to higher level cervical spine injuries than in adults.[20] In addition, cervical spine injuries may not appear on radiographs, therefore, there must be a high suspicion for cervical spine injuries in children with trauma.[5] Cervical spine immobilization may make airway management more difficult. The chin lift and jaw thrust maneuvers, as well as airway adjuncts, must be used in lieu of the head tilt. The larger occiput also may make immobilization of the child's head, neck, and spine in neutral position more difficult (*Figure 2*).

Laryngeal Injury. The difference in laryngeal anatomy in "position, consistency, size and shape" explains the types of injury that occur in children.[48] Laryngeal injuries are less common in children than in adults because of the relatively high location of the larynx in the neck, which allows the airway to be protected by the mandibular arch. A child also has a relatively short neck compared with that of an adult.[49] Up to 80-95% of serious laryngeal injuries in children occur in adolescents, secondary to blunt mechanisms typically resulting from accidents involving motorcycles, snowmobiles, water craft; and clothesline and direct blows during karate, snowboarding, and skating.[48,50] Because of the overall shape and smaller size, the pediatric patient will tolerate traumatic disruption less well than an adult.[48]

A high degree of suspicion is required to diagnose a laryngotracheal separation. Laryngotracheal separation commonly occurs within 2-3 cm of the carina.[49] In the ED, diagnostic assessment should include assessment of airway sounds (e.g., stridor, hoarseness, aphonia, cough, hemoptisis, respiratory distress), cyanosis, subcutaneous air, neck hematoma or tenderness, tracheal deviation, and cartilagenous stepoffs. If feasible, flexible fiberoptic endoscopy is preferred before oral tracheal intubation to avoid complete disruption of the larynx. However, if airway management is emergent—given that cricothyroidotomy is contraindicated in children younger than 10 years—and jet insufflation is fraught with complications, orotracheal intubation, if possible, is the preferred and relatively safe airway management procedure prior to definitive exploration and repair in the operating room.[51]

Tracheobronchial Injuries. Tracheobronchial injuries are also rare.[51] The low incidence is due to the elasticity of the mediastinum and tracheobronchial tree, which allows it to be compressed without causing injury.[51] In adults, bronchial injuries tend to occur in the right-sided main stem bronchus but this predominance is not seen in the pediatric population.[52,53] Therefore, these types of injuries are seen only with major accidents (e.g., falls from high levels or being thrown out of motor vehicles).[53] If tracheobronchial injuries are suspected, endoscopy is mandatory.[49,54]

Blunt Thoracic Injuries. Blunt thoracic injuries are the second leading cause of death from pediatric trauma.[12] Injuries to the vital thoracic structures—not including lung contusions—have a mortality rate of greater than 50%. Multiple studies have shown the most common injury with pediatric blunt chest trauma is a pulmonary contusion. Other common injuries included rib fractures, pneumothorax, and hemopneumothorax. In one study, 25% of the pneumothorax cases were tension pneumothorax.[13] The high incidence of tension pneumothorax may be due to the increased pliability of the pediatric chest.

Children with Special Health Care Needs. Children with apparent Down syndrome facies who undergo trauma should be managed carefully. Children with Down syndrome have a relatively complicated airway due to a large tongue and relative hypotonia. A curved blade may facilitate moving the tongue out of the way. The trachea is usually smaller than in other children of the same age, necessitating an ETT 1-2 sizes smaller than calculated.[55] Atlanto-axial instability also may be present, making them more prone to cervical spine injury.[15] Cervical spine immobilization is particularly important in these cases to prevent further injury.[20] In some cases, an LMA may be the best airway management technique. Children with congenital problems (e.g., Pierre Robin syndrome, tracheomalacia, or cleft palate) who are involved in trauma may have a predictably difficult airway. An LMA may be the best option in these cases because surgical airways are contraindicated in the young child.[21] As stated in the section on RSI, children with neuromuscular diseases should be intubated with a nondepolarizing neuromuscular blockade.

Nonaccidental Trauma. When managing the traumatic airway, the practitioner should always consider the mechanism of the trauma and the possibility of nonaccidental trauma.

Summary

Understanding the differences between the adult and pediatric airway and how these affect airway management in trauma is of critical importance in the timely and appropriate resuscitation of the pediatric trauma patient. This report highlights the specific anatomical and physiologic features unique in children and the implications for pediatric trauma management.

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CE/CME Objectives

Upon completing this program, the participants will be able to:

a.) discuss conditions that should increase suspicion for traumatic injuries;
b.) describe the various modalities used to identify different traumatic conditions;
c.) cite methods of quickly stabilizing and managing patients; and
d.) identify possible complications that may occur with traumatic injuries.

Physician CME Questions

1. At what age is a child's airway considered to be equivalent to an adult's airway?
   A. 5 years
   B. 8 years
   C. 12 years
   D. 16 years

2. Which one of the following paralytic agents is the first choice for pediatric rapid sequence intubation?
   A. Rocuronium
   B. Vecuronium
   C. Succinylcholine
   D. Isradipine

3. An 8-year-old male lost his grip while climbing over a fence and fell chest forward into the fence. He was brought to the emergency department by his mother. He has a puncture wound to his left chest made by the top of the fence. Initially, the patient was breathing comfortably with equal breath sounds. While awaiting chest x-ray, his breathing pattern changed. What would be the first mechanism of respiratory compensation in a pediatric patient in respiratory distress?
   A. Increased work of breathing
   B. Wheezing
   C. Tachypnea
   D. Head bobbing

4. You choose succinylcholine as your paralytic agent to intubate a 6-year-old child involved in a serious motor vehicle accident. Which one of the following medications is recommended before giving succinylcholine to this patient?
   A. Lidocaine
   B. Atropine
   C. Robinul
   D. Midazolam

5. An 8-year-old male with Down syndrome fell from the top of a play structure and hit his head on one of the platforms as he fell. Which

one of the following statements is true when considering intubation of a Down syndrome patient?
A. A straight blade may facilitate moving the tongue out of the way.
B. An ETT 1-2 sizes larger than calculated may be necessary for intubation.
C. These children are more prone to cervical spine injury.
D. An LMA is contraindicated in the Down syndrome population.

6. A 10-year-old female was brought in after falling in gymnastics class from the balance beam. The coach reported that she hit her head on the edge of the balance beam when she attempted to dismount. She arrived by ambulance wearing a cervical spine collar. When you initially examined her, she was responsive and cooperative to your questions with only complaints of pain on the neck. As you were finishing your primary survey, she became increasingly uncooperative and agitated. Which of the following is the *most* important initial step?
A. Re-assess her pupillary response
B. Re-assess her respiratory status
C. Prepare for intubation
D. Rush the patient for a CT scan

7. Which one of the following statements is true about the use of atropine in children?
A. Atropine is used in children younger than 1 year only if succinylcholine is the paralytic agent.
B. Atropine is not indicated for use in adolescents, except for bradycardia.
C. Atropine is given to prevent bradycardia resulting from vagal stimulation.
D. The correct dosing of atropine for a child is 0.1-0.2 mg/kg IV.
E. The maximum dose of atropine in the pediatric population is 2 mg.

8. A completely unresponsive 4-month-old child is brought into the emergency department by his parents. The parents reported he just suddenly "stopped breathing." You can see several bruises on his chest and head. You decide to intubate. Which one of the following procedures is appropriate for positioning this child for intubation?
A. Perform head tilt
B. Place a shoulder roll
C. Place the arms to the side
D. Extend the head back

9. When placing an oral airway in a child, which of the following statements is true?
A. For correct placement, insert the oral airway backward and rotate it into position.
B. Oral airways have no contraindications in the pediatric population.
C. Emesis may occur with oral airways in patients who are conscious.
D. For patients with relatively large tongues, use a smaller oral airway than recommended by age.

10. Which of the following statements regarding the preoxygenation phase of rapid sequence intubation of a child is true?
A. A child can tolerate up to 5 minutes of apnea before developing hypoxia.
B. Preoxygenation is the first step of rapid sequence intubation.
C. Five vital capacity breaths with high flow oxygen can be used if 5 minutes of preoxygenation is not available.
D. Any single intubation attempt should last no longer than 30 seconds.

Answers:
1. B
2. C
3. C
4. B
5. C
6. B
7. C
8. B
9. C
10. D

In Future Issues: **Ultrasound applications in the hypotensive patient**

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