



Current issues in the diagnosis of pediatric cervical spine injury

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Cervical spine injury in pediatric trauma occurs rarely; however, there is significant potential for considerable morbidity when it does occur. Screening for cervical spine injuries has been shown to be most sensitive in adult trauma centers when combined with reliable physical examination findings. Because pediatric trauma patients suffer from a different range of injuries than adults, and often are not reliable due to age limitations or associated head injury, the same strategies employed in adult trauma do not always hold true in children. We look at the differences in adult and pediatric cervical spine anatomy and traumatic mechanisms, as well as the differences between cervical spine injury in infants/children and adolescents/teens. In addition, we examine the literature currently available in each population and derive consensus on the issues that are important in managing the pediatric cervical spine. We hope to provide a framework that trauma centers can use to develop safe and effective cervical spine clearance protocols.

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In the United States, the reported incidence of all spinal cord injuries in the pediatric population is 18.1 spinal cord injuries per 1 million children per year, representing approximately 1300 new cases each year.¹ The incidence of cervical spine injuries in children admitted to major trauma centers undergoing radiological imaging is estimated to be between 1% and 4%.²⁻⁴ Although this incidence is low, 60%-80% of spine injuries in children occur at the cervical level. This is in contrast to adults, in whom cervical injuries represent 30%-40% of all spine injuries. The most common mechanisms of injury include motor vehicle accidents, falls, pedestrian struck by autos, and diving accidents.⁵ Falls are more common in younger children, whereas motor vehicle accidents are more common in older children. Overall, boys younger than 9 years are slightly more likely to be injured than girls. This difference is magnified as children approach driving age and begin to engage in more risk-taking behavior.⁶

Cervical spine injuries in children can be divided into two distinct groups: ≤ 8 years of age and ≥ 9 years.⁷ The variance in injury profiles is likely explained by developmental anatomic differences as well as biomechanical factors. Children younger than 8 years are more likely to sustain high cervical injuries (C1-C3), whereas older children typically injure the cervical spine at lower levels.^{4,8,9} Younger children have increased flexibility of the cervical spine. This increase in mobility is explained by incomplete ossification of the vertebral bodies, ligament laxity, and incomplete development of the spinous processes. When combined with an increase in head-to-torso ratio and relatively weak cervical musculature, this increase in flexibility leads to cervical spine injuries at higher levels. By 8 years of age, the cervical spine is nearing maturity and the injury profile is similar to that of adults.

Anatomical and biomechanical differences

The spinal column undergoes significant anatomic and biomechanical changes during the first 15 years of life. The

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biomechanical and anatomic features of the growing spinal column result in specific injury patterns. A thorough knowledge of the developing spine is essential to clear the pediatric cervical spine. Radiographic studies greatly assist in the process of evaluating of injuries. Similarly, interpretation of these studies demands a full understanding of pediatric anatomy and biomechanics.

Ossifying cartilages form centers of ossification that characterize the developing spine. The ossific centers can occasionally be the site of injury, and synchondroses may be confused with fractures in the immature spine. The atlas is formed from three ossification centers; two form the lateral masses, and a third forms the anterior arch. The anterior arch ossification center may not be visible on radiologic studies until the age of 1 year. By 7 years, fusion of the anterior arch of C1 and the lateral ossification center is usually complete.¹⁰

The axis development is more complex and is composed of ossification centers for the arches and body in addition to two centers for the dens. The ossification centers comprising the dens are radiographically fused at birth.¹⁰ The ossiculum terminale at the tip of the dens appears at about 7 years and fuses to the dens at about 12 years of age. Development of the lower cervical spine (C3-C6) combines three ossification centers: two lateral ossification centers and a third for the vertebral body separated by synchondroses. Synchondroses typically close between 3 and 6 years and should not be confused with fractures.

Several anatomic factors can explain the greater frequency of upper cervical injuries in children when compared with adults. The immature cervical spine has a more horizontal orientation of the facet joints. By adolescence, this orientation shifts to a more vertical alignment. The horizontal position of the cervical facet joints combined with the relative laxity of the cervical ligaments contributes to the increased incidence of upper cervical injuries in

young children. In addition, the relatively increased mass and volume of the infant head compared with the torso contribute to the greater frequency of upper cervical spine injuries in children. These anatomic features result in a spine that is more malleable and better able to tolerate a mechanical deformation than the adult spine. As the child approaches the age of 8 years, the radiographic profile of the spine is similar to adults and the injury pattern mirrors that of the adult population.

The pediatric cervical spine is much more flexible than the adult cervical spine. It is therefore possible to injure the spinal cord without suffering an obvious injury to the bony spine. This particular kind of injury, termed spinal cord injury without radiographic abnormality (SCIWORA), occurs almost exclusively in young children because of their unique biomechanics.

As the child ages, the spine assumes a more adult biomechanical profile and the cervical flexion fulcrum becomes progressively lower. The fulcrum for flexion is at C2-C3 in infants, C3-C4 by 5 years, C4-C5 at 10 years, and C5-C6 (the adult level) by 15 years of age.⁴ More force is required to injure the spinal cord in an older child when compared with infants. Consequently, these injuries are often accompanied by spinal column fractures or injury to soft-tissue structures, such as the ligaments. The differences in pediatric cervical spine development and injury patterns are summarized in Table 1.

Infants and children

Injury patterns

Pediatric cervical spine injuries can be stratified by age into 2 groups: ≤ 8 years (infants and children) and ≥ 9 years

Table 1 Summary of various injury patterns, anatomic differences, and imaging characteristics based on age in pediatric cervical spine injury

	Infants/Children	Adolescents/Teens
Age	0 to 8 years	9-16 years
Injury		
Location	Upper cervical spine	Lower cervical spine
Type	Mostly ligamentous SCIWORA AO dissociation	Mostly osseous "like little adults"
Anatomy		
Vertebra	Cartilaginous, wedge-shaped	Bone, square
Physes	Open	Closed
Dens	Incomplete	Complete
Ligaments	Lax, high water content	Firm, low water content
Facets	Horizontal	Vertical
Clearance	1. Clinical examination/history (AAST, NEXUS) 2. Two-view radiographs (open mouth not useful) 3. (flexion/extension) 4. MRI	1. Clinical examination/history (NEXUS) 2. (Three-view radiographs) 3. CT scan 4. (flexion/extension) 5. MRI

(adolescents and teens).^{4,10} Infants and children who sustain a cervical spine fracture often do so in motor vehicle crashes, whereas in adolescents and teens, injury tends to occur during sporting and recreational events.^{4,10} Previous literature supports the observation that pediatric patients younger than 8 years have a predilection for injuries of the upper cervical spine with very few injuries to the lower cervical spine. Injuries to the atlanto-occipital articulation and the upper cervical spine are uncommon injuries in very young children¹⁰ and can be associated with trauma secondary to vehicle airbag deployment.¹¹ Historically, these injuries have been considered rare and fatal. Recent improvements in prehospital care and better imaging techniques have improved survival with this type of injury. A recent review of 16 cases showed 8 were dead on arrival in the emergency department (ED), 3 died from severe head injuries, and 5 survived. Four of the 5 survivors were functional, and the remaining survivor was ventilator-dependent.¹²

Other upper cervical fractures noted in infants and children younger than 8 years include the odontoid physal fractures and C1-C2 subluxation injuries.¹³ These injuries are rare and somewhat unique to young children. A recent review of all cervical spine injuries in children under 3 years of age in the National Trauma Data Bank showed that nearly half of the cervical spine fractures (48%) were in the lower cervical spine. In addition, more than half of the cervical spinal cord injuries in this population occurred in the lower cervical spine. Motor vehicle accidents (66%) were the most common mechanism in this group.¹⁴ This suggests that one must still pay attention to the lower cervical spine in infants and children younger than 8 years. [Figure 1](#) demonstrates a C2 Hangman's fracture in a child.

SCIWORA

SCIWORA describes an acute spinal cord injury that results in sensory and/or motor deficits without radiographic evidence of vertebral fracture or bony misalignment on plain radiographs or computed tomography (CT) scans. The con-

cept of SCIWORA was proposed in 1907, but the acronym was not described by Pang and Wilberger until 1982.¹⁵ Ninety percent of SCIWORA cases occur in the pediatric population with an average age of 7-8 years.¹⁶ The most common mechanisms resulting in SCIWORA are motor vehicle crashes, falls, and sports accidents. Three-fourths of SCIWORA injuries occur in the cervical spine; most of the remaining injuries occur in the thoracic spine.¹⁶ In addition, children can often have delayed onset of clinical signs and symptoms up to 4 days after the initial injury.¹⁷

Upper cervical SCIWORA often has more severe neurologic consequences than lower cervical SCIWORA. The incidence varies in the pediatric population but likely accounts for 20%-30% of all spinal cord injuries; in some series, this can be as high as 60%.^{16,17} The five most common clinical presentations are partial cord syndrome (55%), complete cord syndrome (27%), central cord syndrome (10%), Brown-Sequard syndrome (5%), and anterior cord syndrome (3%).¹⁶ The cause is unknown but is likely the result of horizontally oriented facet joints (particularly in the upper cervical spine), anterior wedging of the vertebral bodies, and more elastic ligaments and joint capsules in the pediatric population. Recurrent SCIWORA is defined as the onset of a second SCIWORA several days to several weeks after the initial SCIWORA incident. This has been reported in up to 17% of cases.^{16,17}

SCIWORA is often the result of serious trauma, and distracting injuries may complicate the diagnosis. When neurologic deficit is diagnosed clinically and neither plain radiographs nor CT scan of the neck reveals any injury, a magnetic resonance imaging (MRI) scan of the neck is likely the only way to define neural injury. If an abnormal neurologic examination is encountered following trauma, a spinal cord injury should be assumed and the child should be appropriately immobilized. If plain radiographs and CT scans fail to show vertebral damage, MRI scans should be obtained to rule out SCIWORA. If the child is unconscious after injury, rigid immobilization should be maintained and plain radiographs and CT scans should be obtained (although some would advocate moving directly to MRI). If these studies are normal, MRI should be considered if it is anticipated that the child will remain unconscious for an extended period. A protocol to obtain MRI scans on all children who are unconscious within 72 hours of injury allows for more rapid mobilization of the patient. This results in decreased intensive care unit (ICU) and hospital days, thereby justifying the cost of using this diagnostic test routinely.¹⁸ [Figure 2](#) demonstrates an upper cervical cord injury noted on MRI in a child who had persistent tenderness in the upper cervical spine.

Treatment of SCIWORA often requires nothing more than effective bracing. Dynamic flexion extension radiographs are obtained to determine stability in age-appropriate patients. An adequate pediatric cervical spine collar can then be used for 8-12 weeks, as long as the child does not exhibit worsening symptoms.¹⁷ Standard treatment does not

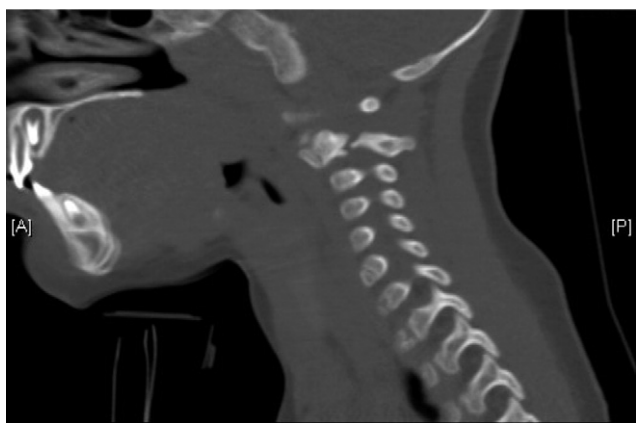


Figure 1 A C2 pedicle or "Hangman's fracture" in a child.



Figure 2 SCIWORA. Narrowing of the spinal cord at the atlanto-occipital junction in a child. The child was neurologically intact but with upper cervical spine tenderness.

affect the final outcome of SCIWORA once significant neurologic damage has been done. Identifying the injury early and stabilizing it before the damage has occurred is the only way to affect prognosis and outcome.¹⁷

Imaging

Despite the low incidence of cervical spine injuries in this population (<2%), the devastating consequences of a missed cervical injury in combination with the perception that the physical examination of the cervical spine is unreliable in this age group prompts many clinicians to rely on radiographic imaging to “clear the spine.” Interpretation of cervical spine radiographs in younger patients can be challenging. Pseudosubluxation is commonly seen in children under 8 years of age. The amount of subluxation should be less than 4.0 mm and should correct with extension.¹⁹ The atlantodens space can be larger in children (up to 4.0 mm), and variations in odontoid development can commonly be misinterpreted as an injury on plain cervical radiographs.¹⁹ Soft tissue spaces can also appear enlarged in a crying and uncooperative child.

In a recent meta-analysis of CT versus plain radiography, there was ample evidence to suggest that CT scan of the cervical spine in adult trauma patients significantly outperforms plain radiography as a screening test. In adult trauma patients with a high risk for injury or significantly depressed

mental status, CT scan likely should be the initial screening test.²⁰ There is insufficient evidence to suggest that cervical spine CT should replace plain radiography as the initial screening test in those who are at low risk but still require radiologic evaluation.²⁰

CT imaging of the cervical spine in children younger than 8 years of age likely does not have as much utility and often exposes the child to unnecessary radiation. New generation multidetector scanners expose the child to increased doses of radiation, and there is an increased risk of iatrogenic cancer with increased exposure.^{21,22} In particular, exposure of the thyroid with cervical spine scanning is worrisome. CT scanning of the cervical spine is very sensitive for osseous injuries and fracture.²³ Unfortunately, most children in this age group sustain more ligamentous injuries than osseous injury. Therefore, the lower sensitivity of CT scanning does not justify the increased risk of radiation exposure in this population.²³

In a review of over 600 children under the age of 5 years, 147 had CT imaging to clear their cervical spine in addition to plain radiographs, and 4 osseous injuries were identified.²⁴ In all 4, the injury was present on the plain radiograph and no new injuries were identified. In this study, if the lateral cervical spine film was adequate and appeared normal, the likelihood of identifying any additional cervical spine fractures was zero. There were no instances where CT scan detected new fractures or dislocations.

The use of flexion–extension radiography has been called into question lately as well. In a review of 247 children who underwent flexion–extension radiography, no children with normal static films were subsequently found to have an injury on flexion–extension.²⁵ Flexion–extension in this review was found to be more useful in ruling out a significant injury in 4 patients who had an abnormality on static films.^{8,25} After trauma, muscle spasm can result in inadequate flexion–extension radiography by limiting normal motion and may limit the excess mobility seen with a significant subluxation injury, resulting in a false-negative evaluation.⁸

MRI is highly sensitive, and the clinical relevance of many of the subtle findings on MRI has not been completely established. In subsequent evaluation of the National Emergency X-Radiography Utilization Study (NEXUS) data with respect to CT scan versus MRI, MRI missed 45% of identified osseous fractures.²³ Often, obtaining a cervical spine MRI requires deep sedation or general anesthesia, takes much longer, and may require transport of potentially unstable patients to areas far from the ED or ICU.²⁶ MRI, however, identifies spinal cord injury as well as soft tissue and ligamentous injury particularly well, both of which are poorly identified on CT scan.²³ In infants and children, MRI may be the study of choice for clearing the difficult cervical spine.

Evaluation of a protocol established to obtain an MRI on all children that could not be cleared clinically or with plain radiographs or CT within 72 hours revealed a trend toward

reduced ICU and hospital days, as well as a savings of \$7,700 per patient.¹⁸ The benefits of early cervical spine clearance with respect to early patient mobilization helped minimize complications, such as skin breakdown, upper respiratory infection, pulmonary dysfunction, and decubitus ulcers.¹⁸

Clearing the C-spine

Both the NEXUS and the Canadian C-spine study have clearly shown that, in appropriate adult patients, clinical examination alone is sufficient to clear the cervical spine.^{2,27} The NEXUS study validated 5 clinical criteria in more than 34,000 patients. The criteria included the absence of tenderness at the posterior midline of the cervical spine, the absence of a focal neurologic deficit, a normal level of alertness, no evidence of intoxication, and absence of clinically apparent pain that might distract the patient.² This instrument identified all but 8 of 818 patients who had a cervical spine injury, with a sensitivity of 99% and a negative predictive value of 99.8%.²

In infants and children, there is a common perception that the physical examination is unreliable. A previous retrospective review of 206 patients from birth to 16 years of age suggested that the absence of 8 clinical criteria similar to the NEXUS criteria had a sensitivity of 98% for detecting cervical spine injury.²⁸ These criteria included neck pain, neck tenderness, abnormal reflexes, weakness, sensory deficit, direct trauma to the neck, limitation of neck mobility, and abnormal mental status. There were few infants in the study, and none had injuries.²⁸

A recently reported multi-institutional study through the American Association for the Surgery of Trauma (AAST) has shown that this perception (lack of reliability of the physical examination) is indeed in error, even in children younger than 3 years.²⁶ From a database of over 12,000 patients younger than 3 years, 83 (0.66%) with cervical spine injuries were identified. Eight of these had cervical cord injuries, confirming that the incidence is extremely low in this group. Four independent predictors of cervical spine injury were identified and weighted: a Glasgow Coma Score (GCS) <14, GCS_{EYE} = 1, motor vehicle accident, and age 2 years or older. Each of these predictors was given a weighted score. A total score < 2 had a negative predictive value of 99.93%, and almost 70% of the database population had a score <2 and would have been eligible for clearance without any imaging.²⁶

Based on the data currently available, it is reasonable to develop protocols that begin with history and physical examination and advance as needed to more sophisticated imaging. One must take into account the likelihood of injury and the clinicians' ability to examine the child. High-energy mechanisms, such as motor vehicle accidents and those that involve injuries above the clavicles, should raise concern for possible cervical spine injury in the pediatric trauma patient. Age and development will play a significant role in the ability to examine the child. Similar to adults, in patients

who are cooperative and have unaltered mental status, a normal neurologic examination, and no distracting injuries, the physical examination is probably reliable. It is reasonable to adopt criteria similar to the NEXUS criteria (no midline tenderness, no intoxication, normal mental status, no focal deficit, no distracting injury). Similarly, in children younger than 3 years, one may consider using the four clinical predictors identified in the AAST multi-institutional study (GCS < 14, GCS_{EYE} = 1, motor vehicle accident, age 2 years or older) to determine which children need further imaging.

A normal examination would be defined as no injury or swelling anteriorly; no bruising, swelling, or midline tenderness posteriorly; and full unaided range of motion without apparent pain or rigidity. If history or examination suggests a child at risk for injury, then a two-view C-spine series would be indicated to identify any obvious injury. In this age group, if plain radiographs are negative yet there is still concern for injury, the available data would suggest that, because most injuries are ligamentous in nature, flexion–extension radiography or an MRI should be obtained. Given the high frequency of SCIWORA in this age group, if there is a neurologic deficit, one should proceed to MRI. An algorithm for cervical clearance in infants and children based on these data is presented in Table 1 and Figure 3.

In this algorithm, one would first assess the mechanism of injury as well as the clinical examination of the patient. If old enough or cooperative enough and without any worrisome risk factors, the child could be cleared clinically if he/she can perform full range of motion without any pain. Even infants

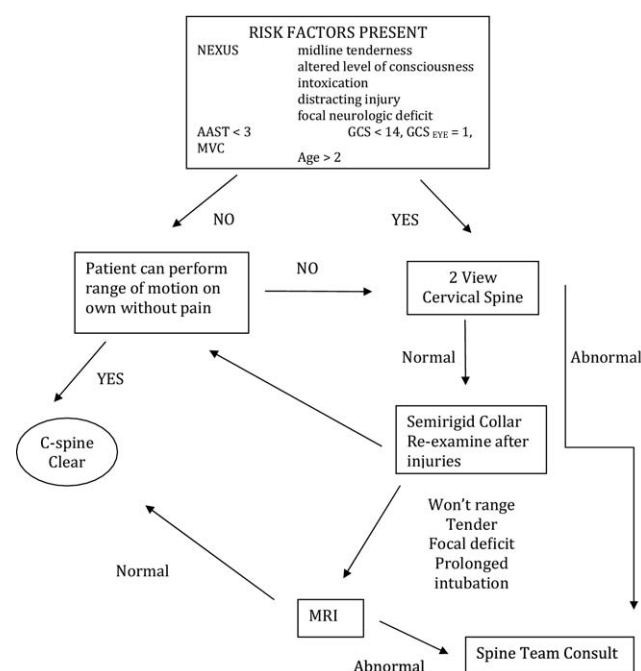


Figure 3 A proposed algorithm for cervical spine clearance in infants in children. Based on the supposition that these injuries will mainly be ligamentous that CT scanning has a very low likelihood of identifying any injuries that can't be seen on plain film, and that reducing radiation exposure in this population is a clinical priority.

can be evaluated by having them follow a toy, bottle, or pacifier. If risk factors are present, a lateral and anterior posterior view of the spine would be adequate to rule out grossly unstable injury. As previously mentioned, in this population, it has been shown that the likelihood of CT scan identifying an injury not seen on plain radiography is extremely low. Because the child is likely being admitted to the hospital at this point, it would be acceptable to place the child in a semirigid collar, and reexamine the following day. If the child still had pain, or was not able to be evaluated due to head or other serious injury, the study of choice to clear the C-spine would be an MRI at a clinically appropriate time. Involvement of the spine team can occur at any time during the algorithm if the child's findings are not straightforward.

Adolescents

Injury pattern

Adolescents and teens are more likely to sustain cervical spine injury as a result of carelessness involving sporting and recreational activities.⁴ Overall, more injuries occur in the adolescent and teen age group; however, they tend to be a lower proportion of serious injuries than in the infants and children.²⁹ Contrary to infants and children, the injury more often affects the lower cervical spine, and the injury patterns mimic those of adults. Diving accidents, which are more common in this age group, also tend to affect the lower cervical spine rather than the upper.²⁹ As children grow, the pivot point of the cervical spine shifts to a lower level, the neck musculature becomes stronger, and the head becomes comparatively smaller, thus making the lower cervical spine more at risk for injury. SCIWORA is extremely rare in this population.⁴

Imaging

As stated previously, CT has little to offer over plain radiographs when screening for cervical spine injury in infants and children.²⁴ Because the cervical spine is relatively mature in this older age group, they can, for most purposes, be evaluated as adults using current adult screening recommendations. Numerous studies in the adult trauma literature call into question the use of plain radiographs of the cervical spine.^{23,30} The NEXUS data would suggest that any adolescent or teen who does not meet any of the five worrisome criteria needs no imaging at all, and the cervical spine could be cleared clinically with a sensitivity in excess of 99%.²

In those who fail to meet the NEXUS criteria for clearance, the sensitivity of plain films for injury is such that more advanced imaging would likely be required.^{23,30} In a meta-analysis of plain radiography versus CT for detecting cervical spine injury in adults, the collective sensitivity of plain radiography was 52%, whereas that of CT was 98%.²⁰ Ample evidence was presented demonstrating that cervical spine CT significantly outperforms plain radiography as a

screening test in patients with depressed mental status or in those who may have an increased risk for a cervical spine injury. The authors conclude, however, that insufficient evidence exists for CT to replace plain radiographs as the screening test of choice for those at low risk in whom cervical spine clearance cannot be completed with physical examination alone.²⁰

The same concerns expressed above with respect to flexion–extension films in infants and children are present in adolescents and teens as well. MRI should be reserved in this population for obtunded patients with severe mechanisms of injury, when the CT scan is equivocal, if neurologic symptoms are present and without obvious radiographic findings, and perhaps in patients whose cervical spine is still not clear 72 hours after admission.⁸

Clearing the C-spine

In this patient population, the NEXUS criteria is an effective screening tool for cervical spine injury with sensitivity equal to that found in adults. If there is midline tenderness, intoxication, altered mental status, focal deficits, or distracting injuries, then the cervical spine cannot be cleared clinically. If any of the above criteria are present, a three-view cervical spine series or a cervical CT should be obtained. Many institutions would obtain a CT scan, as the risk of radiation exposure in teens is less, and the literature as previously discussed would support its increased sensitivity in this population. If plain radiographs and/or CT are negative and tenderness or concern for injury remains, flexion–extension films may be useful. Many institutions, however, would obtain an MRI in this situation. MRI is also indicated if neurologic deficit is present without obvious injury on plain radiographs and/or CT scan. In the event that the patient remains intubated with significant injuries and otherwise cannot be examined clinically, earlier cervical spine clearance with MRI-based protocols can result in decreased ICU and hospital days.¹⁸ An algorithm for cervical clearance in teens and adolescents based on these data is demonstrated in [Table 1](#) and [Figure 4](#).

In this algorithm, adolescents and teens should be old enough and cooperative enough to be assessed clinically in a fashion similar to the NEXUS study. One would first assess the mechanism of injury as well as the clinical examination of the patient. If there are no risk factors present, and the patient has no tenderness and can perform full range of motion without pain, the cervical spine is clear. If there are risk factors present or tenderness, then the literature as discussed previously would support bypassing plain radiographs and obtaining a CT scan with reconstruction of the cervical spine. Because the risk of radiation exposure is less in the fully developed child, the consequences of scanning are less. We should emphasize that one could also place the patient in a collar and reexamine the child at a time remote from the initial assessment. Many children will provide a reliable examination when the chaos of the trauma bay is removed. If there is a neurologic deficit and no lesion on CT

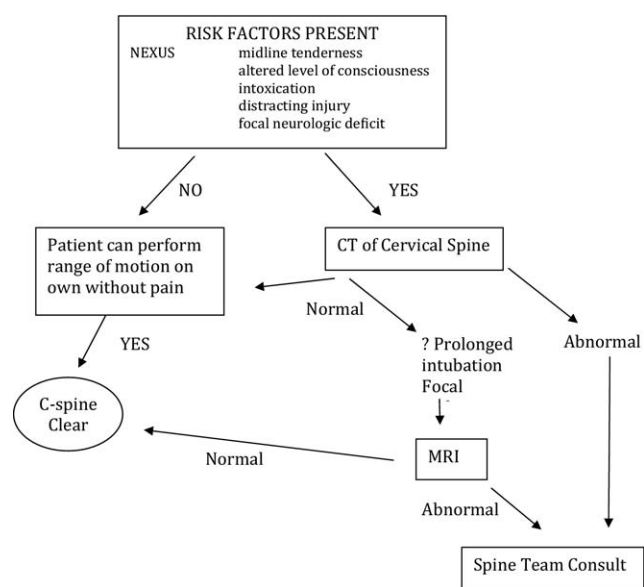


Figure 4 A proposed algorithm for cervical spine clearance in adolescents and teens. Based on the supposition that these injuries will follow an adult pattern of injury and will mainly involve osseous injury.

to account for it, then MRI should be obtained as well. Involvement of the spine team can occur at any time during the algorithm if the child's condition is not straightforward.

Conclusions

Although cervical spine injury is rarely encountered in the pediatric trauma population, any missed injuries may have significant consequences for the patient. The pediatric trauma population can be divided into two groups with respect to cervical spine injury: ≤ 8 years of age and ≥ 9 years. Each group has different cervical spine injury patterns because of differing anatomic and biomechanical properties, and a tailored evaluation and management of these injuries is required. A multidisciplinary approach to cervical spine clearance in the pediatric population is best. A thorough review of national guidelines and the combined efforts of pediatric surgeons, neurosurgeons, orthopedic surgeons, emergency medicine physicians, and radiologists to develop protocols that can be adapted locally and lead to decreased time and missed injuries with cervical spine clearance would appear most effective.

We would contend based on the current data that more imaging is not the answer with respect to improving the ability to clear the pediatric cervical spine. More selective imaging based on appropriate adaptation of history and clinical findings that are employed in adult trauma management should be considered. Acceptable levels of sensitivity should be achievable in this manner while reducing radiation exposure in those at risk in the pediatric trauma population.

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