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The most important skill for the emergency physician is airway management. The Manual of Emergency Airway Management *by Ron Walls, MD, emphasizes that control of the airway is a defining skill of emergency medicine.[1] No other commonly performed procedure has as immediate an effect on life and death as endotracheal intubation. Although challenging in all patients, the procedures of endotracheal intubation (ETI) and rapid sequence induction pose many particular challenges when performed in children. This article will begin by reviewing the existing literature describing the epidemiology of rapid sequence intubation (RSI) in children as well as its affect on survival. The pertinent aspects of pediatric anatomy and physiology will be reviewed. Finally, the various components of RSI in children— including equipment, techniques, medications, and rescue devices— will be discussed.*

—The Editor

Rapid Sequence Intubation in Pediatrics

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Introduction and Epidemiology

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. ETI is considered by many the gold standard among interventions for the pediatric airway.

However, clinical evidence of the usefulness and efficacy of ETI in children is not supported completely by studies examining the technique and its outcomes.

This article will provide an overview of the anatomic, physiologic, pharmacologic, and procedural aspects of advanced pediatric airway management using ETI, RSI, and rescue techniques.

Pediatric ETI in the Prehospital Setting

Although many of the principles of pediatric ETI apply in all health care settings, ETI in the prehospital care setting has unique characteristics and has been the subject of intense controversy. In a landmark study by Gausche et al, prehospital care providers administered either ETI or bag valve mask (BVM) ventilation to children in need of respiratory support in an alternate day fashion. A total of 820 children were enrolled during a 33-month period. No difference was found in either survival or favorable neurologic outcome in children who underwent ETI compared with those who received BVM ventilation alone. The authors concluded that ETI conferred no benefit to critically ill children in the prehospital setting and resulted in significantly longer scene times.[2] All children enrolled had short transport times to definitive medical care (mean 20 and 23 minutes for BVM vs ETI groups, respectively). Intubation success rates varied by age (56-67%) and were considerably lower than those observed in other studies.

Despite the limitations cited above, the Gausche study clearly affected the approach to pediatric prehospital airway management. The most recently published guidelines for Pediatric Advance Life Saving (PALS) included a change in wording regarding ETI use in children, stating that "ventilation via a properly placed tracheal tube is the most effective and reliable method of assisted ventilation," but that ETI "requires mastery of the technical skill to successfully and safely place a tube in the trachea, and it may not always be appropriate in the out-of-hospital setting . . ."[3]

Gausche's findings contrasted with those of previous epidemiologic studies that evaluated prehospital ETI in the pediatric patient in cardiopulmonary arrest. In 1987, Losek and colleagues analyzed 114 children with out-of-hospital cardiac arrest, and found that in children younger than 18 months, successful ETI was a significant predictor of survival to hospital discharge.[4] Ironically, the study also demonstrated a statistically significant decreased likelihood for ETI being attempted in children in the same age range. In 1999, Sirbaugh and colleagues conducted a prospective analysis of 300 children with out-of-hospital cardiac arrest and found that successful ETI was the only significant predictor for on-scene return of spontaneous circulation; however, ETI had no affect on survival.[5]

Use of RSI Medications in Children

The variability of successful outcomes from pediatric ETI use in the prehospital arena, as well as in the emergency department (ED), is due largely to the variability in success rates for tube placement and the occurrence of complications. Little data examining the effect of RSI medications on intubation success in the ED exist. A recently published prospective survey of 11 EDs that performed 156 pediatric intubations during a 16-month period showed that 72% percent of first attempts at ETI were successful overall, varying from 60% in children younger than 2 years to 85% for children ages 12 to 18 years.[5] Intubation was more likely to be successful in children in whom RSI was performed (defined as the use of neuromuscular blockade [NMB] prior to intubation) when compared with ETI attempted with no medications or the use of sedative medications alone. In another recent retrospective review of ED patients, RSI was successful in 78% of cases with the first attempt when medications for RSI were applied according to a pre-established protocol.[6] Easley and colleagues prospectively examined children who underwent ETI and found significant differences in medication use between children's hospital EDs and non-children's hospital EDs. They found that pediatric patients in non-children's hospital EDs were more likely to be intubated without NMB agents or with no medications and also were more likely to experience complications or variances from practice guidelines.[7] This study, however, did not examine or control clinical variables related to patients studied.

Studies of prehospital ETI in children without the use of RSI or sedation medications also have yielded variable intubation success rates, ranging from 39-50% in infants to 71-90% in older children. Several studies have demonstrated significant differences in success of ETI among age groups, with infants and toddlers having lower success rates than older children.[4,8,9] Results of one retrospective study of prehospital ETI in children showed that succinylcholine (SCh) was used by paramedics in 47% of cases, and that patients receiving SCh were more likely to be

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older, more likely to have been injured, and less likely to experience complications related to ETI.[10] This variability in ETI success rates in the literature reflects the complexity of performing ETI on a heterogeneous group of patients in a variable and often uncontrolled setting.

Anatomy

The ability to perform ETI successfully in a pediatric patient begins with knowledge of the unique anatomic features in the head and neck, and a thorough familiarity with a child's airway structures. Differences in technique, positioning, and equipment configuration and size all must be adapted to the unique anatomical considerations listed below.

Size. Airway structures are smaller and the field of vision with laryngoscopy is narrower in children.

Adenoidal Hypertrophy. This condition is common in young children leading to greater tendency to obstruct the nasopharynx; and greater risk for injury to adenoidal tissue with resultant bleeding in hypopharynx when laryngoscopy is performed.

Developing Teeth. Although young infants are edentulous, the underlying alveolar ridge contains developing tooth buds that are susceptible to disruption from laryngoscope trauma. Primary teeth in young children can be avulsed and/or aspirated easily.

Tongue. The tongue is large relative to the size of oropharynx in children.

Superior Larynx. Often referred to as being anterior, the laryngeal opening in infants and young children actually is located in a superior position to that of an adult. (In infants, the larynx is opposite C_3-C_4 as opposed to C_4-C_5 in adults.) A child's normal anatomy makes the angle of the laryngeal opening with respect to the base of the tongue more acute and visualization more difficult.

Hyoepiglottic Ligament. The hyoepiglottic ligament connects the base of tongue to the epiglottis. This ligament has less strength in young children; therefore, a laryngoscope blade in the vallecula will not elevate the epiglottis as efficiently as in an adult.

Epiglottis. The epiglottis of children is narrow and angled acutely with respect to the tracheal axis; thus, the epiglottis covers the tracheal opening to a greater extent and can be more difficult to mobilize.

The narrowest point of the young child's airway occurs at the level of the cricoid cartilage instead of at the level of the glottic opening itself.

The goal of head positioning for direct laryngoscopy is the alignment of the pharyngeal axis (PA), laryngeal axis (LA), and oral axis (OA). In adults, the alignment of the LA and PA often is optimized by the elevation of the occiput. In infants, the prominent occiput makes that maneuver unnecessary, and occipital elevation can potentially worsen the view of the glottic opening.[11]

An understanding of the unique physiologic features of children also is extremely important as a background for discussion of RSI in children.

Respiratory Physiology

Lung. Infants have fewer and smaller alveoli than young children, and their overall gas exchange surface area is disproportionately small. Surface area reaches proportions similar to adulthood by 8 years of age. Channels for collateral ventilation (pores of Kuhn and Lambert's channels) are absent in infancy. The overall effect of those phenomena is a greater tendency for alveolar hypoventilation and for the development of atelectasis during a respiratory illness.[12]

Respiratory Mechanics. The pediatric thoracic skeleton is largely cartilaginous and much more compliant than the adult skeleton. Elastic recoil of the chest wall in the young child is essentially absent. A given change in thoracic pressure will result in a larger change in lung volume, similar to the physiology seen in an adult with emphysema. A given change in volume is associated with little or no change in pressure, so that a greater amount of work is required to generate a tidal breath.

The high compliance of the pediatric chest wall results in a closing volume (CV) (i.e., volume at which terminal bronchioles collapse because they are no longer supported by elastic recoil) that can be elevated with respect to functional residual capacity (FRC). If the already diminished elastic recoil is impaired (i.e., by supine positioning), CV can exceed FRC to a greater extent resulting in the absence of ventilation of some lung segments during normal tidal breathing. Therefore, young patients have a greater tendency for intrapulmonary shunting and hypoxemia with the positioning required for airway management.

Accessory respiratory muscles in young children are composed of a lower percentage of slow-twitch muscle fibers and are more susceptible to fatigue compared with the diaphragm. Also, the architecture of the pediatric thorax (horizontal rib orientation with extensive cartilage composition) is such that intercostal and suprasternal muscles are recruited poorly to assist in respiratory effort.[11]

Airway. Airway diameter and length increase with age. The distal airway (bronchioles) lags in growth behind the proximal airway during the first few years of life. Pouseille's law states that airway resistance is inversely proportional to the 4th power of the radius of the airway. Thus, young children have higher resistance to airflow at baseline in their lower airways, and a change in airway diameter of a given dimension will have a much more profound effect on airway resistance in a small child than in an older child or adult. Such a change can occur as a result of edema, obstruction, or excess secretions. Illnesses that affect the caliber of small airways (e.g., asthma and viral bronchiolitis) produce a disproportionate increase in work of breathing in infants and children.[12]

Cellular Oxygenation. Resting oxygen consumption in the newborn is twice that of an adult (6 mL/kg/min vs 3 mL/kg/min). Oxygen consumption in infants is extremely sensitive to physiologic derangements, such as fever or hypothermia. At a neutral temperature (35°C), oxygen consumption is at a minimal level; either increasing or decreasing temperature results in dra-

Table 1. Guidelines for Laryngoscope Blade Selection

BLADE	PATIENT AGE/WEIGHT
Miller 0	Newborns up to 2.5 kg
Miller 1	0-3 months
Wisconsin 1.5	3 months-3 years
Miller 2/ Macintosh 2	3 years-12 years
Miller 3/ Macintosh 3	>12 years

matic increases in oxygen consumption. The oxyhemoglobin dissociation curve for young infants is shifted to the left (greater affinity for oxygen and poorer tissue oxygen delivery) by the presence of elevated amounts of fetal hemoglobin.[12]

The summary effects of the various respiratory physiologic phenomena described above are a greater tendency for hypoxemia and arterial desaturation. Benumof and colleagues constructed a theoretical model of oxyhemoglobin desaturation to demonstrate the time to critical desaturation of several classes of patients, including children.[13] According to this model, a healthy 10-kg child will desaturate to 90% after approximately three minutes of apnea, much more quickly than healthy or even moderately ill adults.[14] In a clinical study of elective surgery patients, Xue and colleagues found that the mean time to desaturation to 90% was 118 seconds in infants, 168 seconds in toddlers, and 248 seconds in children older than 3 years.[15] The time required for the saturation to fall from 95% to 90% was significantly shorter in infants than older children as well (8 seconds compared with 16 seconds).[15] Those findings occurred following a two-minute period of ventilation with 100% oxygen prior to neuromuscular blockade, a preoxygenation time in a separate clinical study determined to be optimal for minimizing risk of early desaturation.[16] A search of the existing literature yielded no clinical data examining how quickly deoxygenation occurs in ill children, but it is logical to assume that it is more rapid than the range of two to three minutes described by those studies under ideal conditions.

Cardiovascular Physiology

Children have increased vagal tone when compared with that of older patients. In young children, laryngoscopy has a much greater tendency to produce vagally mediated bradycardia. Because children have a limited ability to vary stroke volume to maintain cardiac output, tachycardia is often the sole compensatory mechanism in low cardiac output states; therefore, vagally mediated bradycardia can have a significantly deleterious effect on cardiac output.[11]

Neonatal Physiology

Neonates in particular have significantly fragile cardiopulmonary adaptive mechanisms. Hypoxia is tolerated very poorly, and the response to desaturation often is paradoxical bradycardia. Additionally, neonatal respiratory control is immature and discoordinated, with newborns typically exhibiting periodic breathing (i.e., absence of respiratory effort for up to 15 seconds) for up to several weeks of life. Minute ventilation does not increase to a great enough extent in response to hypercarbia, so hypoxemia results in transient hyperventilation and actually progresses to respiratory depression as oxygen tension falls.

Equipment

A wide range of equipment is available for ETI in adults and children, and there is considerable variability in the preferences of individual practitioners. This section will describe the range of equipment available and give general guidelines for equipment selection according to patient age. It is important to realize that the guidelines discussed below are imperfect. A range of sizes and types of laryngoscope blades, endotracheal tubes, and airway adjuncts should be available for use in each case of pediatric intubation so when an individual child deviates from standard guidelines, rapid adjustments can be made.

Laryngoscope. The two predominant types of laryngoscope blades used in pediatric airway management are the straight and the curved blades. Both types can be used successfully in children and adults depending upon operator experience. Most pediatric practitioners favor the use of straight blades when intubating young children because of the anatomical considerations discussed previously.

When properly applied, the tip of a straight laryngoscope blade rests underneath the tip of the epiglottis, and when upward force is applied, the blade physically lifts the epiglottis out of the way to expose the glottic opening.[17] In contrast, the proper positioning of a curved blade is such that the tip lies in the vallecula, behind the epiglottis, and upward traction pulls the epiglottis up and exposes the glottic opening.[17] The less acute angle of the epiglottis with respect to the anterior hypopharyngeal wall, creates a visual axis for the intubator that is obstructed to a greater degree by the epiglottis. A direct line of sight often is easier to achieve by lifting the epiglottis itself rather than by indirect force applied to the vallecula. This is why a straight blade often is preferred for ETI in young children. Additionally, the weak tensile strength of the hyoepiglottic ligament lessens the degree of traction on the epiglottis created by this force, and a curved blade may not afford the same degree of elevation of the epiglottis in a young child. Guidelines for the selection of sizes of blades according to patient age are listed in Table 1.

Endotracheal Tubes (ETTs). Like all other structures in the developing child, the caliber and conformation of the airway grows and develops with age. Endotracheal tubes (ETTs) exist in a wide range of sizes to accommodate the full spectrum of the pediatric age group from birth through adulthood.

The two most commonly applied rules for sizing of ETTs are the age-based rule and selection based upon body length (the Broselow-Luten tape). The age-based rule is:

[Age in years / 4] + 4 = ETT size.

King and colleagues found age-based rules predicted ETT size correctly within a range of 1 mm in 97.5% of patients.[18] The Broselow-Luten tape selects the size of ETT based upon the length of the patient. The initial study of the validity of the Broselow-Luten tape found it to be more accurate than age-based selection criteria.[19] A more recent study by Hofer and colleagues also found that the Broselow tape was more accurate (correct in 55% of patients) than the age-based rule (correct in 41%), but also found that the Broselow tape was prone to underestimating ETT size (in 39% of patients), whereas the age-based rule tended to overestimate (in 57% of patients).[20] Another recent study found that there was no difference between the accuracy rates of the two methods, and that Broselow tape measurement and the age-based rule predicted the same size of ETT in 66% of patients.[21]

Another commonly quoted method for rapid estimation of ET size applied to children is that the diameter of a child's airway is approximately the same diameter as his fifth digit. Two operating room-based studies have suggested that the rule is inaccurate; one study found that the width of the nail of the fifth digit was a more accurate predictor of ETT size than the diameter of the finger itself.[18, 22]

As mentioned above, the narrowest point in the airway of the young child occurs at the level of the cricoid cartilage, below the insertion of the vocal cords. In these patients, uncuffed endotracheal tubes are often the most appropriate tubes to achieve easy passage through the upper airway and the ability to ventilate effectively without excessive air leakage. At about 8 years of age, the conformation of the airway approximates that of an adult; older children most often require cuffed endotracheal tubes to achieve a good fit in the trachea. Deakers and colleagues studied 282 consecutive patients in a pediatric intensive care unit (PICU) setting comparing children with uncuffed and cuffed ETTs and found that there was no significant difference in the occurrence of post-extubation stridor or any significant long-term sequelae from airway problems.[23] In a randomized study, Khine and colleagues found no significant difference in the incidence of post-extubation croup in children intubated with cuffed ETTs compared with those intubated with uncuffed ETTs.[24] In children younger than 8 to 10 years of age, an uncuffed ET should be used, but current PALS recommendations state that "cuffed endotracheal tubes . . . may be appropriate under circumstances in which high inspiratory pressure is expected."[25]

Adjunctive Devices and Techniques

Oropharyngeal and Nasopharyngeal Airways. The use of oropharyngeal (OP) and nasopharyngeal (NP) airways in children can be a useful intermediate step in maintaining airway patency. The generous size of the child's tongue and adenotonsillar tissue predisposes to upper airway obstruction, either from a diseased airway or during RSI when there is loss of airway and glottic tone. Both devices exist in a range of sizes suitable for all pediatric ages. The correct size of an OP airway for a patient can be estimated by the distance from the patient's central incisors to the angle of the mandible; for NP airways, the correct size is estimated by the distance from the nare to the earlobe. OP airways, when properly positioned, tend to rest against the base of the tongue and can induce gagging and vomiting, so they should be used only in the unconscious patient.[17]

Cricoid Pressure. The technique of cricoid pressure initially was described by Sellick in 1961 as a technique to prevent aspiration of regurgitated gastric contents during anesthesia induction.[26] It also prevents insufflation of air into the stomach with positive-pressure ventilation. The technique is performed by applying gentle pressure on the cricoid ring, displacing it backward to occlude the posterior esophagus. This technique has become common practice for airway management in children and adults. Caution should be maintained as several studies have shown that cricoid pressure commonly is done incorrectly or ineffectively and can cause undesired effects or complications. Those performing the maneuver should be trained to do so.

Current literature has not examined the use of cricoid pressure for RSI in the ill child specifically. The theoretical rationale for its use is very strong. As previously mentioned, desaturation with induction is common in ill children. The establishment of a safe oxygen reservoir followed by the use of medications to achieve intubating conditions rapidly to prevent desaturation often does not occur in pediatric patients. Often it is very necessary to support ill children with positive pressure ventilation (PPV) during RSI, and the prevention of gastric insufflation with cricoid pressure can be of great importance.

Laryngeal Manipulation Maneuvers. The technique of backward-upward-rightward pressure of the larynx—commonly referred to as BURP—was described initially by Knill and has been advocated as a technique that optimizes the view of the glottic opening in cases of difficult laryngoscopy.[27] An assistant applies direct pressure on the thyroid cartilage, displacing it dorsally, upward toward the head, and 0.5-2.0 cm to the patient's right. Takahata and colleagues found that the BURP maneuver performed better than simple cricoid pressure in improving glottic visualization in unexpected difficult laryngoscopy cases.[28] External laryngeal manipulation (ELM) is a technique described initially by Benumof and colleagues in which the intubator uses his/her right hand to maneuver the laryngeal structures while maintaining his/her own line of sight with the airway opening.[29] When an optimal position is found, the intubator signals an assistant to maintain that position of the larynx while the patient is intubated. This technique has been validated by Levitan and colleagues using videographic imaging in adults intubated by emergency medicine interns.[30]

Neither of these techniques has been studied in children but could be logically extrapolated to the pediatric patient if gentle external force is used; the amount of pressure needed to occlude or distort the pediatric airway is much less than that required in an adult.

Medications

The general sequence for medication administration to facilitate RSI in children consists of three types of drugs given in rapid succession:

- Vagolytics;
- Sedatives; and
- Neuromuscular blocking agents.

Multiple agents exist for use in RSI, and the benefits and risks of each are discussed below. Preferences vary among practitioners. Current PALS guidelines do not support the use of any uniform approach to drug selection.[3] Familiarity with multiple drugs for pediatric RSI is important for anyone who frequently manages ill children.

Vagolytics. *Atropine.* The rationale for the use of atropine as a premedication for pediatric RSI is to alleviate the risk of vagal-mediated bradycardia that may occur during laryngoscopy. A dose of 0.02 mg/kg (minimum dose 0.1 mg, maximum 1 mg) is given as an initial bolus prior to sedation or paralysis. Doses of less than 0.1 mg have been associated with paradoxical bradycardia.

Results from numerous studies in the anesthesia literature have suggested that atropine premedication before laryngoscopy in healthy children undergoing surgery is not necessary due to an exceedingly low incidence of bradycardia in those patients.[31,32] Comparable data are lacking regarding the emergently ill child. One study of critically ill children who underwent protocol-based RSI by flight paramedics found an association between the omission of atropine and the occurrence of bradycardia during RSI, although this phenomenon was observed only in two patients.[33] Although high quality data to support the routine use of atropine in all RSI events are lacking, many emergency medicine practitioners use it in children younger than 8-10 years.[34]

Sedatives. *Barbiturates (Thiopental).* Thiopental is the most commonly used barbiturate for RSI. It has a rapid onset (peak effect at 10-20 seconds) and brief duration of action (5-30 minutes). Thiopental decreases cerebral metabolic activity and thus, lowers cerebral blood flow, making it advantageous for use in the patient with increased intracranial pressure (ICP). It also has inherent anticonvulsant effects and may be beneficial when used in a child with seizures who requires ETI. Recommended dosing ranges from 2 to 8 mg/kg intravenously. Like all barbiturates, thiopental is a peripheral vasodilator and a myocardial depressant. It can lower blood pressure and impair cardiac contractility and should not be used in the hypoperfused or hypotensive child.[35]

Benzodiazepines (Midazolam). Midazolam has sedative, amnestic, anticonvulsant, and anxiolytic properties. Its time of onset following intravenous administration ranges from 60-90 seconds, and its duration of activity is similar to thiopental (5-30 minutes). Midazolam can be given by multiple routes. Recommended dosing is 0.1-0.3 mg/kg intravenously.

The hemodynamic side effect profile of midazolam is similar to, but much milder than, that of the barbiturates. Midazolam can lower systemic vascular resistance and blood pressure, and can be disadvantageous in the hypovolemic patient, although these effects are observed less commonly than with thiopental. Paradoxical agitation can occur in children following midazolam administration in rare instances.[35]

One study of midazolam dosing for RSI found that 56% of children were given induction doses less than the commonly recommended dose of 0.1 mg/kg. The mean dose of midazolam given to all children was 0.08 mg/kg (+/- 0.04 mg/kg).[36]

Opioids (Fentanyl). Fentanyl is a fast-acting narcotic (peak effect 1-2 minutes, duration 30-40 minutes), which produces analgesia, sedation, and euphoria. It does not result in systemic histamine release as other opioids do, and as a result is less likely to produce hypotension. Recommended dose range is 1-3 mcg/kg intravenously.

Fentanyl does have sympatholytic effects and can cause a transient decrease in heart rate.[35] The effect of fentanyl on ICP is not well known in children. There is evidence that fentanyl blunts the hemodynamic response to laryngoscopy, which is desirable in patients with known or suspected increased ICP.[37,38] Conversely, there is one known case report that describes an increase in ICP in a head-injured child following the administration of fentanyl.[39] Chest wall rigidity is a rare side effect of fentanyl that has been observed in multiple case reports[40-44]; prevention of this effect is best accomplished by either slow administration or simultaneous use of a neuromuscular blockade.

Ketamine. Ketamine is a rapidly acting agent (onset within a few seconds, duration 10-20 minutes) that produces analgesia, dissociative anesthesia, and amnesia. The dissociative state of sedation produced by ketamine is unique among the agents discussed here; patients can continue to have their eyes open and even to speak. Additionally, ketamine is unique among induction agents in that airway reflexes and respiratory drive are well preserved. A recent pilot study of children receiving ketamine for procedural sedation found no detectable hypoxemia or hypercapnea in any patient, suggesting that significant subclinical respiratory depression does not occur.[45] Ketamine also has inherent bronchodilator properties and is recommended as a component of RSI of patients in status asthmaticus.[46] Recommended doses range from 1-3 mg/kg intravenously. Ketamine also can be given intramuscularly at increased doses (3-5 mg/kg).

Hemodynamically, ketamine increases heart rate, mean arterial pressure, and cardiac output. The mechanisms for those changes are not well understood. Ketamine has been recommended as an induction agent for patients with hypovolemia, septic shock, or cardiac tamponade, even though there may be a theoretical risk of the myocardial depression when catecholamine stores are depleted.[46] One recent case series evaluated PICU patients receiving ketamine for procedural sedation; 88% of the patients in the survey were American Society of Anesthesia-class 3 or greater for their present illness (severe systemic disease), and no adverse outcomes attributable to ketamine were reported.[47] No specific data on hemodynamic parameters were included in the study.

Ketamine increases ICP, intraocular pressure, and intragastric pressure. It is not recommended for use in the head-injured patient or the patient at risk for elevated ICP. Emergence reactions characterized by delirium or agitation have been associated with ketamine; evidence that the concurrent use of benzodiazepines reduces this side effect is mixed.[46,48] Ketamine stimulates salivary and tracheobronchial secretions, so the concurrent use of atropine is recommended in older patients for whom atropine premedication for RSI would not be indicated otherwise. Laryngospasm is an uncommon side effect that has been linked to ketamine use secondary to sensitized laryngeal reflexes. In a systematic review of ketamine use in children, Green et al reported an overall incidence of two cases of laryngospasm in 11,589 patients (0.017%).[49,50] In the context of RSI, this is only significant in rare cases where simultaneous neuromuscular blockade is not being used.

Etomidate. Etomidate is a rapidly acting sedative that reaches peak effect within a few seconds of IV administration. It is a pure hypnotic sedative, with no inherent analgesic properties. The side effect profile is very favorable, with minimal hemodynamic effects demonstrated in laboratory and clinical studies. The hemodynamic stability associated with etomidate has made it a favored agent for use in adults with pre-existing cardiac disease. Etomidate also lowers cerebral blood flow and ICP without changing mean arterial pressure, making it an advantageous agent in the patient with increased ICP or a head injury.[46] Recommended dosing is 0.3 mg/kg intravenously.

Etomidate has been associated with adrenocortical suppression when administered as a continuous infusion. One randomized trial in adults found that adrenal suppression was detectable for 12 hours following a single dose of 0.3 mg/kg of etomidate for RSI, but cortisol levels remained normal in those patients, and no clinically significant effects were noted.[51] Myoclonus is a common side effect that has been noted with etomidate use; this should not be a significant concern when accompanied by a neuromuscular blockade for RSI.[46]

Two case series have been published that specifically examine the use of etomidate for RSI in children.[52,53] A total of 189 patients were retrospectively reviewed; no evidence of clinically significant adrenal suppression was noted, and only four patients had clinically significant hypotension. None were thought to be related to etomidate administration. At present, no prospective data exist for the use of etomidate in pediatric RSI.

Propofol. Propofol is an intravenous hypnotic agent that is used widely in anesthesia practice. It has a very rapid onset (within seconds) and a brief duration of activity (5-10 minutes) when given as a bolus of 1 to 2 mg/kg intravenously. It has significant myocardial depressant effects and lowers blood pressure and respiratory drive.[46] Long-term use of propofol infusion in children has been associated with severe metabolic acidosis,[54] although a recent cohort of PICU patients receiving propofol infusion for a median of 16.5 hours showed no incidence of acidosis.[55] The combination of an unfavorable hemodynamic profile and high cost have made propofol an uncommon agent for use in RSI for children.

The choice of sedatives for RSI are plentiful and the most variable among all the medications used in RSI. The agent selected should depend upon the individual patient's underlying pathophysiology after a careful analysis of the risks and potential complications of each agent. In a multihospital survey by Sagarin et al, etomidate was the most commonly used agent among children undergoing RSI (42%), followed by thiopental (22%), midazolam (18%), and ketamine (7%).[56]

Neuromuscular Blocking Agents (NMB)

Succinylcholine (SCh). Succinylcholine is the most widely used NMB for RSI in all categories of patient age and diagnosis. It has a rapid onset (20-60 seconds) and brief duration of action (5-10 minutes) when given in recommended doses of 1 to 2 mg/kg intravenously. It also has been used effectively when given by the intramuscular and intraosseous routes.

SCh has several important and well-described side effects. Bradycardia has been noted to occur with SCh, particularly when repeated doses are required for paralysis. This is due to the structural similarity between SCh and acetylcholine, and readily is prevented by premedication with atropine. Although there are no well-designed studies documenting the relationship between succinylcholine use and bradycardia, children appear to be prone to bradycardia. Therefore, many airway experts have recommended making atropine an essential step in RSI in children when using SCh.

The transient muscle fasciculations that precede paralysis with SCh administration can be of clinical significance in cases of increased ICP, eye injury, and increased intragastric pressure; these fasciculations can be minimized through premedication with a defasciculating dose of vecuronium (0.01 mg/kg). SCh can cause a transient increase in serum potassium levels, averaging 0.5 mEq/L. That increase can be exacerbated in certain patients, including those with crush injuries or patients with denervating disorders or congenital skeletal muscle myopathies; the use of SCh in those patients has been associated with life-threatening hyperkalemia and cardiac arrest.

In the late 1980s and early 1990s, a series of cases of unexpected hyperkalemic cardiac arrest was reported in apparently healthy children who had received SCh for airway management. A total of 36 reported cases were described, and all of those children were found on subsequent workup (or autopsy) to have previously undiagnosed myopathic disorders, Duchenne's muscular dystrophy most common among them. Based upon those findings, the Food and Drug Administration's Advisory Committee for Anesthetic and Life Support Drugs recommended a labeling revision for SCh at its meeting in 1992. The new label states that routine use of SCh in children should be avoided and alternative agents (nondepolarizing NMBs) used except in specific circumstances, including patients with laryngospasm or a full stomach, or when intramuscular use is needed secondary to IV access being difficult or absent.[57]

Succinylcholine, however, remains in widespread use in children for RSI despite the labeling change. A survey of anesthesiologists in the United Kingdom performed soon after the labeling change showed that 86% of anesthesiologists continued to use it routinely in their pediatric patients.[58] In the previously cited multihospital survey by Sagarin and colleagues, SCh was the NMB used in 91% of patients who underwent RSI.[56] The fact that the speed of onset of SCh is unparalleled by other agents is well-recognized, and when a given clinical situation is dominated by the need for very fast onset of intubating conditions, SCh remains the arguable drug of choice.

Nondepolarizing NMBs

Vecuronium. Vecuronium is a nondepolarizing NMB of intermediate duration (30-60 minutes). At recommended doses of 0.1-0.2 mg/kg IV, its time of onset ranges from 90-120 seconds. Increasing the dose of vecuronium (doses of 0.3-0.4 mg/kg) can shorten the time of onset but results in prolonged periods of neuromuscular blockade. One anesthesia study found that younger children were more resistant to paralysis by vecuronium and required higher dosing.

Koller and colleagues compared 0.3 mg/kg of vecuronium with 1 mg/kg of SCh in healthy adults undergoing elective surgery and found no significant difference in intubating conditions at 60 seconds following NMB administration.[59]

Rocuronium. Rocuronium is a rapid-onset NMB with a shorter duration of action than other nondepolarizing agents. Results of studies of adults have demonstrated onset of paralysis at 60-90 seconds and a duration of action of 20-30 minutes following IV administration of recommended doses of 0.6 mg/kg.

Stoddart and colleagues compared 0.6 mg/kg of rocuronium and 1 mg/kg of SCh in healthy children undergoing elective surgery and found no significant difference in intubating conditions at 60 seconds following NMB administration; there were significant differences in the time of onset and duration of paralysis as measured by train-of-four monitoring.[60] Cheng and colleagues performed a similar study of intubating conditions 60 seconds following NMB administration, comparing 1.5 mg/kg of SCh with rocuronium at doses of 0.6 mg/kg and 0.9 mg/kg; they found that the higher-dose of rocuronium was no different than SCh at those doses, but that 0.6 mg/kg of rocuronium resulted in less favorable intubating conditions compared with SCh.[61]

Other Nondepolarizing NMBs

Pancuronium. Pancuronium is among the oldest of the nondepolarizing NMBs. Its time of onset is 1.5-3 minutes following an IV dose of 0.1 mg/kg, and its duration of action is longer than vecuronium or rocuronium (40-60 minutes). Pancuronium has inherent anticholinergic effects and frequently results in increases in heart rate.

Mivacurium. Mivacurium is a short-acting NMB with a time of onset of 75-90 seconds and a brief duration of action (10-20 minutes). Studies comparing mivacurium and SCh in children have shown that paralysis occurs more slowly with mivacurium, but still in a time frame suitable for RSI.[62] Rapid injection of mivacurium can result in histamine release, resulting in tachycardia and hypotension in some cases. Recommended dosing is 0.2-0.3 mg/kg.[63]

Atracurium and *cis*-Atracurium. Atracurium and *cis*-atracurium are moderately short-acting NMBs with times of onset of 90-120 seconds and duration of activity of 30-45 minutes. These agents are distinctive in that their elimination from the body occurs through non-specific ester hydrolysis and Hoffman degradation; thus, they are advantageous in the setting of pre-existing hepatic and/or renal disease (the other agents above are metabolized through either renal or hepatic elimination pathways). Recommended dosing is 0.6 mg/kg for atracurium and 0.1 mg/kg for *cis*-atracurium.[63]

Adjunctive Medications

Lidocaine. Lidocaine has been advocated as a useful adjunct to RSI in patients with increased ICP. Its theoretical benefit is a reduction of the sudden and potentially harmful increase in blood pressure and cerebral blood flow that results from laryngoscopy and tracheal suctioning.[64,65] Data on its usefulness in this regard are mixed. A recent systematic review concluded that there is no evidence of improved neurologic outcome from premedication with intravenous lidocaine prior to RSI.[66] An operating room-based study by Splinter found that intravenous lidocaine had no effect on the heart rate and blood pressure changes induced by laryngoscopy and ETI in children, and that these changes were more pronounced with increasing age.[67] At recommended doses of 1 to 2 mg/kg, there is minimal risk of toxicity in the pediatric patient, and still it is used routinely by many practitioners.[35] Recommended timing of the dose is 2 to 3 minutes prior to laryngoscopy.

Confirmation of Endotracheal Tube Placement

Confirming that an endotracheal tube has been placed in the trachea is necessary following every intubation. Several clinical signs, such as the presence of breath sounds, visible rise of the chest wall, absence of sounds over the epigastrium, and condensation within the tube lumen often are relied upon at the bedside. Current PALS recommendations, however, recognize that those signs can be unreliable, and have mandated that exhaled carbon dioxide detection be employed in all patients.[25]

End Tidal Carbon Dioxide (ETCO$_2$). ETCO$_2$ detection is the most common way to confirm proper endotracheal tube placement. Several types of ETCO$_2$ detectors are available commercially. Most EDs will have disposable colorimetric devices, which register exhaled CO_2 by a change in color of a piece of paper in a plastic chamber, but some use capnography, which digitally displays the exact partial pressure of exhaled CO_2 with or without a waveform.

Results from several studies have supported the specificity and sensitivity of $ETCO_2$ in infants and children. In the patient in full cardiopulmonary arrest, the absence of pulmonary blood flow may limit the amount of carbon dioxide in the alveoli, making $ETCO_2$ prone to false- negative results. A study by Bhende and colleagues found that the specificity of $ETCO_2$ detection was slightly worse in the arrested patient.[68]

Esophageal Detection Devices. The imperfect specificity of $ETCO_2$ in the arrested patient has led to the development of alternative devices to confirm endotracheal tube placement. The principle behind the use of the esophageal detection device (EDD) relies upon the collapsibility of the esophagus compared with that of the cartilage-reinforced trachea. EDDs function by aspirating air from the endotracheal tube by negative pressure (e.g., use of a syringe-like device or a semirigid plastic bulb that reinflates when squeezed). If negative pressure is applied to a tube in the trachea, the reinforced trachea will resist collapse and the EDD will fill with air, confirming that the tube is in the trachea. Conversely, negative pressure applied to a tube in the esophagus will collapse the esophagus around the end of the tube and result in slow or incomplete filling of the EDD with air.

EDDs have been shown to be accurate in older children.[69] Some studies have shown their accuracy to be poor in children younger than one year of age and when used with uncuffed endotracheal tubes.[70,71] One recent operating room-based study by Sharieff and colleagues examined the accuracy of a self-inflating bulb-type EDD in children weighing fewer than 20 kg intubated with uncuffed endotracheal tubes and found an overall sensitivity of 97-100% and a specificity of 94-96%.[72] Currently, no recommendations exist for the routine use of EDDs in children.

Rescue Devices in Pediatric Airway Management

Laryngeal Mask Airway. The laryngeal mask airway (LMA) is a device designed to secure the airway in the unconscious patient. It consists of a teardrop-shaped inflatable cuff surrounding a fenestrated latex window that faces the glottic opening when properly positioned. The device is inserted blindly into the open mouth of the patient and advanced until resistance is felt, at which point the cuff is inflated. Studies of the use of the LMA by various medical personnel have shown that it is easy to place and rarely associated with significant complications.[73,74] LMAs are made in a range of sizes that are appropriate for all ages from neonate to adult.

It is important to remember that LMAs do not isolate the esophagus from the trachea; when properly placed, the apex of the cuff sits just above the entrance to the esophagus. Thus, patients with an LMA in place may not be protected from aspiration to the same extent as when an endotracheal tube is in place. One recent meta-analysis of data on LMA use in the operating room found that aspiration is uncommon and occurred with comparable frequency in patients with BVM ventilation alone.[75] Currently, PALS does not recommend the use of LMAs in children as a result of limited data comparing their use with ETI and BVM ventilation in the resuscitation of children;[25] nonetheless, they are used widely in operating room settings, EDs, and by some prehospital care systems.

Conclusion

Management of the pediatric airway is a skill that is critical in the emergency department. 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 patients outcome. No other skill is as important for the ED physician.

References

1. Walls RM. The decision to intubate. In: Walls RM, ed. *Manual of Emergency Airway Management*. Philadephia: Lippincott Williams & Wilkins;2000:3-7.
2. Gausche M, Lewis RJ, Stratton SJ, et al. Effect of out-of-hospital pediatric endotracheal intubation on survival and neurological outcome: A controlled clinical trial. *JAMA* 2000;283:783-790. [Erratum appears in *JAMA* 2000;283:3204].
3. Guidelines 2000 for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Part 10: Pediatric advanced life support. The American Heart Association in collaboration with the International Liaison Committee on Resuscitation. *Circulation* 2000;102:I291-342.
4. Losek JD, Hennes H, Glaseser P, et al. Prehospital care of the pulseless, nonbreathing pediatric patient. *Am J Emerg Med* 1987;5: 370-374.
5. Sirbaugh PE, Pepe PE, Shook JE, et al. A prospective, population-based study of the demographics, epidemiology, management, and outcome of out-of-hospital pediatric cardiopulmonary arrest. *Ann Emerg Med* 1999; 33:174-184. Erratum appears in *Ann Emerg Med* 1999;33:358.
6. Marvez-Valls E, Henry D, Ernst AA, et al. Protocol for rapid sequence intubation in pediatric patients -- A four-year study. *Med Science Monit* 2002;8:CR229-234.
7. Easley RB, Segeleon JE, Haun SE, et al. Prospective study of airway management of children requiring endotracheal intubation before admission to a pediatric intensive care unit. *Crit Care Med* 2000; 28: 2058-2063.
8. Aijian P, Tsai A, Knopp R, et al. Endotracheal intubation of pediatric patients by paramedics. *Ann Emerg Med* 1989;18:489-494.
9. Kumar VR, Bachman DT, Kiskaddon RT. Children and adults in cardiopulmonary arrest: Are advanced life support guidelines followed in the prehospital setting? *Ann Emerg Med* 1997;29:743-747.
10. Brownstein D, Shugerman R, Cummings P, et al. Prehospital endotracheal intubation of children by paramedics. *Ann Emerg Med* 1996. 28:34-39.
11. King C, Stayer SA. Emergenct endotracheal intubation. In: Henretig F, King C, eds. *Textbook of Pediatric Emergency Procedures*. Philadelphia: Williams and Wilkins;1997:161-238.
12. Helfaer M, Nichols DG, Rogers MC. Developmental physiology of the respiratory system. In: Rogers MC, eds. *Textbook of Pediatric*

Intensive Care. Baltimore:Williams & Wilkins;1996: 97-126.
13. Farmery AD, Roe PG. A model to describe the rate of oxyhaemoglobin desaturation during apnoea. *Br J Anaesth* 1996;76: 284-291. [Erratum appears in *Br J Anaesth* 1996;76:890].
14. Benumof JL, Dagg R, Benumof R. Critical hemoglobin desaturation will occur before return to an unparalyzed state following 1 mg/kg intravenous succinylcholine. *Anesthesiology* 1997;87: 979-982.
15. Xue FS, Luo LK, Tong SY, et al. Study of the safe threshold of apneic period in children during anesthesia induction. *J Clin Anesth* 1996; 8:568-574.
16. Xue FS, Tong SY, Wang XL, et al. Study of the optimal duration of preoxygenation in children. *J Clin Anesth* 1995;7:93-96.
17. Scarfone RJ. Airway adjuncts, oxygen delivery, and suctioning the upper airway. In: Henretig F, King C, eds. *Textbook of Pediatric Emergency Procedures*. Philadelphia: Williams and Wilkins; 1997: 101-118.
18. King BR, Baker MD, Braitman LE, et al. Endotracheal tube selection in children: A comparison of four methods. *Ann Emerg Med* 1993; 22:530-534.
19. Luten RC, Wears RL, Broselow J, et al. Length-based endotracheal tube and emergency equipment in pediatrics. *Ann Emerg Med* 1992; 21:900-904. [Erratum appears in *Ann Emerg Med* 1993;22:155].
20. Hofer CK, Ganter M, Tucci M, et al. How reliable is length-based determination of body weight and tracheal tube size in the paediatric age group? The Broselow tape reconsidered. *Br J Anaesth* 2002; 88: 283-285.
21. Davis D, Barbee L, Ririe D. Pediatric endotracheal tube selection: A comparison of age-based and height-based criteria. *AANA Journal* 1998;66:299-303.
22. van den Berg AA, Mphanza T. Choice of tracheal tube size for children: Finger size or age-related formula? *Anaesthesia* 1997;52: 701-703.
23. Deakers TW, Reynolds G, Stretton M, et al. Cuffed endotracheal tubes in pediatric intensive care. *J Pediatr* 1994;125:57-62.
24. Khine HH, Corddry DH, Kettrick RG, et al. Comparison of cuffed and uncuffed endotracheal tubes in young children during general anesthesia. *Anesthesiology* 1997;86:627-631; discussion 27A.
25. Murphy MF. Special devices and techniques for managing the difficult or failed airway. In: Walls RM, ed. *Manual of Emergency Airway Management*. Phladelphia: Lippincott Williams & Wilkins;2000: 68-81.
26. Sellick B. Cricoid pressure to control regurgitation of stomach contents duting induction of anesthesia. *Lancet* 1961;ii:404-406.
27. Knill RL. Difficult laryngoscopy made easy with a "BURP". *Ca J Anaesth* 1993;40:279-282.
28. Takahata O, Kubota M, Mamiya K, et al. The efficacy of the "BURP" maneuver during a difficult laryngoscopy. *Anesth Analg* 1997;84: 419-421.
29. Benumof JL, Cooper SD. Quantitative improvement in laryngoscopic view by optimal external laryngeal manipulation. *J Clin Anesth* 1996; 8:136-140.
30. Levitan RM, Mickler T, Hollander JE. Bimanual laryngoscopy: Avideographic study of external laryngeal manipulation by novice intubators. *Ann Emerg Med* 2002:40:30-37.
31. Shorten GD, Bissonnette B, Hartley E, et al. It is not necessary to administer more than 10 micrograms kg-1 of atropine to older children before succinylcholine. *Ca J Anaesth* 1995;42:8-11.
32. McAuliffe G, Bissonnette B, Boutin C. Should the routine use of atropine before succinylcholine in children be reconsidered? *Ca J Anaesth* 1995;42:724-729.
33. Sing RF, Reilly PM, Rotondo MF, et al. Out-of-hospital rapid-sequence induction for intubation of the pediatric patient. *Acad Emerg Med* 1996;3:41-45.
34. Schneider RE. Drugs for special clinical circumstances. In: Walls RM, ed. *Manual of Emergency Airway Management*. Philadelphia: Lippincott Williams & Wilkins;2000:135-139.
35. Decker JM, Lowe DA. Rapid Sequence Induction. In: Henretig F, King C, eds. *Textbook of Pediatric Emergency Procedures*. Philadelphia: Williams and Wilkins;1997:141-160.
36. Sagarin MJ, Barton ED, Sakles JC, et al. Underdosing of midazolam in emergency endotracheal intubation. *Acad Emerg Med* 2003;10: 329-338.
37. Abdallah C, Karsli C, Bissonnette B. Fentanyl is more effective than remifentanil at preventing increases in cerebral blood flow velocity during intubation in children. *Ca J Anaesth* 2002;49:1070-1075.
38. Sims CH, Splinter WM. Fentanyl blunts the haemodynamic response of children to laryngoscopy. *Ca J Anaesth* 1990;37:S91.
39. Tobias JD. Increased intracranial pressure after fentanyl administration in a child with closed head trauma. *Ped Emerg Care* 1994;10: 89-90.
40. Neidhart P, Burgene MC, Schwieger I, et al. Chest wall rigidity during fentanyl- and midazolam-fentanyl induction: Ventilatory and haemodynamic effects. *Acta Anaesthesiolog Scand* 1989;33:1-5.
41. Wells S, Williamson M, Hooker D. Fentanyl-induced chest wall rigidity in a neonate: A case report. *Heart & Lung* 1994;23:196-198.
42. MacGregor DA, Bauman LA. Chest wall rigidity during infusion of fentanyl in a two-month-old infant after heart surgery. *J Clin Anesth* 1996;8:251-254.
43. Fahnenstich H, Steffan J, Kau N, et al. Fentanyl-induced chest wall rigidity and laryngospasm in preterm and term infants. *Crit Care Med* 2000;28:836-839.
44. Muller P, Vogtmann P. Three cases with different presentation of fentanyl-induced muscle rigidity--A rare problem in intensive care of neonates. *Amer J Perinatol* 2000;17:23-26.
45. Kim G, Green SM, Denmark TK, et al. Ventilatory response during dissociative sedation in children-a pilot study. *Acad Emerg Med* 2003;10:140-145.
46. Reves J, Glass P, Lubarsky D. Nonbarbiturate intravenous anesthetics. In: Miller R, ed. *Anesthesia*. New York:Churchill-Livingstone;2000:259-289.
47. Green SM, Denmark TK, Cline J, et al. Ketamine sedation for pediatric critical care procedures. *Ped Emerg Care* 2001;17:244-248.
48. Sherwin TS, Green SM, Khan A, et al. Does adjunctive midazolam reduce recovery agitation after ketamine sedation for pediatric procedures? A randomized, double-blind, placebo-controlled trial. *Ann Emerg Med* 2000;35:229-238.

49. Green SM, Nakamura R, Johnson NE. Ketamine sedation for pediatric procedures: Part 1, A prospective series. *Ann Emerg Med* 1990; 19:1024-1032.
50. Green SM, Johnson NE. Ketamine sedation for pediatric procedures: Part 2, Review and implications. *Ann Emerg Med* 1990;19: 1033-1046.
51. Schenarts CL, Burton JH, Riker RR. Adrenocortical dysfunction following etomidate induction in emergency department patients. *Acad Emerg Med* 2001;8:1-7.
52. Sokolove E, Price DD, Okada P. The safety of etomidate for emergency rapid sequence intubation of pediatric patients. *Pediatr Emerg Care* 2000;16:18-21.
53. Guldner G, Schultz J, Sexton P, et al. Etomidate for rapid-sequence intubation in young children: Hemodynamic effects and adverse events. *Acad Emerg Med* 2003;10:134-139.
54. Parke TJ, Stevens JE, Rice AS, et al. Metabolic acidosis and fatal myocardial failure after propofol infusion in children: Five case reports. *BMJ* 1992;305:613-616.
55. Cornfield DN, Tegtmeyer K, Nelson MD, et al. Continuous propofol infusion in 142 critically ill children. *Pediatrics* 2002;110:1177-1181.
56. Sagarin MJ, Chiang V, Saldes JC, et al. Rapid sequence intubation for pediatric emergency airway management. *Pediatr Emerg Care* 2002; 18:417-423.
57. Badgwell JM, Hall SC, Lockhart C. Revised label regarding use of succinylcholine in children and adolescents. *Anesthesiology* 1994;80: 243-245.
58. Robinson AL, Jerwood DC, Stokes MA. Routine suxamethonium in children. A regional survey of current usage. *Anaesthesia* 1996;51: 874-878.
59. Koller ME, Husby P. High-dose vecuronium may be an alternative to suxamethonium for rapid-sequence intubation. *Acta Anaesthesiol Scand* 1993;37:465-468.
60. Stoddart A, Mather SJ. Onset of neuromuscular blockade and intubating conditions one minute after the administration of rocuronium in children. *Paediatr Anaesth* 1998:8:37-40.
61. Cheng CA, Aun CS, Gin T. Comparison of rocuronium and suxamethonium for rapid tracheal intubation in children. *Paediatr Anaesth* 2002;12:140-145.
62. Cook DR, Gronert BJ, Woelfel SK. Comparison of the neuromuscular effects of mivacurium and suxamethonium in infants and children. *Acta Anaesthesiolog Scan* 1995;106:35-40.
63. Zuckerberg AL, Nichols DG. Aiway management in pediatric critical care. In: Rogers MC, eds. *Textbook of Pediatric Intensive Care*. Baltimore: Williams & Wilkins;1996:51-76.
64. Lev R, Rosen P. Prophylactic lidocaine use preintubation: A review. *J Emerg Med* 1994;12:499-506.
65. Yano M, Nishiyama H, Yokota H, et al. Effect of lidocaine on ICP response to endotracheal suctioning. *Anesthesiology* 1986;64: 651-653.
66. Robinson N, Clancy M. In patients with head injury undergoing rapid sequence intubation, does pretreatment with intravenous lignocaine/ lidocaine lead to an improved neurological outcome? A review of the literature. *Emerg Med J* 2001;18:453-457.
67. Splinter WM. Intravenous lidocaine does not attenuate the haemodynamic response of children to laryngoscopy and tracheal intubation. *Ca J Anaesth* 1990;37:440-443.
68. Bhende MS, Thompson AE. Evaluation of an end-tidal CO_2 detector during pediatric cardiopulmonary resuscitation. *Pediatrics* 1995;95: 395-399.
69. Morton NS, Stuart JC, Thomson MF, et al. The oesophageal detector device: Successful use in children. *Anaesthesia* 1989;44:523-524.
70. Haynes SR , Morton, NS. Use of the oesophageal detector device in children under one year of age. *Anaesthesia* 1990;45;1067-1069.
71. Wee MY, Walker AK. The oesophageal detector device. An assessment with uncuffed tubes in children. *Anaesthesia* 1991;46;869-871.
72. Sharieff GQ, Rodarte A, Wilton N, et al. The self-inflating bulb as an airway adjunct: Is it reliable in children weighing less than 20 kilograms? *Ann Emerg Med* 2003;10:303-308.
73. Lopez-Gil M, Brimacombe J, Alvarez M. Safety and efficacy of the laryngeal mask airway. A prospective survey of 1400 children. *Anaesthesia* 1996;51: 969-972.
74. Lopez-Gil M, Brimacombe J, Cebrian J, et al. Laryngeal mask airway in pediatric practice: A prospective study of skill acquisition by anesthesia residents. *Anesthesiology* 1996;84:807-811.
75. Brimacombe JR, Berry A. The incidence of aspiration associated with the laryngeal mask airway: A meta-analysis of published literature. *J Clin Anesth* 1995;7:297-305.

CME Instructions

Physicians participate in this continuing medical 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 that will be provided at the end of the semester and return it in the reply envelope provided to receive a certificate of completion. When your evaluation is received, a certificate will be mailed to you.

CME Objectives

The CME objectives for *Pediatric Emergency Medicine Reports* are to help physicians:

a.) Quickly recognize or increase index of suspicion for specific conditions;

b.) Understand the epidemiology, etiology, pathophysiology, historical and physical examination findings associated with the entity discussed;

c.) Be educated about how to correctly formulate a differential diagnosis and perform necessary diagnostic tests;

d.) Apply state-of-the-art therapeutic techniques (including the implications of pharmacologic therapy discussed) to patients with the particular medical problems discussed;

e.) Provide patients with any necessary discharge instructions.

Physician CME Questions

81. Which of the following is *not* an advantage of the laryngeal mask airway (LMA)?
    A. Ease of insertion
    B. Multiple available sizes for children
    C. Blind technique
    D. Isolation of trachea from the esophagus

82. A 7-year-old with Duchenne's muscular dystrophy presents with pneumonia and respiratory failure. All of the following drugs could be used safely for RSI in this patient, *except*:
    A. etomidate.
    B. thiopental.
    C. succinylcholine.
    D. vecuronium.
    E. atropine.

83. The best initial choice of endotracheal tube for a 6-year-old would be a:
    A. 5.0 ETT, cuffed.
    B. 5.5 ETT, uncuffed.
    C. 5.5 ETT, cuffed.
    D. 6.0 ETT, cuffed.
    E. 6.0 ETT, uncuffed.

84. 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.

85. 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 more likely to be floppy and less protuberant than that of an adult.
    D. The narrowest point of the infant airway occurs at the level of the vocal cords.

86. Which of the following RSI medications is *not* matched correctly with its side effect?
    A. Fentanyl – chest wall rigidity
    B Ketamine – bronchospasm
    C. Thiopental – hypotension
    D. Etomidate – myoclonus
    E. Midazolam – paradoxical agitation

87. The confirmation of endotracheal tube placement by end-tidal carbon dioxide ($ETCO_2$) is:
    A. optional by current PALS recommendations.
    B. more specific in a patient in cardiac arrest.
    C. accomplished by colorimetry or capnography.
    D. less accurate in young children than esophageal detection devices (EDDs).

88. 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.

89. The epiglottis of an infant:
    A. is relatively small and floppy compared with the adult epiglottis.
    B. is lifted directly by the tip of a properly used curved (Macintosh) laryngoscope blade.
    C. is angled more acutely with respect to the trachea than that of an adult.
    D. lies in front of the tip of a properly used straight laryngoscope blade.

90. Atropine:
    A. has a minimum dose of 100 mcg and a maximum dose of 1 mg.
    B. should be avoided in children who undergo RSI with succinylcholine.
    C. should not be used together with ketamine.
    D. is contraindicated for RSI in neonates.

Answer Key:

81.d.
82.c
83.b
84.c
85.a
86.b
87.c
88.a
89.c.
90.a.

In Future Issues:	Headaches in Children

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Cervical spine injuries, although uncommon (0.9-6% of blunt trauma patients),[1-5] have the potential to result in permanent neurologic devastation for the patient. Appropriate suspicion for cervical spine injury, immobilization, and the decision to obtain radiographic imaging are all important aspects of the acute care of an adult who has sustained a blunt traumatic injury (as discussed in Part 1 of this series); but the responsibilities of emergency department (ED)/trauma physicians do not end with the decision to obtain radiologic imaging.

The physician must then decide the most appropriate initial imaging modality (plain radiographs, computerized tomography [CT], or magnetic resonance imaging [MRI]) for the patient and when an adequate evaluation has been performed. Understanding the indications, advantages, and limitations of each radiographic modality is critical to obtaining a diagnostic evaluation that effectively identifies or excludes a cervical spine injury.

This issue presents the physician with a thorough discussion of the imaging alternatives available and facilitates clinical decision-making for diagnostic imaging. The author also provides a comprehensive discussion of the evaluation of a patient with a potential ligamentous injury to the cervical spine.

—The Editor

The Evaluation and Clearance of the Cervical Spine in Adult Trauma Patients: Clinical Concepts, Controversies, and Advances, Part 2

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Introduction

Although cervical spine injury is uncommon, the implications of a missed injury are profound and may result in many serious complications for the patient and the physician. In one series, missed spinal injuries were responsible for 3% of malpractice claims and 9% of total dollars paid in claims.[6] A portion of these missed injuries resulted from inaccurate interpretation of radiographs or failure to obtain the appropriate imaging required to make the diagnosis. Trauma care providers must have a thorough understanding of imaging modalities, their indications, and more importantly, their limitations. Alternatives available include plain radiographs, CT, and MRI. Formulating an imaging approach to a patient with a potential cervical spine injury allows the trauma care provider to achieve an accurate diagnosis in a timely manner with minimal risk to the patient. Understanding the roles and risks with flexion-extension radiographs and fluoroscopy allows the trauma care provider to accurately identify ligamentous injury to the cervical spine, without placing the patient at risk for neurologic complications.

Radiographic Cervical Spine Clearance

Plain Films vs Computed Tomography. Although there is increasing consensus among clinicians as to which patients require cervical spine imaging, extensive variation still exists in the approach.[1] Once the decision to perform radiographic clearance has been made, the question remains: What study should I order: plain radiography, CT, or both? The ideal strategy is one that accurately and inexpensively identifies all cervical spine injuries. Unfortunately, no current approach singularly fits that bill.

Conventional radiography remains the most commonly employed approach to traumatic spine assessment in most hospitals in the world.[7] Most trauma physicians agree that at least a three-view series (i.e., lateral, open mouth, and anteroposterior) is the minimally acceptable standard for radiographic evaluation of most blunt trauma patients. A consensus agreement among emergency physicians, radiologists, and trauma surgeons states that, in an alert patient with cervical tenderness in the absence of neurologic injury, an adequate three-view series is sufficient for excluding cervical spine injury.[8] The addition of oblique views (five-view series) to improve sensitivity and improve detection of the lateral and posterior spinal elements adds little to the overall evaluation and simply prolongs the diagnostic work-up of these patients.[9] However, the swimmer's or oblique view may improve visualization of the cervico-thoracic junction when the lateral view fails to display these areas adequately.[10] The routine addition of flexion-extension views to the standard plain films is not necessary unless there is specific concern for ligamentous injury.

A single lateral view of the cervical spine is insensitive for excluding cervical spine injury. A survey of more than 100 hospitals in the mid-1990s revealed that 33% of their physicians were clearing the cervical spine using only lateral radiographs.[11] As many as 15-46% of cervical fractures were missed when cross-table lateral radiographs solely were used to exclude cervical spine injury.[6,11,12]

Although obtaining plain radiography is inexpensive, poses a low radiation risk, and is available widely, it has several distinct limitations and disadvantages. The diagnosis of significant cervical spine injury using plain films in the severely injured or unconscious patient is challenging. In many cases, the cervico-cranium (C_1-C_2) and cervicothoracic junction (C_7-T_1) are shown inadequately, or the quality of the portable films is poor. Plain films are repeated in almost 50-70% of those patients to obtain a complete study.[13,14] The result is more time lost, additional x-rays taken, and higher cost.[15,16] Moreover, the frequency of inadequate or false-positive plain radiographs increases with injury severity.[16]

In recent years, the diagnostic efficacy of cervical plain radiographs for demonstrating and excluding injury has come under increasing scrutiny. Results from a number of studies have exposed the limitations of conventional radiography. Fractures that are clearly evident on CT are not always evident on plain films. In a series comparing plain films with CT, Woodring and Lee showed that plain films revealed only 33% of all fractures and 55% of subluxations or dislocations.[11] They also found that 23% of patients (half of whom had unstable injuries) initially were diagnosed as normal.[11] Nunez et al found that 42% of injuries were not seen on plain films, including 10 patients with unstable fractures.[14] When pooling the data from several retrospective series (recognizing potential design limitations), the overall sensitivity of plain films in detecting cervical spine injury is only 53%, while that of CT is 98%.[6,14,17-19]

The availability of such an effective imaging strategy raises the question: Shouldn't everyone be screened using CT? The initial role of cervical CT was an adjunct to plain films, not a screening tool. CT was reserved for further delineation of areas suspicious for injury and areas poorly defined on plain films.[20-22] However, the widespread use of this imaging modality led to the identification of fractures and subluxations not readily apparent on plain film radiographs.

Helical CT represents an advance from the older approach of single acquisition CT. Advantages of helical CT include faster acquisition and image reconstruction times, reduction of arti-

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Table. Harborview High-Risk Criteria

The presence of any of the following criteria indicates a subject at sufficiently high risk to warrant the initial use of CT to evaluate the cervical spine.

- High-energy injury mechanism, including high-speed (> 35 mph) motor vehicle or motorcycle crash, motor vehicle crash with a death at the scene, fall from height greater than 10 feet.
- High-risk clinical parameter, including significant head injury (i.e., intracranial hemorrhage or unconsciousness in emergency department), neurologic signs or symptoms referable to the cervical spine, pelvic or multiple extremity fractures.

Adapted from: Hanson JA, et al. *AJR Am J Roentgenol* 2000;174: 713-717.

facts, and a higher quality of reformatted and three dimensional images.[23] In the multiple-trauma patient, helical CT can assess several body regions in less time. Before helical CT, the time required for the scan itself and heating and cooling of the tube made screening of the entire cervical spine impractical.[24]

Rather than adopting CT as the primary screening modality, an early approach advocated limited use of CT to examine portions of the spine that were anatomically difficult to see on plain films, such as the cervicocranial and cervicothoracic junctions.[25] These guidelines recommended standard plain radiography supplemented by regional CT of the cervicocranium and areas of suspicion. However, results of a recent study revealed that the approach would have missed 71% (29/41) of injuries that occurred below the C_2 level and did not show up on plain films.[17]

Some centers routinely obtain cervical spine CT in all patients who are getting a CT scan of the head or body. That practice is supported by several small studies and is in keeping with the most recent American College of Radiology (ACR) Guidelines (2002), which recommend cervical spine CT in patients with paresthesias, altered level of consciousness, and in whom cranial CT will be obtained.[8] When CT of the head and cervical spine are obtained together, the overall time for cervical spine evaluation was reduced by an average of 17 minutes, and the estimated additional cost was only $184.42 per patient.[6,18,26-28] That approach also identified a significant number of fractures (occipital condyle fractures and C_1/C_2 fractures) not seen on plain films.[29]

An additional advantage of obtaining a cervical spine CT is its ability to provide information about surrounding anatomical structures. In one series, other injuries were detected in 9% of patients undergoing CT of the cervical spine, including fractures of the upper thoracic spine, proximal ribs, mandible, and skull base.[30] Small, apical pneumothoraces and airway injuries also may be detected.[26]

Considering the ease of obtaining a CT, the time saved, and the diagnostic sensitivity, there is a propensity to use it routinely for cervical spine clearance instead of conventional radiography. Advantages of helical CT compared with plain radiographs include improved accuracy and faster diagnosis; disadvantages include greater expense and higher radiation doses.[19,30] It is well known that the risk of thyroid cancer increases with radiation exposure, especially in children.[18,31,32] Estimates of radiation risk from a complete cervical CT scan vary depending upon the technique and type of scanner. Rybicki et al found that helical CT exposed the thyroid to 14 times the radiation of standard cervical spine plain radiographs, even when accounting for the need for repeat radiographs.[33]

With the radiation risk and cost of CT in mind, a number of authors have attempted to define high-risk patients who should be screened primarily with cervical CT.[6,18,26,30,34] High-risk patients as described by Hanson and Blackmore are patients with a probability of cervical spine injury exceeding 5-10%.[26,30] This definition included patients suffering a high-energy mechanism injury or presenting with a high-risk clinical parameter.[30,34] (*See Table.*) In their small prospective study, Berne et al defined high-risk patients as those who had an altered mental status, were unconscious, or required an admission to an intensive care unit.[18] Screening high-risk patients with CT has been shown to be cost-effective, time efficient, and clinically efficacious.[15,35]

Although Blackmore et al did not find CT to be cost-effective in low-risk patients (less than 4% chance of injury),[35] Griffin et al suggest there is a growing body of evidence that CT should replace plain films for the screening evaluation of the cervical spine in all blunt trauma patients.[17] In their recent, retrospective review of 1,199 trauma patients, they found that plain radiographs—interpreted as normal by the radiologists without recommendation for further radiography—failed to identify 41 of 116 cervical spine injuries detected by CT. A number of factors made it difficult to draw any firm conclusions from their study: 1) the retrospective nature of data collection; 2) types of injuries missed (including transverse process and spinous process fractures); 3) types of patients evaluated (including patients with neurologic deficits or deaths); and 4) absence of missed injuries (patients with normal plain films still were scanned). Before adopting a strategy of screening all patients with CT, further prospective research is needed.

Before abandoning plain films completely, it is important to understand that screening radiography is not intended to detect every cervical spine injury.[36] Rather, when plain films reveal an injury or area of suspicion, or prove to be inadequate, other modalities such as CT or MRI should be used to evaluate for cervical spine injuries. In a review of 34,069 patients screened with plain radiography, Mower et al found that screening radiography only missed three injuries associated with spinous instability, or one unstable injury for every 11,000 screening evaluations.[36]

No radiological modality—including CT— is 100% sensitive in the detection of cervical spine injuries. Brohi et al describe a patient with a C_6-C_7 bilateral facet dislocation missed on CT scan.[37] Schenarts et al revealed that CT had a sensitivity of 96% and missed three injuries seen on plain films (an atlanto-occipital dislocation and two subluxations).[19] They also describe the case of a patient with a C_4 fracture—missed on both CT and plain films—who suffered a severe neurologic injury after removal of

Figure 1. Cervical Spine Fracture Missed by Computed Tomography (CT)

Figure 1A: Sagittally reformatted CT image of the cervical spine showing multilevel disc degeneration, but no apparent bony injury.

Figure 1B: Normal axial CT through the inferior aspect of the C_6 vertebral body.

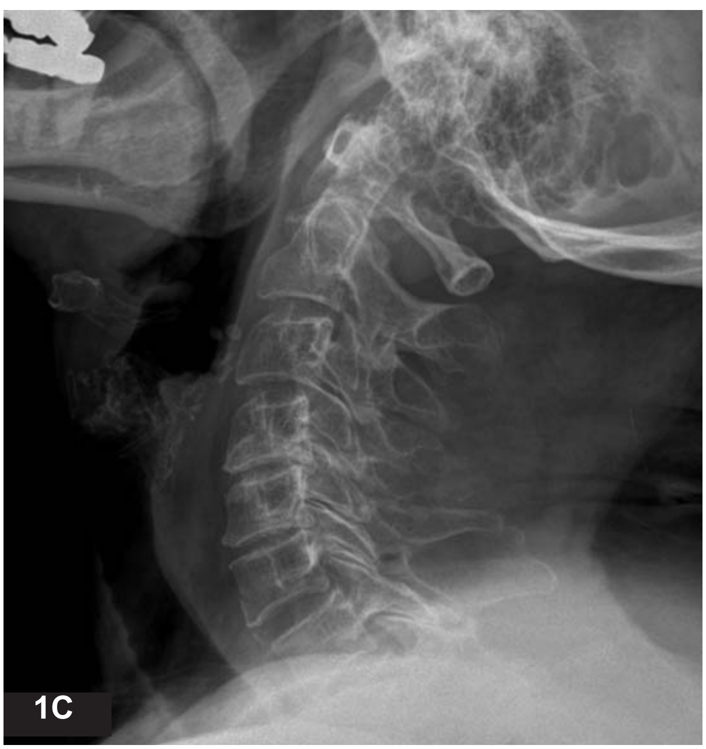

Figure 1C: Lateral extension radiograph of the cervical spine in the same patient reveals a fracture of the anteroinferior aspect of the body of C_6.

Figure 1D: Magnified view of the fracture through the C_6 vertebral body.

Images courtesy of Kathryn Stevens, MD, FRCR, BSc(hons).

Figure 2. Swimmer's View and Dynamic Fluoroscopy in a Patient with a Potential Spine Injury

Figure 2A. Swimmer's view shows C_6-C_7 vertebral bodies.
Figure 2B. Fluoroscopic image of extension test shows abnormal angulation and anterior widening of C_6-C_7 interspace.

Reprinted with permission from Robert KQ et al. *South Med J.* 2000;93:974-976.

the cervical collar. Berne et al showed that helical CT of the entire cervical spine had a sensitivity of 90% and missed two stable injuries (a ligamentous injury and spinous process fracture).[18] The rationale for missed ligamentous injuries on CT is that moderate subluxation may be noted only when evaluating the spine in profile.[23] Though the addition of the lateral radiograph allows for detection of fractures or subluxation that might be subtle or overlooked on axial CT images (See Figure 1.), the improved technology of multi-detector scanners and reformatting may make this practice unnecessary.[38]

The identification of a cervical spine injury on plain films or CT mandates evaluation of the remainder of the cervical spine and the thoracic and lumbosacral spine to exclude concomitant spinal injuries.[37] The incidence of multiple level, non-contiguous fractures has been reported to be 15-24%.[39,40] Recent use of MRI reveals that percentage could be much higher (42%).[41]

Magnetic Resonance Imaging. MRI has several advantages as an imaging modality: high-resolution capabilities; the lack of ionizing radiation; multiplanar imaging capabilities; and the ability to visualize soft-tissue structures including intervertebral discs, ligaments, and the spinal cord. Disadvantages of MRI include prolonged acquisition time, impaired monitoring abilities, and several absolute contraindications (e.g., pacemakers, aneurysm clips, and metallic foreign bodies). In addition, MRI is not available universally, and patient transfer might be required to obtain this study.

In the acute trauma patient with potential cervical spine injury, the indications for MRI as part of the ED evaluation include: 1) complete or incomplete neurologic deficits with radiographic evidence of fracture or subluxation; 2) neurologic deficits not explained by plain films or CT findings (i.e., spinal cord injury without radiographic abnormality [SCIWORA]); 3) deterioration of neurologic function; and 4) suspicion of ligamentous injury following inadequate or negative flexion-extension film findings.[42]

Will MRI replace CT as the primary adjunct to plain film imaging? The ability of MRI to visualize cervical spine fractures (in addition to spinal cord and soft-tissue injuries) has been variable.[43-44] Holmes et al found that MRI missed 45% of osseous fractures identified on CT.[45] While MRI is clearly superior to CT in identifying spinal cord and ligamentous injuries, CT remains the preferred adjunct to plain radiography for the identification of bony injuries.

Diagnosis of Ligamentous Injury

Awake and Alert Patients. Patients without cervical spine fractures still may harbor unstable ligamentous injuries. Although the prevalence of isolated ligamentous injury in the absence of a cervical spine fracture is thought to be low—a reported frequency of 0.04-0.2% in all blunt trauma patients—the consequences of a missed ligamentous injury can be devastating for the patient.[46,47] The true incidence of such injury is actually unknown; a gold standard for such diagnosis currently does not exist. Although traditional cervical spine radiography is useful for detecting fractures and subluxation, the detection of ligamentous injury is less precise.[48] For that reason, a patient with normal cervical spine radiography still may remain in a cervical collar until his or her ligaments can be cleared clinically or definitive imaging is obtained.

If a patient has negative results on radiographic studies, is alert and awake, and denies neck pain, the cervical spine is considered clear. However, the persistence of cervical pain while initial radiographs are normal requires the exclusion of ligamentous injury. While ligamentous injury may be inferred on the basis of an injury seen on CT or plain radiographs, the possibility of ligamentous injury causing instability in the absence of fracture may be excluded through the use of flexion-extension films or MRI.

Flexion-extension radiographs generally are obtained by asking an upright patient to actively flex and extend the neck during cervical spine imaging. This action should be performed only by patients under their own power; the physician should never forcibly assist the patient with flexion or extension. Flexion-extension radiographs should be obtained only in awake, alert, cooperative patients without neurologic symptoms or deficits. Under those circumstances, the risk of neurologic compromise produced by flexion and extension of the cervical spine is very unlikely. When performed voluntarily by the patient, no serious adverse events have been reported.[37,43,48-51]

The goal in interpreting flexion-extension radiographs is to identify or exclude signs of soft-tissue ligamentous injury, such as abnormal subluxation, angulation, or uncovering of facet joints.[52,53] However, following an acute injury, pain associated with motion or muscle spasm may limit a patient's ability to flex and extend adequately. A patient must have a range greater than 30° in each direction from the neutral position for flexion-extension radiographs to be considered adequate.[54] The inability to flex and extend adequately may lead to masking of abnormalities (e.g., subluxation) and result in false-negative studies. Results from a number of series have revealed that 28-59% of flexion-extension radiographs obtained in acutely injured patients were deemed inadequate.[53,55-57]

For that reason, the practice of obtaining flexion-extension radiographs in the acutely traumatized patient has been questioned by numerous studies.[53,57-60] Most recently, the American College of Radiology stated in its guidelines that those views in general are not very helpful and should be reserved for follow up of symptomatic patients 7-10 days after initial injury.[8] In such cases, patients are discharged with a semi-rigid collar and pain medications, and asked to return when they can cooperate actively for flexion-extension radiographs. In a case series by Wilberger et al, 8 of 62 patients (13%), who returned 2-4 weeks after initial flexion-extension films for a repeat set, had significant ligamentous instability requiring cervical fusion.[55]

Do flexion-extension radiographs have any role in the acutely injured patient? Rather than completely abandoning them, a logical approach may be to screen the patient first for the ability to flex and extend the neck adequately. In patients with an adequate range of motion (i.e., greater than 30° in each direction from the neutral position), films may be warranted. In such patients with adequate mobility and negative radiographs, the cervical spine would be cleared effectively. This strategy is supported by the findings of Insko et al, who found that in patients with adequate imaging, flexion-extension radiographs had a false-negative rate of 0%.[57]

In cases of inadequate flexion-extension radiographs, patients also may be studied with an MRI to exclude ligamentous injuries. A negative MRI in the first 48 hours post injury combined with normal plain films and/or CT is sufficient to clear a patient.

Obtunded Patients. The evaluation of ligamentous injury in the obtunded or intoxicated individual is somewhat more difficult. In these patients, a detailed neurologic examination often is not feasible, and the physical exam may be unreliable. For that reason, obtunded, impaired, or distracted patients should not have flexion-extension studies performed in the ED, as such a practice is unsafe and potentially dangerous.

However, obtunded patients who are admitted to the hospital and subject to prolonged immobilization are at risk for detrimental consequences. Prolonged application of a cervical collar in obtunded patients has been associated with skin ulceration, interference with care of neck and shoulder wounds, difficulty with the placement of central lines, increased risk of aspiration, and

Figure 3. Adult SCIWORA

Figure 3. MRI image revealing spinal cord contusion in a patient with spinal canal narrowing at C_5-C_6 and an osteophyte causing mild impression on the thecal sac. There was no evidence of ligamentous injury or prevertebral hematoma. The patient's CT scan revealed no acute fractures or dislocation.

Image courtesy of S.V. Mahadevan, MD.

patient discomfort.[56,61,62] Additionally, the use of cervical collars alone is not sufficient for immobilizing the cervical spine.[63,64]

For those reasons, clearance of the cervical spine and removal of the collar should be performed in a timely manner. No clear consensus exists as to how to evaluate these patients, and practice varies greatly as to how to exclude ligamentous injury.[1] If a patient shows clinical improvement, has a clear sensorium, and can be examined reliably, then a ligamentous injury could be excluded either clinically or with flexion-extension radiographs. In a patient who remains obtunded, recommendations vary from removal of the collar after 24 hours in patients with normal radiographs, to indefinite immobilization in the cervical collar, to MRI and dynamic flexion-extension under fluoroscopy.[47]

MRI is highly sensitive for the recognition of ligamentous injuries, identifying soft-tissue injuries in 25% of obtunded patients with negative radiographs.[51,65] MRI has the added benefit of being able to exclude spinal cord injuries. A negative MRI study within 48 hours of injury implies the absence of ligamentous injury. However, MRI may be overly sensitive for the detection of ligamentous injuries and may reveal injuries of unclear clinical significance.[56] In addition, MRI may not be feasible in unstable patients due to prolonged scanning times and impaired monitoring abilities.[62]

Dynamic fluoroscopy may be used to evaluate for ligamentous injury in obtunded patients who are not candidates for MRI due to contraindications or instability. (*See Figures 2A and 2B*). Unlike MRI, this test may be performed in the critical care unit.[37] Unfortunately, dynamic fluoroscopy often is labor intensive and has the potential to induce secondary neurologic injury. Active flexion-extension under fluoroscopy places patients at risk for neurologic impairment due to subluxation at non-visualized segments or disc abnormalities not demonstrated by radiographs or CT.[66] There are reports of patients who developed quadriplegia following dynamic fluoroscopic evaluation.[47,67]

Due to the exceedingly low incidence of isolated ligamentous instability in obtunded patients with normal radiography, some authors have suggested that the cervical spine can be cleared with an adequate lateral view of the cervical spine and a helical CT from the occiput to T_4 with sagittal and coronal reconstructions.[56] That practice has yet to be validated in a large clinical trial and is in contrast to the most current *Eastern Association for the Surgery of Trauma (EAST) Guidelines*.[68]

Spinal Cord Injury without Radiographic Abnormality (SCIWORA)

Pang and Wilberger defined the term SCIWORA (spinal cord injury without radiographic abnormality) in 1982 to describe a syndrome of post-traumatic neurologic injury without evidence of fracture or ligamentous instability on plain radiographs or CT.[69] Although this syndrome classically is associated with children—playing a role in as many as 50% of pediatric spinal cord injuries—it also may occur in adults.[46,62-77] While the clinical presentations of this syndrome in children and adults may be similar, the hypothesized mechanisms by which they occur differ.

In the pediatric population, highly elastic ligaments in the juvenile spine are thought to allow transient intersegmental vertebral dislocation followed by spontaneous reduction, resulting in damage to the spinal cord, but a normal-appearing, bony vertebral column.[71] Adult patients with degenerative cervical spine conditions and stenosis of the spinal canal also are at risk for SCIWORA. In such patients with pre-existing cervical spondylitic changes, hyperextension can lead to pinching of the spinal cord between vertebral osteophytes and the inward bulging of the ligamentum flavum. (*See Figure 3*.) However, Bhatoe reported another mechanism for SCIWORA in young adult patients who lacked features of pre-existing cervical spine disease.[78] He concluded that acute stretching of the spinal cord from hyperflexion and torsional strain leads to SCIWORA in these patients.

Patients with SCIWORA often present with profound or progressive paralysis, either immediately or within 48 hours of a traumatic incident. While a significant number of patients have demonstrable neurologic deficits at time of presentation, others may present with transient or delayed symptoms. Pang et al found that almost 52% of the patients in their study with SCIWORA had a delayed onset of neurologic deficits ranging from 30 minutes to 4 days.[70] A number of these children had transient warning symptoms immediately following their trauma that had been ignored initially.[70] The observation of delayed deterioration by different investigators highlights the importance of screening patients for SCIWORA warning signs, such as transient weakness, paresthesias, numbness, shock-like sensations, or focal clumsiness following a traumatic event.[71,79] Although the initial neurologic exam may be unremarkable, frequent patient reassessment may detect an evolving neurologic condition. Results from one study showed that several adult patients had normal initial neurologic exams and later developed neurologic deficits.[46]

Hendey et al in their review of the NEXUS database found that the NEXUS criteria also were useful in identifying all 27 patients with SCIWORA.[77] The criteria may have a role in identifying patients at reduced risk for SCIWORA, although that has not been validated prospectively.

When Pang and Wilberger originally defined SCIWORA, MRI did not exist.[80] With its advent, some authors note that the term SCIWORA now may be a misnomer because most patients actually have a demonstrable radiographic spinal cord abnormality seen on MRI.[74] MRI has revealed such findings as spinal cord hemorrhage or edema, intervertebral disc herniation, and spinal cord transection. Occasionally, the MRI may be normal.

In their series, Pang and Wilberger reported that the primary predictor of neurologic outcome in SCIWORA was the presenting neurologic status.[69] More recent studies have revealed that the appearance of the spinal cord on MRI provides better prognostic information regarding the patient's ultimate neurological outcome.[79] A normal-appearing spinal cord (i.e., absence of signal change) portends an excellent outcome; the presence of edema or microhemorrhages without frank hematomyelia (hemorrhage into the spinal cord) is associated with significant improvement of neurologic function over time; and the presence of hematomyelia or cord transection is associated with severe, permanent neurologic injury.[80-82]

Conclusions

The evaluation and clearance of the cervical spine in adult trauma patients are challenging and evolving aspects of trauma care. Trauma care providers should have a thorough understanding of risk factors for cervical spine injury, techniques for protecting patients from exacerbation of their injuries, advances in the practice of clinical and radiographic clearance of the cervical spine, and the diagnosis of such conditions as isolated ligamentous injury and SCIWORA syndrome.

With adequate training, improved detection, and proper care, physicians can prevent the life-altering complications of cervical spine injury such as neurologic injury, severe disability, and death.

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References

1. Grossman MD, Reilly PM, Gillett T, et al. National survey of the incidence of cervical spine injury and approach to cervical spine clearance in U.S. trauma centers. *J Trauma* 1999;47:684-690.
2. Hoffman JR, Wolfson AB, Todd K, et al. Selective cervical spine radiography in blunt trauma: Methodology of the National Emergency X-Radiography Utilization Study (NEXUS). *Ann Emerg Med* 1998;32:461-469.
3. Diliberti T, Lindsey RW. Evaluation of the cervical spine in the emergency setting: Who does not need an X-ray? *Orthopedics* 1992;15:179-183.
4. Stiell IG, Wells GA, Vandemheen K, et al. Variation in emergency department use of cervical spine radiography for alert, stable trauma patients. *CMAJ* 1997;156:1537-1544.
5. Roth BJ, Martin RR, Foley K, et al. Roentgenographic evaluation of the cervical spine: A selective approach. *Arch Surg* 1994;129: 643-645.
6. Barba CA, Taggert J, Morgan AS, et al. A new cervical spine clearance protocolusing computed tomography. *J Trauma* 2001;51: 652-657.
7. Cassar-Pullicino VN. Spinal injury: Optimising the imaging options. *Eur J Radiol* 2002;42:85-91.
8. Daffner RH, Dalinka MK, Alazraki N, et al. American College of Radiology ACR Appropriateness Criteria: Suspected Cervical Spine Trauma [Electronic]. Available at: www.acr.org. Accessed Sept. 20, 2003.
9. Freemyer B, Knopp R, Piche J, et al. Comparison of five-view and three-view cervical spine series in the evaluation of patients with cervical trauma. *Ann Emerg Med* 1989;18:818-821.
10. Turetsky DB, Vines FS, Clayman DA, et al. Technique and use of supine oblique views in acute cervical spine trauma. *Ann Emerg Med* 1993;22:685-689.
11. Woodring JH, Lee C. Limitations of cervical radiography in the evaluation of acute cervical trauma. *J Trauma* 1993;34:32-39.
12. Bachulis BL, Long WB, Hynes GD, et al. Clinical indications for cervical spine radiographs in the traumatized patient. *Am J Surg* 1987;153:473-478.
13. Velmahos GC, Theodorou D, Tatevossian R, et al. Radiographic cervical spine evaluation in the alert asymptomatic blunt trauma victim: Much ado about nothing. *J Trauma* 1996;40:768-774.
14. Nunez DB Jr, Zuluaga A, Fuentes-Bernardo DA, et al. Cervical spine trauma: How much more do we learn by routinely using helical CT? *Radiographics* 1996;16:1307-1321.
15. Blackmore CC, Zelman WN, Glick ND. Resource cost analysis of cervical spine trauma radiography. *Radiology* 2001;220:581-587.
16. Blackmore CC DR. Specificity of cervical spine radiography: Importance of clinical scenario. *Emerg Radiol* 1997;4:283-286.
17. Griffen MM, Frykberg ER, Kerwin AJ, et al. Radiographic clearance of blunt cervical spine injury: Plain radiograph or computed tomography scan? *J Trauma* 2003;55:222-227.
18. Berne JD, Velmahos GC, El-Tawil Q, et al. Value of complete cervical helical computed tomographic scanning in identifying cervical spine injury in the unevaluable blunt trauma patient with multiple injuries: A prospective study. *J Trauma* 1999;47:896-902.
19. Schenarts PJ, Diaz J, Kaiser C, et al. Prospective comparison of admission computed tomographic scan and plain films of the upper cervical spine in trauma patients with altered mental status. *J Trauma* 2001;51:663-669.
20. Woodring JH, Lee C. The role and limitations of computed tomographic scanning in the evaluation of cervical trauma. *J Trauma* 1992;33:698-708.
21. Borock EC, Gabram SG, Jacobs LM, et al. A prospective analysis of a two-year experience using computed tomography as an adjunct for cervical spine clearance. *J Trauma* 1991;31:1001-1006.
22. Choi D. Cervical x-rays and the atlanto-axial region: Supplementary computed tomography may be required in trauma. *Scott Med J* 2000;45:151.
23. LeBlang SD, Nunez DB, Jr. Helical CT of cervical spine and soft tissue injuries of the neck. *Radiol Clin North Am* 1999;37:515-532.
24. Cornelius RS. Imaging of acute cervical spine trauma. *Semin Ultrasound CT MR* 2001;22:108-124.
25. Ross SE, Schwab CW, David ET, et al. Clearing the cervical spine: Initial radiologic evaluation. *J Trauma* 1987;27:1055-1060.
26. Blackmore CC, Mann FA, Wilson AJ. Helical CT in the primary trauma evaluation of the cervical spine: An evidence-based approach. *Skeletal Radiol* 2000;29:632-639.
27. Keenan HT, Hollingshead MC, Chung CJ, et al. Using CT of the cervical spine for early evaluation of pediatric patients with head trauma. *AJR Am J Roentgenol* 2001;177:1405-1409.
28. Daffner RH. Helical CT of the cervical spine for trauma patients: A time study. *AJR Am J Roentgenol* 2001;177:677-679.
29. Link TM, Schuierer G, Hufendiak A, et al. Substantial head trauma: Value of routine CT examination of the cervicocranium. *Radiology* 1995;196:741-745.
30. Hanson JA, Blackmore CC, Mann FA, et al. Cervical spine injury: A clinical decision rule to identify high-risk patients for helical CT screening. *AJR Am J Roentgenol* 2000;174:713-717.
31. Schneider AB. Radiation-induced thyroid tumors. *Endocrinol Metab Clin North Am* 1990;19:495-508.
32. Atherton JV, Huda W. Energy imparted and effective doses in computed tomography. *Med Phys* 1996;23:735-741.
33. Rybicki F, Nawfel RD, Judy PF, et al. Skin and thyroid dosimetry in

cervical spine screening: Two methods for evaluation and a comparison between a helical CT and radiographic trauma series. *AJR Am J Roentgenol* 2002;179:933-937.
34. Blackmore CC. Evidence-based imaging evaluation of the cervical spine in trauma. *Neuroimaging Clin N Am* 2003;13:283-291.
35. Blackmore CC, Ramsey SD, Mann FA, et al. Cervical spine screening with CT in trauma patients: A cost-effectiveness analysis. *Radiology* 1999;212:117-125.
36. Mower WR, Hoffman JR, Pollack CV Jr, et al. Use of plain radiography to screen for cervical spine injuries. *Ann Emerg Med* 2001; 38:1-7.
37. Brohi K, Wilson-Macdonald J. Evaluation of unstable cervical spine injury: A 6-year experience. *J Trauma* 2000;49:76-80.
38. Lawrason J, Novelline RA, Rhea JT, et al. Can CT eliminate the initial portable lateral cervical spine radiograph in the multiple trauma patient? A review of 200 cases. *Emerg Radiol* 2001;8:272-275.
39. Hadden WA, Gillespie WJ. Multiple level injuries of the cervical spine. *Injury* 1985;16:628-633.
40. Henderson RL, Reid DC, Saboe LA. Multiple noncontiguous spine fractures. *Spine* 1991;16:128-131.
41. Qaiyum M, Tyrrell PN, McCall IW, et al. MRI detection of unsuspected vertebral injury in acute spinal trauma: Incidence and significance. *Skeletal Radiol* 2001;30:299-304.
42. Gibbs MA, Jones AE. Cervical Spine Injury: A-State-Of-The-Art Approach to Assessment and Management. *Emer Med Pract* 2001; 3:1-24.
43. Benzel EC, Hart BL, Ball PA, et al. Magnetic resonance imaging for the evaluation of patients with occult cervical spine injury. *J Neurosurg* 1996;85:824-829.
44. Katzberg RW, Benedetti PF, Drake CM, et al. Acute cervical spine injuries: Prospective MR imaging assessment at a level 1 trauma center. *Radiology*1999;213:203-212.
45. Holmes JF, Mirvis SE, Panacek EA, et al. Variability in computed tomography and magnetic resonance imaging in patients with cervical spine injuries. *J Trauma* 2002;53:524-530.
46. Demetriades D, Charalambides K, Chahwan S, et al. Nonskeletal cervical spine injuries: Epidemiology and diagnostic pitfalls. *J Trauma* 2000;48:724-727.
47. Davis JW, Kaups KL, Cunningham MA, et al. Routine evaluation of the cervical spine in head-injured patients with dynamic fluoroscopy: A reappraisal. *J Trauma* 2001;50:1044-1047.
48. Brady WJ, Moghtader J, Cutcher D, et al. ED use of flexion-extension cervical spine radiography in the evaluation of blunt trauma. *Am J Emerg Med* 1999;17:504-508.
49. Ajani AE, Cooper DJ, Scheinkestel CD, et al. Optimal assessment of cervical spine trauma in critically ill patients: A prospective evaluation. *Anaesth Intensive Care* 1998;26:487-491.
50. Banit DM, Grau G, Fisher JR. Evaluation of the acute cervical spine: A management algorithm. *J Trauma* 2000;49:450-456.
51. D'Alise MD, Benzel EC, Hart BL. Magnetic resonance imaging evaluation of the cervical spine in the comatose or obtunded trauma patient. *J Neurosurg*1999;91:54-59.
52. Robert KQ 3rd, Ricciardi EJ, Harris BM. Occult ligamentous injury of the cervical spine. *South Med J* 2000;93:974-976.
53. Wang JC, Hatch JD, Sandhu HS, et al. Cervical flexion and extension radiographs in acutely injured patients. *Clin Orthop* 1999;365:111-116.
54. Marion DW, Domier R, Dunham CM, et al. EAST Practice Management Guidelines for Identifying Cervical Spine Injuries Following Trauma. Available at: http://www.east.org/tpg/chap3.pdf.
55. Wilberger JE, Maroon JC. Occult posttraumatic cervical ligamentous instability. *J Spinal Disord* 1990;3:156-161.
56. Anglen J, Metzler M, Bunn P, et al. Flexion and extension views are not cost-effective in a cervical spine clearance protocol for obtunded trauma patients. *J Trauma* 2002;52:54-59.
57. Insko EK, Gracias VH, Gupta R, et al. Utility of flexion and extension radiographs of the cervical spine in the acute evaluation of blunt trauma. *J Trauma* 2002;53:426-429.
58. Harris MB, Waguespack AM, Kronlage S. 'Clearing' cervical spine injuries in polytrauma patients: Is it really safe to remove the collar? *Orthopedics* 1997;20:903-907.
59. Pollack CV Jr, Hendey GW, Martin DR, et al. Use of flexion-extension radiographs of the cervical spine in blunt trauma. *Ann Emerg Med* 2001;38:8-11.
60. Ralston ME, Chung K, Barnes PD, et al. Role of flexion-extension radiographs in blunt pediatric cervical spine injury. *Acad Emerg Med* 2001;8:237-245.
61. Davis JW, Parks SN, Detlefs CL, et al. Clearing the cervical spine in obtunded patients: The use of dynamic fluoroscopy. *J Trauma* 1995; 39:435-438.
62. Chiu WC, Haan JM, Cushing BM, et al. Ligamentous injuries of the cervical spine in unreliable blunt trauma patients: Incidence, evaluation, and outcome. *J Trauma* 2001;50:457-464.
63. Grady MS, Howard MA, Jane JA, et al. Use of the Philadelphia collar as an alternative to the halo vest in patients with C_{-2}, C_{-3} fractures. *Neurosurgery* 1986;18:151-156.
64. Rosen PB, McSwain NE Jr, Arata M, et al. Comparison of two new immobilization collars. *Ann Emerg Med* 1992;21:1189-1195.
65. Albrecht RM, Kingsley D, Schermer CR, et al. Evaluation of cervical spine in intensive care patients following blunt trauma. *World J Surg* 2001;25:1089-1096.
66. Albrecht RM, Malik S, Kingsley DD, et al. Severity of cervical spine ligamentous injury correlates with mechanism of injury, not with severity of blunt head trauma. *Am Surg* 2003;69:261-265.
67. Davis JW, Phreaner DL, Hoyt DB, et al. The etiology of missed cervical spine injuries. *J Trauma* 1993;34:342-346.
68. Marion DW, Domier R, Dunham CM, et al. Determination of Cervical Spine Stability in Trauma Patients. Available at: http://www.east.org/tpg/chap3u.pdf.
69. Pang D, Wilberger JE Jr. Spinal cord injury without radiographic abnormalities in children. *J Neurosurg* 1982;57:114-129.
70. Pang D, Pollack IF. Spinal cord injury without radiographic abnormality in children—the SCIWORA syndrome. *J Trauma* 1989;29: 654-664.
71. Kriss VM, Kriss TC. SCIWORA (spinal cord injury without radiographic abnormality) in infants and children. *Clin Pediatr* (Phila) 1996;35:119-124.
72. Brown RL, Brunn MA, Garcia VF. Cervical spine injuries in children: A review of 103 patients treated consecutively at a level 1 pediatric trauma center. *J Pediatr Surg* 2001;36:1107-1114.

73. Kokoska ER, Keller MS, Rallo MC, et al. Characteristics of pediatric cervical spine injuries. *J Pediatr Surg* 2001;36:100-105.
74. Gupta SK, Rajeev K, Khosla VK, et al. Spinal cord injury without radiographic abnormality in adults. *Spinal Cord* 1999;37:726-729.
75. Kothari P, Freeman B, Grevitt M, et al. Injury to the spinal cord without radiological abnormality (SCIWORA) in adults. *J Bone Joint Surg* Br 2000;82:1034-1037.
76. Bhatoe HS. Spinal cord injury. *J Neurosurg* 2001;94:339-340.
77. Hendey GW, Wolfson AB, Mower WR, et al. Spinal cord injury without radiographic abnormality: Results of the National Emergency X-Radiography Utilization Study in blunt cervical trauma. *J Trauma* 2002;53:1-4.
78. Bhatoe HS. Cervical spinal cord injury without radiological abnormality in adults. *Neurol India* 2000;48:243-248.
79. Spinal cord injury without radiographic abnormality. *Neurosurgery* 2002;50:S100-104.
80. Cirak B, Ziegfeld S, Knight VM, et al. Spinal injuries in children. *J Pediatr Surg* 2004;39:607-612.
81. Davis PC, Reisner A, Hudgins PA, et al. Spinal injuries in children: Role of MR. *AJNR Am J Neuroradiol* 1993;14:607-617.
82. Grabb PA, Pang D. Magnetic resonance imaging in the evaluation of spinal cord injury without radiographic abnormality in children. *Neurosurgery* 1994;35:406-414.

CE/CME Questions

1. Which of the following statements is true regarding the role of computerized tomography (CT) in evaluating patients for cervical spine injury?
   A. CT of the cervical spine may be able to detect cervical spine injuries not readily apparent on plain radiographs.
   B. CT of the cervical spine should be obtained in all blunt trauma patients to exclude injury.
   C. CT is highly sensitive for the detection of ligamentous injury.
   D. CT imaging of the cervical spine poses a lower radiation risk to patients than plain radiographs.

2. Which of the following statements is true regarding plain radiographs of the cervical spine?
   A. A single lateral view is sufficient to exclude cervical spine injury.
   B. The routine addition of oblique views (five-view series) significantly improves the sensitivity.
   C. The routine addition of flexion-extension views is not indicated unless there is specific concern for ligamentous injury.
   D. The frequency of inadequate or false-positive films decreases with injury severity.

3. Which of the following is *not* an indication for cervical spine MRI as part of the ED evaluation?
   A. Cervical spine fracture or subluxation with neurologic deficit
   B. Suspected Spinal Cord Injury without Radiographic Abnormality (SCIWORA)
   C. Deterioration in neurologic function
   D. Suspicion of cervical spine ligamentous injury
   E. All of the above are indications for MRI.

4. Which of the following statements is true regarding flexion-extension films?
   A. Flexion-extension films are obtained while the clinician actively flexes and extends the neck of the acutely injured patient.
   B. Flexion-extension films may be obtained safely in obtunded or comatose patients.
   C. Flexion-extension films are extremely efficient in completely excluding ligamentous injury in the acutely injured patient.
   D. Flexion-extension films are unlikely to produce neurologic injury when obtained in the alert, cooperative patient.

5. Spinal Cord Injury without Radiographic Abnormality (SCIWORA):
   A. is an entity only found in the pediatric patient.
   B. occurs in adults by the same mechanism as in children.
   C. often presents with profound or progressive paralysis either immediately or within 48 hours.
   D. may be excluded with an initial normal neurologic examination.

6. Which of the following statements is *not* true regarding plain radiographs for a patient with a potential cervical spine injury?
   A. Plain radiographs are inexpensive.
   B. Plain radiographs in the severely injured or unconscious patient are all that is needed to exclude a spinal injury.
   C. Frequently, the cervicocranial area is viewed inadequately on a plain radiograph.
   D. Plain radiographs are repeated in almost 50-70% of severely injured or unconscious patients to obtain an adequate study.

7. Which of the following is an advantage of helical CT vs single acquisition CT?
   A. Faster image acquisition
   B. Faster image reconstruction times
   C. Reduction of image artifacts
   D. Higher quality reformatted and three-dimensional images
   E. All of the above

8. Which of the following statements is true regarding the initial use of CT to evaluate the cervical spine?
   A. High-risk clinical parameters, including a history of loss of consciousness, warrant the initial use of CT scan to evaluate the cervical spine.
   B. High-energy mechanisms, warranting the initial use of CT scan for the evaluation of the cervical spine, include high-speed (> 35 mph) motor vehicle or motorcycle crashes.
   C. High-energy mechanisms, warranting the initial use of CT scan for the evaluation of the cervical spine, include a fall from 8 feet.
   D. High-risk clinical parameters include a history of amnesia for the event following a fall from 6 feet.

9. A 35-year-old male presents to the ED following a motorcycle crash. He is unconscious and has a GCS score of 10. The patient was intubated in the field with appropriate spinal immobilization, which has been maintained. Following stabilization of the patient, which of the following would be the best initial test to evaluate the cervical spine?
   A. Flexion-extension radiographs

B. Oblique plain radiographs of the cervical spine
C. MRI
D. CT scan of the cervical spine

10. A 38-year-old female presents after a fall from a chair. She has a GCS score of 15 and no neurologic deficits. The initial radiographs (lateral, anterioposterior, and open-mouth view) are read by the radiologist as normal. She is complaining of neck pain. The patient has less than 30° of motion in both flexion and extension from the neutral position. The next step should be to:
A. administer diazepam and actively flex and extend the neck.
B. obtain a CT scan of the cervical spine.
C. discharge the patient in a semi-rigid collar with careful instruction and follow-up.
D. have the physician forcibly assist the patient during flexion-extension radiographs to obtain adequate radiographs.

Answer Key:

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

CE/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 certificate of completion.** When your evaluation is received, a certificate will be mailed to you.

CE/CME Objectives

Upon completing this program, the participants will be able to:
a.) Identify the indications, advantages, and limitations of plain radiography for the evaluation of patients with potential blunt cervical spine injury;
b.) Recognize the indications for the use of CT and MRI of the cervical spine;
c.) Define and translate into clinical practice the appropriate evaluation of a patient with a potential ligamentous injury of the cervical spine; and
d.) Discuss the presentation, diagnosis, and management of a patient with SCIWORA.

In Future Issues: **Knee Injuries**