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Trauma Reports

Vol. 8, No. 1

Supplement to *Emergency Medicine Reports* and *Pediatric Emergency Medicine Reports*

Jan./Feb. 2007

Traumatic injury remains the leading cause of death and a major cause of disability among children around the world.[1-3] Each year in the United States, there are more than 100,000 cases of traumatic brain injury (TBI) in children; 10%-15% are severe, resulting in permanent neurologic damage.[4]

Although TBI is the most common cause of death in childhood, many of these deaths may be preventable. Inadequate evaluation, resulting in inappropriate treatment, may contribute to approximately 30% of deaths in children with severe trauma.[5] Prompt, accurate assessment of the severity of injury and early initiation of appropriate critical care — including adequate oxygenation, ventilation and correction of hypotension — is of crucial importance in preventing these deaths. This article reviews the critical aspects of airway assessment and management in the pediatric trauma patient.

— The Editor

Airway Management in the Pediatric Trauma Patient

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Issues in Infants and Children

Although the majority of children have structurally normal airways, normal changes occur with the child's physical maturation.[6] Additionally, among the children requiring emergency respiratory intervention, those with abnormal airways are overrepresented because of respiratory problems directly related to the structural abnormality, or their frequent association with other congenital anomalies.

Even the normal infant or child has several airway characteristics that increase the risk of airway obstruction and may make airway management challenging.

Anatomic Considerations of the Pediatric Airway. Many of the important anatomic and physiologic differences that exist between infants, children, and adults are either poorly understood or poorly appreciated (*Table 1*).[7] Ideally, respiratory compromise and failure should be anticipated rather than recognized so that

Statement of Financial Disclosure

Dr. Dietrich (editor in chief) reports that she receives grant/research support from the National Institutes of Health and is the medical director for the Ohio Chapter of the American College of Emergency Physicians. Drs. Perkins (co-author), and Ma (peer reviewer), Ms. Finerty (nurse reviewer), and Ms. Neff (nurse reviewer) report no relationships with companies related to this field of study. Dr. Fontane (co-author) reports that she is a stockholder in Pfizer, Inc.

appropriate measures can be taken before gas exchange is severely altered. Early, appropriate intervention will prevent the effects of hypoxemia and hypercarbia on the pediatric patient's central nervous and circulatory systems.

The Tongue. In newborns and infants up to about 2 years of age, the tongue lies entirely within the oral cavity. Unlike the adult, no portion of the tongue contributes to the upper anterior wall of the pharynx. Furthermore, in the infant, the tongue occupies a relatively large portion of the oral cavity (compared with the relatively smaller ratio of the adult tongue to the adult oral pharynx), which contributes to obstruction of airflow through the oral passageway.

When an obtunded child is difficult to ventilate, the tongue is the first site of potential obstruction to consider. Babies lying supine tend to flatten their tongues against the soft palate during inspiration. The tongue, especially if it is dry, stays against the soft palate during passive exhalation of air through the nose and is in a position to obstruct the next inspiration or positive-pressure breath and mask ventilation.

Nasal Passages. The nose of an infant is soft, distensible, and has relatively more mucosa and lymphoid tissue than the adult nose. The nares are angled forward, and the passageway through the turbinates to the posterior nasopharynx is more of a straight line back to the occiput. This is a helpful anatomic guide when attempting to pass a nasotracheal, nasopharyngeal airway, or nasogastric tube.

The nasal airway is the primary pathway for normal breathing in an infant.[7] During quiet breathing, resistance through the nasal passages is considerably greater than during mouth breathing. Despite the higher resistance, preferential or instinctive breathing through the nose is important for air warming, humidification, and particle filtration. Of note, total airway resistance and potentially compromised breathing is increased significantly in infants with nasal congestion, increased secretions, or by the presence of a nasogastric tube.

The Pharynx. The entrance to the pharynx is lined with rich lymphoid tissue (tonsils and adenoids). Hypertrophic adenoids may cause the normal nasal air conditioning mechanisms to be bypassed by causing partial or complete nasopharyngeal obstruction and forcing infants and children to breathe orally. Also, serious hemorrhaging from friable and inflamed adenoids can occur with placement of a nasal airway or nasogastric tube. Enlarged or hypertrophic tonsils may obstruct the entrance to the oropharynx.

The Larynx. In the newborn infant, the larynx is located at a level corresponding to the base of the occiput and C_1 to the superior border of C_4. This relatively high position of the larynx enables the epiglottis to pass up behind the soft palate and lock the larynx directly into the nasopharynx. This provides a direct air channel from the external nares through the nasal cavities, nasopharynx, larynx, and trachea to the lungs. Liquids can pass on either side of the interlocked larynx and nasopharynx into the esophagus. This anatomic configuration creates two separate pathways: a respiratory tract from the nose to the lungs and a digestive tract from the oral cavity to the esophagus. The separate respiratory and digestive routes prevent the mixing of ingested food and inhaled air. Hence, the newborn can breathe and swallow liquids simultaneously.[8,9] The connection between the epiglottis and the soft palate is constant, except for interruptions that occur during crying or with disease.

The combination of the large tongue, which is entirely within the oral cavity, and the high glottis makes it more difficult to establish a line of vision between the mouth and larynx during laryngoscopic examination. Because relatively more tissue is contained in less distance, the infant's larynx appears to be anterior and can make endotracheal intubation more difficult than in the adult.

Anatomic Transitions. Major position changes of the upper respiratory structures occur after the second year of life. The posterior third of the tongue descends into the neck and forms the upper anterior wall of the pharynx. The larynx begins a gradual descent to a lower position in the neck. By 7 years, the larynx lies between the upper border of the third cervical vertebrae (C_3) and the lower border of C_5 (from the tip of the epiglottis to the inferior border of the cricoid). By adulthood, the larynx descends farther and is located between the upper border of C_4 and the upper border of C_7. The lower position of the larynx in older children and adults results in a larger supralaryngeal portion of the pharynx. A true oropharynx is now apparent even during maximum elevation of the larynx. With the disappearance of the ability of the epiglottis to make contact with the soft palate, two separate pathways (i.e., one for air and one for liquids) no longer exist.

The larynx is the narrowest portion of the entire pediatric airway. The cricoid cartilage forms a complete ring, protecting the

Trauma Reports™ (ISSN 1531-1082) is published bimonthly by AHC Media LLC, 3525 Piedmont Road, N.E., Six Piedmont Center, Suite 400, Atlanta, GA 30305. Telephone: (800) 688-2421 or (404) 262-7436.

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POSTMASTER: Send address changes to ***Trauma Reports***, P.O. Box 740059, Atlanta, GA 30374.

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Table 1. The Pediatric Airway: Anatomic and Physiologic Differences

- Abundant secretions
- Greater dependence on nasopharyngeal patency
- Relatively larger tongue
- Relatively smaller oral cavity
- Size and security of teeth
- Relative and absolute size of tonsils and adenoids
- Floppier, more u-shaped or oblonged epiglottis[
- More acute angle between epiglottis and laryngeal opening
- More oblique inclination of the vocal cords
- Small caliber of glottis, trachea and airways
- Larynx higher in the neck
- Shorter neck
- Short trachea
- Small cricothyroid membrane
- Incomplete airway cartilage development
- Cricoid ring most narrow portion of the airway
- More prominent occiput
- Higher resistance to airflow
- Influence of sleep state on airway patency
- Enhanced bronchoconstriction

upper airway from compression. In the adult, the airway diameter of vocal cords and the trachea are of equal dimensions. If an endotracheal tube will pass comfortably through the vocal cords, it will equally traverse the cricoid cartilage. However, the newborn's laryngeal structures resemble a funnel — the narrowest portion of the airway is not the vocal cords, but the cricoid ring. An endotracheal tube that passes easily through the vocal cords may be tight within the cricoid ring, causing either temporary or permanent damage to the cricoid cartilage and potentially resulting in short- or long-term airway difficulties (e.g., subglottic stenosis).

Neck Position. Neck position plays a crucial role in airway obstruction. Because the infant has a large occiput, the head flexes forward onto the chest when the infant is lying supine with the head in the midline. In contrast, extreme neck extension also can obstruct the airway.[7] Midposition of the head with slight extension (the 'sniffing position') is preferred for airway maintenance. This is accomplished by placing a small pad under the shoulders to establish the best axis. Neutral cervical spine requirements (in the pediatric trauma patient) can be managed by this same airway positioning.[10]

The Pulmonary System. Compared with adults, the thoracic volume of a child is small and the airways are narrow and short. By virtue of the relatively small and short pediatric trachea, extubation or inadvertent endotracheal tube migration into either mainstem bronchus may occur during intubation. In addition, endotracheal tube movement readily occurs with changes in head position. Neck flexion displaces the tip of the endotracheal tube farther into the trachea, whereas extension of the neck moves the tube farther out of the trachea.[11]

There is a smaller amount of elastic and collagen tissue in the neonatal lung than in the adult lung. As a result, liquid or air can easily enter the pulmonary interstitium; this may explain the increased tendency of infants to develop pulmonary edema, pneumomediastinum, pneumothorax, and interstitial emphysema. Reduced elastic fibers contribute to the tendency for small airway collapse. Because elastic recoil of the thorax and lung is low, pleural pressure is nearly atmospheric and may contribute to airway closure.

The relative sizes of lung volumes and capacities remain the same throughout life. The tidal volume averages 6-7 mL/kg and constitutes approximately 8% of total lung capacity. Because the absolute tidal volume of the child is small, mechanical ventilators for children must be capable of providing small tidal volumes. Additionally, when infants receive manual or mechanical ventilatory support, the alveoli served by the peripheral airways require time to fill and empty. Inspiratory time must be adequate for chest expansion and alveolar ventilation, and expiratory time must be adequate to allow alveoli to empty. If alveoli do not empty completely prior to the next breath, they become overdistended, and complications, such as alveolar rupture or pneumothorax, may occur.

Chest Wall Mechanics. The chest wall encloses and supports the lungs. The cartilaginous ribs of the infant and young child are twice as compliant as the bony ribs of the older child or adult. During respiratory distress, the infant's chest wall retracts and, thereby, reduces the ability to maintain functional residual capacity, prevents increases in tidal volume, and increases the work of breathing.

Because of their soft, compliant chest walls, newborns and infants tend to have a low relaxation lung volume. However, they are capable of maintaining functional residual capacity above this low relaxation volume by various mechanisms directed at breaking expiratory flow (e.g., grunting). Unfortunately, these mechanisms may not be effective when lung compliance is reduced (e.g., pulmonary contusion), when neurologic control is impaired (e.g., trauma, drug effects), or when the infant's trachea is intubated.[7] Under these circumstances, the functional residual capacity may decrease to volumes incompatible with alveolar stability, resulting in alveolar closure, atelectasis, and hypoxemia. Furthermore, because children have compliant chest walls, health care providers must use caution when restraining children to backboards for spinal immobilization. Excessive restraints may impair chest wall movement.[12] As the child grows, chest wall compliance decreases and elastic outward recoil of the rib cage increases because of an increase in chest wall muscle tone. These changes improve the child's ability to maintain functional residual capacity, reducing the likelihood of atelectasis and small airway closure.

In infants, the ribs are oriented in a more horizontal direction than in adults and they articulate with both the spinal column and sternum. The infant's chest has less anterior-posterior displacement during inspiration than the adult chest. Intercostal muscles lack the leverage needed to lift the ribs and expand the chest effectively. These factors tend to reduce the mechanical efficiency of respiratory muscle function during the first years of life. As the child grows, the rib articulation changes to a 45° downward angle and the intercostal muscles are able to elevate the ribs and

contribute to chest expansion. Consequently, the intercostal muscles relative to the ribs are not maximally efficient and effective in young infants; they act primarily to stabilize the ribs and chest wall during the first years of life.

The Diaphragm. In the newborn, the diaphragm is nearly horizontal, whereas in adults, insertion is oblique. Horizontal insertion of the diaphragm tends to draw the lower ribs inward during spontaneous respiration. This diaphragmatic work is wasted since the resulting chest wall distortion does not improve ventilation. The tendency to draw the ribs inward is exaggerated in the supine position. Because oblique insertion expands the chest, the efficiency of diaphragmatic contraction increases with growth. Moreover, any compromise of diaphragmatic excursion (e.g., gastric distention) can predispose the child to the development of respiratory failure. Therefore, it is important to prevent abdominal distention in the child.

Endotracheal Tube Size. Even selecting an endotracheal (ET) tube of the correct size is less straightforward in children than in adults. The formula (internal diameter = age(years)/4 + 4) is the best approximation for children older than 2 years, while published guidelines work best for younger infants. A tube with its diameter equal to the width of the child's fifth fingernail is likely to be appropriate. In most cases there should be a leak around the tube at 20-30 cm H_2O.[6] Multiple studies have indicated that the absence of a leak at less than 30-40 cm H_2O is highly predictive of postextubation upper airway obstruction.[13,14]

Because the narrowest portion of the child's airway is at the cricoid (rather than at the vocal cords, as in adults), uncuffed tubes commonly provide an adequate fit with minimal loss of delivered tidal volume. Traditional recommendations have been to use uncuffed endotracheal tubes in children younger than 8 years. However, in an attempt to avoid intubating children with inappropriately large tubes, physicians often select a tube that is so small and has such a large leak around it that effective ventilation is impossible. Recent evidence shows that cuffed tubes can be used safely in younger children, and may actually decrease the risk of complications, at least in the short term.[15] Khine and colleagues recommend using the following formula for a cuffed tube:

$$\text{internal diameter} = \text{age [years]}/4 + 3$$

using an upward rounding approach to age (e.g., a child who has passed his first birthday is considered to be 2 years old).[16] In the operating room, tube selection by this formula is appropriate in 99% of patients.

Appropriate depth of placement is also important. Most of the available recommendations lead to inappropriate tube placement in many patients. Excessively low placement often is associated with mainstem bronchial intubation, atelectasis, pneumothorax, and severe hypoxemia. A tube placed too high is more likely to be dislodged. One suggestion for correct placement is to multiply the endotracheal tube diameter by 3 to determine appropriate depth. Using the diameter chosen according to the age-based formula ([age/4] + 4) results in inappropriate placement in more than 40% of patients.[17] One of the simplest and best suggestions to date is to use a tube with markings along its entire length, and place the 3.0-cm mark at the cords for all infants requiring a 3.0-3.5 internal diameter tube, at 4.0 cm for those with 4.0-4.5 tubes, and at 5.0 cm for those with 5.0-5.5 tubes.[18] Obtaining a chest x-ray soon after intubation, with the child's head in neutral position, is strongly recommended. Once the tube is in good position, noting and recording its depth and making sure that all subsequent x-rays are taken in the same neutral position minimizes further need for x-rays (and the associated exposure and cost).

Even with the tube in good position, right upper lobe atelectasis is common in infants and young children. While pooling of secretions and debris in a small, posteriorly angled bronchus is often the cause, a recent report notes that persistent right upper lobe atelectasis in children can be associated with a tracheal bronchus, a variation occurring in approximately 2% of the population.[19] While this would rarely be a problem in a larger patient, the length of trachea available for ET tube placement in a small child is sufficiently short that the potential to occlude the bronchial orifice is substantial.

The Trauma Patient: Initial Assessment and Management

In the initial stabilization of all trauma patients, including head-injured children, control of the airway and adequate ventilation are the first priorities. In TBI, it is particularly important to maintain oxygenation and prevent hypoxemia, since even moderate reductions in PaO_2 levels can contribute to secondary neural injury in the injured brain. The traumatically injured brain is particularly susceptible to secondary insults such as hypoxia-ischemia. In addition, even moderate hypoxia (PaO_2 level less than 40-50 mmHg), which might not reach a level that affects cerebral viability, is a potent vasodilator and may contribute to cerebral swelling. It is also important to maintain normocarbia, since even moderate hypercarbia can cause arteriolar vasodilation and increased cerebral blood volume, which could further contribute to increased intracranial pressure and precipitate herniation. Hypercarbia (and hypoxemia) may have several causes in head-injured patients, especially in the field, where poor airway control and respiratory failure are common. Hypercarbia has been found in 15%-20% of head-injured patients and can be prevented by intubation and ventilation.[20]

Bag-valve-mask Ventilation. Airway management in children is a difficult task. The anatomic and physiologic differences in children must be kept in mind when approaching the patient. Remember that the single most common cause of respiratory deterioration in infants and children is an inadequate airway.

The sniffing position is accomplished by placing the child on a hard surface and rotating the head back so that the child's face is directed upward. In the case of the trauma victim, this maneuver must be performed with in-line stabilization to protect a potentially unstable cervical spine from further injury. In the trauma victim, the head should not be forcefully rotated. In this situation, gentle in-line stabilization in the neutral position is used, and further manipulation is restricted to the jaw-thrust or

chin-lift maneuvers or insertion of an oral or endotracheal airway.

Despite proper positioning of the head, decreased tone in the muscles protecting the upper airway or a foreign body in the airway still may produce obstruction. The first problem can be relieved by the jaw-thrust or normal chin-lift maneuvers, the insertion of the oral airway, or the insertion of an endotracheal tube. The jaw-thrust maneuver is performed by placing a finger behind the angle of the mandible on each side and exerting anterior pressure to life the jaw. The chin lift maneuver is performed by placing a finger under the chin and lifting. Both of these maneuvers displace the mandible anteriorly and separate the tongue from the posterior pharyngeal wall.

Opening the airway also can be accomplished by inserting an oral pharyngeal airway. An oral airway is 'sized' by placing it next to the child's cheek. The end of the oral airway should just touch the angle of the mandible. An oral airway that is too small can be swallowed, and one that is too large can traumatize the posterior pharynx or come to rest in the laryngeal vestibule, thus creating even more upper airway obstruction and defeating its own purpose. An oral airway should only be placed in a child after the child's airway has been visually inspected for a foreign body. Otherwise, there is risk that the oral airway may push a foreign body deeper into the child's airway, making removal more difficult. Oral airways are poorly tolerated by most conscious patients. When an oropharyngeal airway is introduced into a conscious or stuporous patient— especially in an infant or child — laryngospasm or vomiting may be induced. Care should be taken in its placement because incorrect insertion usually displaces the tongue backward into the pharynx and can result in or worsen airway obstruction.

In addition to the above maneuvers to open the airway, constant attention to nasopharyngeal and oral suctioning is necessary to remove secretions that can compromise airway patency. Because neonates are obligate nosebreathers with small nasopharynxes, even a small amount of secretions can cause major obstruction, as can a nasogastric tube.

Frequently, opening the airway is all that the patient needs to breathe effectively. If the patient does not spontaneously breathe when the patency of the airway is established, ventilation is necessary.

The use of the bag-valve device and mask has several advantages: It provides an immediate means of ventilatory support; it conveys a sense of compliance of the patient's lungs to the rescuer; it can be used with spontaneously breathing patients; and it can deliver an oxygen-enriched mixture to the patient.

Typically, the bag-valve device is available in three sizes: adult, child, and infant. Studies show that standardized adult and pediatric bag-valve devices provide equally effective ventilation in an infant mannequin lung model. Also, the use of larger resuscitation bags did not result in excessive ventilation.

Small-volume (infant) self-inflating bag devices do not deliver an adequate tidal volume to the infant with poorly compliant lungs. The small bag volumes also limit the duration of inspiration, which needs to be prolonged when the lungs are atelectatic. Thus, child-size and adult-size self-inflating bags may be utilized for the entire range of infants and children.

Although its use has gained widespread acceptance in all care settings, the bag-valve-mask device also has been characterized as cumbersome and difficult to use. The most frequent problem with the bag-valve-mask device is the inability to provide adequate ventilatory volumes to a patient who is not endotracheally intubated. This most commonly results from the difficulty of providing a leak proof seal to the face while maintaining an open airway. It also occurs when the bag is not squeezed sufficiently enough to force an adequate amount of air into the patient's lungs.

Optimizing bag ventilation during cardiopulmonary resuscitation or ventilation of an unprotected airway is mandatory to minimize the risk of pulmonary complications and the occurrence of gastric inflation due to excessive airway pressure.[21,22] Numerous studies have underlined the difficulty of providing safe and effective bag ventilation in these situations.[21,22]

Good bag-valve-mask ventilation technique is mandatory because the child must be kept alive while preparations are made for a safe and controlled intubation. This is not a basic life support skill as much as an initial life support skill.

Endotracheal Intubation. Endotracheal intubation is often accomplished after the airway has been secured and the patient has been adequately ventilated with a bag-valve-mask device to ensure oxygenation and removal of carbon dioxide.

The decision to intubate and begin ventilatory assistance is always a clinical one; arterial blood gas values are at best a helpful guide. Early elective intubation is often wise, even if progressive CO_2 retention does not occur, or if hypoxemia is corrected but with high concentrations of supplemental oxygen.

Pitfalls in intubation include lack of experience in intubating children, selection of the incorrect route for intubation, failure to preoxygenate, improper use of the laryngoscope, forcing the tracheal tube into the airway, passing the tube too far or not far enough, prolonged attempts to intubate, and equipment malfunction or unavailability.

When used by properly trained providers, ventilation via a tracheal tube is the most effective and reliable method of assisted ventilation. (*See Tables 2 and 3.*)

Identify the Difficult Airway Prior to the Intubation Procedure. Expert performance of endotracheal intubation can be life-saving, while inability to perform this technique adequately can be life-threatening. Identification of potential problems, preintubation anatomic evaluation, equipment and drug preparation, and anticipation of potential complications will allow for a high success rate. Furthermore, physicians must have a logical, safe, alternate plan for airway management when faced with a patient who is difficult to intubate or who cannot be ventilated.

If time allows, a pre-intervention history and physical examination will identify most patients who will be difficult to intubate. The American Society of Anesthesiologists risk classification system will identify patients at highest risk for adverse outcome from administration of general anesthetics, paralysis, and endotracheal intubation (*Table 4*).[23]

Table 2. Endotracheal Intubation: Advantages and Indications

ADVANTAGES OF ENDOTRACHEAL INTUBATION:

- The airway is isolated to ensure adequate ventilation and delivery of oxygen without inflating the stomach.
- The risk of pulmonary aspiration of gastric contents is minimized.
- Inspiratory time and peak inspiratory pressures can be controlled.
- Secretions and other debris can be suctioned from the airways.
- Positive end-expiratory pressure can be delivered.

INDICATIONS FOR ENDOTRACHEAL INTUBATION INCLUDE:

- Inadequate central nervous system control of ventilation resulting in apnea or inadequate respiratory effort
- Functional or anatomic airway obstruction
- Excessive work of breathing leading to fatigue
- Need for high peak inspiratory pressures or positive end-expiratory pressures to maintain effective alveolar gas exchange
- Lack of airway protective reflexes
- Permitting paralysis or sedation for diagnostic studies while ensuring protection of the airway and control of ventilation

Table 3. Intubation Equipment

BEFORE ATTEMPTING INTUBATION, ASSEMBLE THE FOLLOWING EQUIPMENT:

- A tonsil-tipped suction device or a large-bore suction catheter
- A suction catheter of appropriate size to fit in the tracheal tube
- A properly functioning manual resuscitator, oxygen source, and a face mask of appropriate size
- A stylet to provide rigidity to the tracheal tube and help guide it through and beyond the vocal cords. If a stylet is used, it is important to place the stylet tip 1 to 2 cm proximal to the distal end of the tracheal tube to prevent trauma to the trachea from the stylet.
- Three tracheal tubes, 1 tube of the estimated required size and tubes 0.5 mm smaller and 0.5 mm larger
- A laryngoscope blade and handle with a functioning bright light (and spare bulb and batteries if possible)
- An exhaled CO_2 detector (capnography or colorimetric)
- Tape to secure the tube and gauze to dry the face. An adhesive solution also may be used on the tube and face, or a tracheal tube holder may be considered.

Direct examination of the airway can identify patients who will be at greatest risk for difficult intubation and inability to ventilate. A few simple measurements can be useful and include the mental-hyoid distance and the upper-lower incisor distance. The upper-lower incisor distance with open mouth should be assessed in infants and children. A quick look into the posterior pharynx (without any instruments) will reveal either evidence of a difficult airway (e.g., a large tongue, blood, swelling, or secretions) or an easier airway with visible faucial pillars, soft palate, and uvula. While a short neck, small mandible, large tongue, obesity, high arched palate, scoliosis, and limited mandible or cervical spine mobility account for a significant number of difficult airway cases, some patients who appear normal to conventional examination still may present an unanticipated airway problem. (*See Tables 5 and 6.*)[24]

Prior to endotracheal intubation, clinicians must have a plan of action for dealing with difficult or failed attempts at intubation. Always prepare rescue equipment in advance whether or not difficulties are anticipated. If patients have anatomic obstruction (e.g., fractured larynx) or maxillofacial trauma, equipment, and personnel (e.g., surgeon and anesthesiologist) should be readied in case surgical airway techniques are necessary.

Predictable consequences or risks attend laryngoscopy and intubation (*Table 7*). Efforts must be made to minimize these problems.

The Intubation Procedure. In a child with a perfusing rhythm, endotracheal intubation should always be preceded by the administration of supplemental oxygen. Assist ventilation only if the patient's effort is inadequate. If a rapid sequence intubation (RSI) procedure is anticipated (*See Rapid Sequence Intubation section on page 7*), avoid assisted ventilation, if possible, because it often inflates the stomach and increases the risk of vomiting and aspiration. If trauma to the head and neck or multiple trauma is present, the cervical spine should be immobilized during intubation.

Because morbidity can occur from an improperly placed tracheal tube or from hypoxia created during prolonged intubation attempts, attempts should not exceed approximately 30 seconds, and the heart rate and pulse oximetry should be monitored continuously.

Intubation is probably best performed by the most skilled provider present. In a child in cardiac arrest, do not delay intubation to apply a device to continuously monitor the rhythm. Furthermore, pulse oximetry will not function if the patient does not have detectable pulsatile perfusion.

Either a straight or a curved laryngoscope blade may be used. When a straight blade (preferred blade in infants and children) is used, the blade tip is usually passed over the epiglottis to rest above the glottic opening. Use the blade traction to lift the base of the tongue and directly elevate the epiglottis anteriorly, exposing the glottis. When using a curved blade, insert the tip of the blade into the vallecula (the space between the base of the tongue and the epiglottis) to displace the base of the tongue anteriorly. Do not use the laryngoscope blade and handle in a prying or levering motion, and do not place pressure directly on the teeth, lips, or gums.

The appropriate depth of insertion of a tracheal tube can be estimated from the following formula:

Depth of insertion (cm) = internal tube diameter (in mm) · 3.

An alternative formula to estimate appropriate depth of insertion in children older than 2 years is:

Depth of insertion (cm) = (age in years/2) +12.

Verification of Proper Tube Placement. Once the tracheal tube is positioned, provide positive-pressure ventilation, observe

Table 4. American Society of Anesthesiologists (ASA) Risk Classification

ASA CLASS
I. Patient normally health
II. Mild to moderate systemic disease
III. Severe systemic disease
IV. Severe systemic disease – constant threat to life
V. Moribund – not expected to survive

Table 5. Anatomic Indicators of Difficult Airway

- Large tongue or inability to see soft palate, uvula, or faucial pillars
- Limited distance between upper and lower incisors
- Limited hinge movement of TMJ (e.g., trismus from deep space infection, maxillofacial trauma)
- Micrognathia
- Cervical spine abnormalities
- High-arched palate
- Macroglossia or glossoptosis
- The morbidly obese patient
- Upper airway obstruction, bleeding, trauma, burn, inhalational injury, craniofacial abnormality

Key:
TMJ = temporomandibular joint

chest wall movement, and listen for breath sounds over the peripheral lung fields. If the tube is properly positioned, there should be symmetrical, bilateral chest rise during positive-pressure ventilation, and breath sounds should be easily auscultated over both lung fields, especially in the axillary areas. Breath sounds should be absent over the upper abdomen. The presence of water vapor in the tube is not a reliable indicator of proper tracheal tube position. Tracheal tube placement should be confirmed by monitoring exhaled CO_2 levels, especially in children with a perfusing rhythm.

Securing the Endotracheal Tube. Once intubated, the ET tube then needs to be secured with tape so that displacement does not occur with movement. Taping the tube is a two-person job!

Although there are several methods of effective taping, always be sure that the head and the tube move as a unit and that kinking and angular bends of the tube are not possible. Stabilization to prevent rotation, flexion, or extension of neck is necessary before patient movement. Flexion and extension of the head may displace the tube either into a mainstem bronchus or up into the pharynx, with potential catastrophic consequences.[25]

After the tube is taped into place, confirm its position within the trachea clinically and by chest x-ray because transmitted breath sounds may be heard over the left hemithorax despite a right main bronchus intubation. In addition, the chest x-ray helps to identify and correct the position of a tube located high in the trachea, which is at high risk of displacement during movement.

Always measure and record the depth of the ET tube at the lip or the child's incisors. After any patient movement or changes in clinical status, confirm that the depth of the ET tube has not changed.

Once the ET tube is placed and secured, constant cardiopulmonary monitoring is essential. If an intubated child begins to deteriorate, consider the following possible complications:

- displacement of the endotracheal tube into the right mainstem bronchus, pharynx, or esophagus;
- ET tube obstruction with saliva, mucus, blood, foreign body, or purulent secretions;
- mechanical failure involving the bag-valve device or the ventilator; or
- pneumothorax

Rapid Sequence Intubation. Rapid sequence intubation (RSI) was developed as a means of handling the airway of a decompensating patient in the ED. It should be differentiated from rapid sequence *induction*, which is the classic anesthesia term used to describe the induction of anesthesia.[26] RSI is now a standard part of training in emergency medicine residencies and is increasingly taught in pediatric resuscitation courses.[27-31]

The goal of RSI is to take a patient from his/her starting level of consciousness to an unconscious, neuromuscularly blocked state and perform tracheal intubation without intervening positive-pressure ventilation. Because most ED patients are not fasting, patients are at increased risk of aspiration if positive-pressure ventilation is performed before airway control and air is allowed to enter the stomach. In most situations, correctly performed RSI allows a clinician to manage a patient's airway without positive-pressure ventilation until the ET tube is secured in the patient's trachea. RSI also increases the chance of successful placement of the ET tube through relaxation of the patient's musculature by neuromuscular blockade and gives the clinician the ability to manage the physiologic response of the body to laryngoscopy by the addition of various pharmacologic agents.

Medications used in RSI typically can be divided into two categories: *induction agents* and *neuromuscular blocking agents*. The induction agents fall into many classifications, but all serve to sedate the patient to intubate. The most commonly used induction agents are the benzodiazepines (e.g., midazolam, lorazepam, and diazepam), thiopental, ketamine, etomidate, and the opioids. Each has its advantages and disadvantages in specific clinical scenarios. All are given after the patient is preoxygenated but before any neuromuscular blockers are administered. The clinician must be familiar with the indications and common side effects of these medications and know when a situation calls for a specific agent. Clinical scenarios to remember are the hypotensive patient and the patient with raised intracranial pressure.

The benzodiazepines are sedative/hypnotic drugs often used in clinical practice to control seizure activity. They are efficient sedatives and amnestic agents but do not provide any pain control. Their rate of onset depends upon the agent, but midazolam (Versed®) has the quickest onset and shortest duration of the group. Midazolam (Versed®; 0.1 to 0.2 mg/kg IV) is extremely versatile and can be given via oral, intravenous, intramuscular, subcutaneous, and intranasal routes. The most common side effects with benzodiazepines are respiratory depression — most

Table 6. Potential Indications of a Difficult Intubation

ANATOMIC ABNORMALITIES
Short neck
Receding mandible
Narrowed mouth with high arched palate
Limited movement of mandible
Maxillary protrusion
Cervical rigidity
Obesity
CONGENITAL ABNORMALITIES
Choanal atresia
Encephalocele involving nasofrontal region
Macroglossia
Treacher-Collins syndrome
Craniofacial dysotosis (Crouzon's syndrome)
Klippel-Feil syndrome
Achondroplasia
Subglottic cysts
Cystic hygroma
Vascular compression of trachea
Subglottic stenosis
Mucopolysaccharide disease
Laryngeal web
Down syndrome
TRAUMA
Facial injuries
Mandibular fractures
Maxillary fractures
Laryngeal and tracheal trauma
Hemorrhage into respiratory tract
Tracheal rupture
Cervical spine injury
INFLAMMATORY
Rheumatoid arthritis
Cervical fixation
Temporomandibular disease
Cricoarytenoid disorders
Ankylosing spondylitis
TUMOR MASS
Cystic hygroma
Hemangioma

Table 7. Complications of Laryngoscopy and Intubation

- Tachyarrhythmias and bradyarrhythmias
- Impedance to systemic and jugular venous return
- Hypertension or hypotension
- Hypoxia
- Hypercarbia
- Increased intracranial, intragastric, and intraocular pressures
- Injury to airway structures (from lips or nose to alveoli)
- Regurgitation or vomiting with possible aspiration
- Inadvertent placement of the tube into the esophagus, soft tissues, or cranial vault
- Cervical spinal cord injury
- Generation of significant pain and anxiety

often seen with diazepam — and hypotension. The patient should be observed for a fall in blood pressure. For this reason, the benzodiazepines should be used with caution in patients with severe cardiovascular compromise, such as those with multiple trauma.

Thiopental (Pentothal®; 2 to 5 mg/kg IV) is a barbiturate that has been commonly used as an induction agent in RSI. It also can cause hypotension but is a very useful agent in patients with increased intracranial pressure. It is the drug of choice in normotensive patients with isolated head injuries or raised intracranial pressures. It produces significant cardiovascular depression and should be avoided in patients with volume depletion or hypotension.

Ketamine (Ketalar®; 1 to 2 mg/kg IV over 1 to 2 minutes) is a dissociative amnestic agent similar to the street-drug phencyclidine. It induces a 'dissociative amnesia' in patients, which is described as a sensation in which the mind is 'separated' from the body. Ketamine increases the release of catecholamines, which helps thwart the usual bradycardia commonly seen in pediatric patients when the insertion of a laryngoscope causes vagal stimulation and helps to dilate the small airways through beta-2 receptor activation. Ketamine is very useful in patients with status asthmaticus but should not be used in patients at risk for increased intracranial pressure as it tends to increase intracranial pressure secondary to the adrenergic surge.

Etomidate (Amidate®; 0.2 to 0.3 mg/kg IV) is a more recent addition to the RSI armamentarium and is classified as an imidazole hypnotic agent. The benefit of using etomidate is that it does not cause either hypotension or an increase in intracranial pressure. This useful characteristic makes etomidate an ideal drug for the multi-trauma patient at risk for closed head injury and hypotension, and these favorable hemodynamic benefits seem to extend even to young children.[32,33] Care must be taken, however, when using this drug in patients with adrenal suppression, as etomidate can cause further adrenal suppression by directly inhibiting the conversion of cortisol from 11-deoxycortisol in the adrenal gland. This phenomenon has been documented even after a single dose of etomidate.[34,35]

Narcotics such as fentanyl and morphine have been used in the past for induction, but large doses are required to have significant sedative effects. They are sometimes combined with benzodiazepines. This combination causes a drop in systemic vascular resistance and, therefore, should be avoided in patients with cardiovascular compromise. For this reason, the other agents previously mentioned are preferred in the setting of RSI.

The paralytic agents can be divided into *depolarizing* and *nondepolarizing agents*. All work at the neuromuscular junction to paralyze the muscle. Succinylcholine (Anectine®, Quelicin; 1.0 to 1.5 mg/kg IV) is the classic depolarizing agent and works to bind to the neuromuscular receptor and depolarize the fiber to

render it immune to further stimulation. Its strengths are its quick onset (approximately 30 to 60 seconds) and short duration (5 to 10 minutes). It has been shown to induce a rise in potassium of approximately 0.5 to 1.0 mEq/L[26] and cause a slight increase in intracranial pressure as well as slightly increase airway secretions. It should, therefore, be used with caution in any patient at risk for hyperkalemia as succinylcholine-induced arrhythmias are well documented.[27] It should be avoided in patients with a history of renal failure, paralysis, a significant burn older than 48 hours, or those confined to bed. Because an undiagnosed myopathy (e.g., muscular dystrophy) may lead to hyperkalemia and cardiac arrest, some authorities recommend avoiding succinylcholine in pediatric patients, especially males.[26]

The rise of intracranial pressure by succinylcholine can be blunted by pretreatment of the patient with lidocaine (Xylocaine; 1.5 mg/kg IV) 3 minutes before the succinylcholine is administered. Lidocaine should be strongly considered in the management of patients at risk for increased intracranial pressures, although the exact mechanism by which the drug attenuates a rise in intracranial pressure is not definitely established.[36]

Atropine (0.02 mg/kg IV; minimum dose 0.1 mg; maximum single dose of 0.5 mg for a child and 1.0 mg for an adolescent) should be given to all patients younger than 5 years before inducing neuromuscular blockade to block the bradycardia secondary to vagal stimulation by laryngoscope blade insertion. However, it must be recognized that pretreatment with atropine does not prevent bradycardia in all cases.[37] Atropine also blocks the increased secretions caused by succinylcholine and ketamine.

Pancuronium (Pavulon®; 0.1 mg/kg IV), rocuronium (Zemuron®; 0.6 to 1.0 mg/kg IV), and vecuronium (Norcuron®; 0.15 mg/kg IV) are the most commonly used nondepolarizing agents and bind to the neuromuscular receptor causing blockade but no depolarization. All act less quickly and last much longer than succinylcholine. Of these drugs, rocuronium has the fastest onset of action (60 to 90 seconds) with a duration of action of approximately 30 to 45 minutes. Pancuronium has the slowest onset and longest duration of action lasting up to 60 to 90 minutes. Mivacurium (0.2 to 0.3 mg/kg IV), another nondepolarizing agent, also can be used in RSI. While this drug has an onset of action similar to the other nondepolarizers, its duration of action is only twice as long as succinylcholine.[26] Mivacurium causes histamine release and may cause hypotension, but this side effect seems to be attenuated when the medication is given slowly over 30 seconds or more.[26]

There is no risk of raising potassium levels or intracranial pressure with these nondepolarizing agents, making them ideal when succinylcholine is contraindicated. Due to their long duration of action, though, it is essential to have a secondary means of oxygenating and ventilating the patient close at hand in case the ET tube cannot be placed. In patients who are difficult to ventilate with a bag-valve mask, a laryngeal mask airway (LMA) may be helpful to oxygenate and ventilate before repeat laryngoscopy.[38]

There is evidence that RSI is safe and effective in pediatric patients.[30,31,39-41] RSI is associated with a higher success rate of intubation and a lower complication rate. Importantly, intubation without premedication may worsen outcomes for unconscious patients with intracranial hemorrhage.[42]

Alternative Airway Devices. In the absence of personnel trained in tracheal intubation, or if attempts at tracheal intubation fail, there are alternative airway devices that may be better than an oropharyngeal airway and bag-valve device.

The laryngeal mask airway (LMA) allows rapid, effective ventilation with a single operator, with improved oxygenation, less hand fatigue, and less risk of gastric inflation compared with ventilation with a facemask.[43-46] Training in use of the LMA is quicker and easier than for tracheal intubation, although the number of insertions required to achieve and maintain sufficient skill has not been defined.[44]

Currently PALS does not recommend the use of LMAs in children as a result of limited data comparing their use with ET intubation and BVM ventilation in the resuscitation of children; nonetheless, they are used widely in operating room settings, emergency departments, and by some prehospital care systems.[29,47]

Controlled Ventilation. The use of controlled ventilation has long been a modality for the treatment of intracranial hypertension and is based on the known cerebrovascular response to changes in $PaCO_2$. The relative change in cerebral blood flow (CBF) during variations of $PaCO_2$ levels depends upon several factors including baseline CBF, cerebral perfusion pressure, and anesthetic drugs.[48] However, in a wide variety of subjects and conditions, most studies report a change in global CBF of 1-2 mL/100 g/min for each 1 mmHg change in $PaCO_2$. One group suggested that intracranial hypertension in children should be effectively treated almost exclusively with vigorous hyperventilation.[49] Random and 'blind' hyperventilation recently has come into question as a therapeutic intervention because it was found to worsen outcome in adults with severe TBI.[50] Hyperventilation therapy is not recommended in the first 24 hours after head injury, especially as a prophylactic therapy.[51,52] This position is supported by the results of reviews and studies in adults and children that together indicate that hypocapnia in the setting of acute head injury may cause harm by inducing cerebral ischemia. This concern of decreasing perfusion in the early period after injury, has prompted the use of moderate hyperventilation (i.e., $PaCO_2$ of 35 mmHg) that can aid intracranial pressure management without inducing ischemia.[51,53] Current recommendations for $PaCO_2$ management after TBI discourage the use of prophylactic hyperventilation and suggest that hyperventilation should be used only when increased intracranial pressure is refractory to other methods of control.

Inadvertent hyperventilation is extremely common with manual ventilation, regardless of the personnel or setting.[43,54-57] This may have adverse effects on the injured brain through a variety of mechanisms. First, cerebral vasoconstriction with hypocapnia is well documented and can result in global ischemia through a decrease in cerebral blood flow as well as local ischemia, especially in critical areas of brain surrounding the primary injury.[43] Second, positive-pressure ventilation reverses the pattern of negative intrathoracic pressure associated with spontaneous respiration, potentially obstructing venous return and decreasing blood

pressure and cardiac output; this occurs to a greater degree with increasing ventilatory rates.[52] Lastly, the increase in mean intrathoracic pressure that accompanies hyperventilation with positive-pressure ventilation can be transmitted in a retrograde fashion through the jugular venous system, raising intracranial pressure as a result. Recent data also suggest that injurious ventilation strategies lead to an increase in cytokine release, endothelial apoptosis, and mortality from both overinflation and from the absence of positive end-expiration pressure. The specific characteristics of prehospital ventilation with regard to each of these factors have not been defined; however, it is possible that a lower end-tidal carbon dioxide value is a surrogate marker for injurious ventilation.

Utilization of continuous end-tidal carbon dioxide (E_TCO_2) monitoring in the prehospital environment as well as in the ED may decrease complications of inadvertent hyperventilation and unrecognized misplaced endotracheal tubes. In a recent study, no unrecognized misplaced intubations were found in patients for whom paramedics used continuous E_TCO_2 monitoring.[58] Failure to use continuous E_TCO_2 monitoring was associated with a 23% unrecognized misplaced intubation rate.[58]

Conclusions

The establishment and maintenance of a patent airway has been the initial step in resuscitation of both children and adults for as long as resuscitation guidelines have existed. Management of the pediatric airway is a skill that is critical in the prehospital environment as well as in the ED. A thorough understanding of a child's anatomy and access to and knowledge of the appropriate equipment and pharmacologic adjuncts enable the ED physician to secure the airway in a timely efficient manner that optimizes the patient's outcome. No other skill is as important![29]

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CNE/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.

CNE/CME Instructions

Physicians and nurses participate in this continuing medical education/continuing education program by reading the article, using the provided references for further research, and studying the questions at the end of the article. Participants should select what they believe to be the correct answers, then refer to the list of correct answers to test their knowledge. To clarify confusion surrounding any questions answered incorrectly, please consult the source material. **After completing this activity, you must complete the evaluation form provided and return it in the reply envelope provided in order to receive a letter of credit.** When your evaluation is received, a letter of credit will be mailed to you.

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CNE/CME Questions

1. Which one of the following systemic abnormalities is an important contributor to secondary brain injury?
   A. Hypoxemia
   B. Hypernatremia
   C. Hypothermia
   D. Hypokalemia

2. Which of the following statements regarding pediatric intubation is *false*?
   A. Secondary confirmation of ET placement should be performed routinely.
   B. Hyperventilation should be performed routinely.
   C. End-tidal CO_2 detection is the most common secondary confirmation method.
   D. BVM is an acceptable prehospital technique for managing the pediatric airway.

3. Even with the endotracheal tube in good position, right upper lobe atelectasis is common.
   A. True
   B. False

4. Which of the following statements regarding the pediatric respiratory system is *not* true?
   A. Infants have greater chest wall compliance than adults.
   B. Infants have higher oxygen consumption than adults.
   C. Infants have lower airway resistance than adults.
   D. Infants have fewer alveoli than adults.

5. Pediatric patients:
   A. have a greater tendency to become bradycardic with laryngoscopy.
   B. tolerate supine positioning without desaturation better than adults.
   C. can maintain oxyhemoglobin saturation during a longer period of apnea than adults.
   D. recruit accessory respiratory muscles with greater efficiency than adults.

6. Which of the following statements concerning early management of TBI in children is correct?
   A. The routine use of hyperventilation is indicated because cerebral blood flow is elevated.
   B. There is strong association between adverse outcomes and early hypotension in patients with TBI.
   C. Routein hyperventilation should be initiated in the first 12 hours.
   D. Hyperventilation improves outcomes in children with mild hand injuries.

7. Regarding pediatric airway anatomy:
   A. Children have relatively larger tongues than adults.
   B. The pediatric larynx is located inferiorly to that of an adult.
   C. The epiglottis of a child is similar to that of an adult.
   D. The narrowest point of the infant airway occurs at the level of the vocal cords.

8. Shortly after intubation, a child becomes hypoxemic. Which of the following mechanisms could be responsible?
   A. Pneumothorax
   B. Obstructed endotracheal tube
   C. Accidental extubation
   D. All of the above

9. Excessively low endotracheal tube placement may be associated with atelectasis or pneumothorax.
   A. True
   B. False

10. A short neck, small mandible, large tongue, or high arched palate may indicate a potentially difficult airway.
    A. True
    B. False

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

In Future Issues:

Carbon monoxide poisoning

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1. discuss conditions that should increase suspicion for traumatic injuries
2. describe the various modalities used to identify different traumatic conditions
3. cite methods of quickly stabilizing and managing patients
4. identify possible complications that may occur with traumatic injuries

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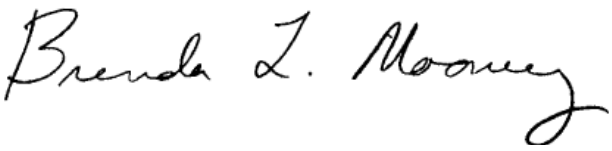
On behalf of AHC Media, we thank you for your trust and look forward to a continuing education partnership.

Sincerely,



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