Head and Cervical Spine Evaluation for the Pediatric Surgeon

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KEYWORDS

• Pediatric trauma • Cervical spine • Traumatic brain injury • Imaging • Evaluation

KEY POINTS

- Head Evaluation
  - Traumatic brain injury (TBI) is the most common cause of death among children with unintentional injury.
  - Patients with isolated loss of consciousness and Glasgow Coma Scale (GCS) of 14 or 15 do not require a head CT.
  - Maintenance of normotension is critical in the management of the severe TBI patient in the emergency department (ED).
- Cervical spine evaluation
  - Although unusual, cervical spine injury (CSI) is associated with severe consequences if not diagnosed.
  - The pediatric spine does not complete maturation until 8 years and is more prone to ligamentous injury than the adult cervical spine.
  - The risk of radiation-associated malignancy must be balanced with the risk of missed injury during.

HEAD EVALUATION

Introduction

The purpose of this article is to guide pediatric surgeons in the initial evaluation and stabilization of head and CSIs in pediatric trauma patients. Extensive discussion of the definitive management of these injuries is outside the scope of this publication.

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The diagnostics and management strategies contained within this text are written in the context of the ED or trauma bay.

TBI is a broad term and refers to an acquired condition that results in temporary or permanent alteration in brain function. GCS is frequently used to classify TBI as mild (14–15), moderate (9–13), and severe (3–8).[1] The GCS is not as well validated for pediatric populations nor does it hold the same prognostic value as for adults.[2,3]

In the United States, the primary cause of death for individuals aged 0 to 14 years of age is unintentional injury, with TBI the injury most often associated with death.[4,5] This population group is estimated to experience more than 500,000 TBI events per year, the majority caused by falls and being struck by or against an object.[6,7] From the 2001 to 2002 to 2009 to 2010, the number of TBI-related ED visits doubled for patients aged 0 to 4 years of age.[8]

Nonaccidental trauma (NAT) was responsible for 80% of serious or fatal TBIs.[9] Nationwide, this leads to approximately 800 deaths annually.[10] (For more information regarding NAT, see Paul Kim and Richard A Falcone's article, "Non-accidental Trauma in Pediatric Surgery," in this issue).

Relevant Anatomy and Pathophysiology

Commonly used nomenclature for TBI includes intra-axial and extra-axial. Intra-axial lesions refer to injuries of the brain parenchyma and include diffuse axonal injury (DAI), contusions, infarctions, and cerebral edema. Extra-axial injuries are outside the brain parenchyma and contain skull/facial fractures and hemorrhage (epidural, subdural, and subarachnoid).[11,12]

Although contusions and infarctions are more discrete injuries, DAI (also referred to as traumatic axonal injury) involves larger portions of the brain, although not necessarily uniformly. DAI occurs when the brain experiences angular, or rotational, forces causing a shearing effect on neurons.[11,12]

A few interrelated concepts must be discussed to understand normal brain physiology and the perturbations that are associated with TBI. The Monro-Kellie doctrine states that the cranial vault contains a fixed volume, and the sum of the volumes of the brain, intracranial blood, and intracranial cerebrospinal fluid is constant. The brain is relatively incompressible and the blood and cerebrospinal fluid volumes vary. In children, prior to fusion of the fontanels, there is some expansion in the cranial volume.[13,14] Furthermore, newer research suggests that in intracranial hypertension (ICH), excessive pressure is not equally exerted on all portions of the brain.[15]

Damage to the brain may occur not only as a result of the primary injury but also from postinjury factors, such as hypotension, hypoxemia, pyrexia, hypoglycemia, and cerebral edema (secondary injury). Secondary insults vary in both preventability and reversibility and may result from both systemic and intracranial factors.[16,17]

Cerebral perfusion pressure (CPP) is defined as the difference between the mean arterial pressure and the intracranial pressure (ICP). Generally, the ideal CPP is 70 mm Hg for an adult patient.[18] Children are known, however, to have greater tolerance of low CPP and the ideal CPP is unclear for children. The youngest children tolerate the lowest values off CPP, with the ideal value falling between 30 mm Hg and 40 mm Hg.[19]

Cerebral blood flow (CBF) is maintained over a wide range of both CPP and ICP. As a function of systolic blood pressure, CBF is maintained when SBP ranges from 60 mm Hg to 150 mm Hg through autoregulation. Autoregulation of CBF may be perturbed by trauma, hypoxia, or hypercarbia.[17,20]

Important physiologic differences between adults and children include greater elasticity of the cranial vault and tolerance of lower CPP in the pediatric population.

Clinical Presentation and Examination

The initial evaluation of all trauma patients, including patients with suspected head or cervical spine trauma, should adhere to the American College of Surgeons Advance Trauma Life Support algorithm and begin with a primary survey of the airway, breathing, circulation, and neurologic disability, followed by a secondary survey. During the secondary survey, a full neurologic examination should be performed, including calculation of the GCS. **Box 1** summarizes the common signs and symptoms seen in children with a TBI.[21] In addition, a thorough history of present illness and past medical history should be taken with attention paid to factors that are associated with clinically significant TBI (**Box 2**).[21]

Diagnostic Evaluation

Computed tomography scan

The noncontrast head computed tomography (CT) scan is the default imaging modality in TBI because it is an excellent tool to evaluate for both intra-axial and extra-axial hemorrhage, brain herniation, and skull and facial fractures. The short period of time required to perform a head CT allows for rapid identification and treatment of life-threatening lesions.[12] **Fig. 1** depicts a right-sided epidural hematoma that is easily identified on CT scan in a 2-year-old who sustained a fall from height onto a tile floor.

For patients with severe TBI, there is strong evidence supporting the use of head CT to rule out serious intracranial pathology.[22,23] For patients with mild or moderate TBI, however, the data are less clear and at times conflicting. There is considerable debate as to the significance of historical features, such loss of consciousness and amnesia, and physical examination as well as what role these should play in the decision to order a head CT.[12,24–28]

That said, Lee and colleagues[28] conducted a multicenter prospective study of more than 40,000 children aged 0 to 18 years who presented to the ED with minor, blunt head trauma and a GCS of 14 or 15 with no other physical examination findings. Those with loss of consciousness did not have a statistically significant higher rate of clinically significant TBI and thus routine head CT for this patient population was not recommended. The American College of Radiology has generated guidelines that recommend a noncontrast head CT in cases of suspected or confirmed NAT.[29]

All these considered, reasonable indications for head CT are listed:

- GCS less than 13
- Minor trauma combined with neurologic deficits or evidence of basilar skull fracture

Box 1
Signs and symptoms of traumatic brain injury

Clinical findings in traumatic brain injury

Altered mental status

Loss of consciousness

Headache

Emesis

Neurologic deficit

Skull fracture

Data from National Clinical Guideline Centre (UK). Head injury: triage, assessment, investigation and early management of head injury in children, young people and adults 2014.

Box 2
Prognostic factors associated with clinically significant traumatic brain injury

Loss of consciousness

Amnesia

Preceding drug/alcohol use

Anticoagulant use

History of bleeding diathesis

Mechanism of injury (high vs low energy)

Emesis

History of neurosurgery

Data from National Clinical Guideline Centre (UK). Head injury: triage, assessment, investigation and early management of head injury in children, young people and adults 2014.

- High-energy mechanism
- Suspected or confirmed NAT

Repeat head computed tomography

It is common practice at many institutions for routine, serial head CT scans to be obtained on patients with head injuries. Whether as inpatient, or in the ED, repeat head CT scan should be reserved for patients who have experienced a change in their

Fig. 1. Epidural hematoma sustained in a 2-year-old who presented with lethargy and emesis following a fall from standing height.

neurologic examination.[30–32] For those with diagnosed intracranial injury, it is recommended to collaborate with a neurosurgeon for the timing of any additional imaging.

Magnetic resonance imaging

Indications for MRI include TBI with symptoms that are not explained by head CT findings, in particular DAI, as well as subacute injuries with neurocognitive deficits.[11,12,29] Rapid-sequence MRI may be used to supplant follow-up head CT in brain injured children, to decrease the radiation burden. Again, imaging studies should be ordered only after consultation with neurosurgery or neurology.

Management

As discussed previously, the definitive management of TBI typically is not undertaken by a pediatric surgeon in the trauma setting. Pediatric surgeons should, however, initiate management of the brain injury awaiting arrival of a neurosurgeon should the occasion arise. This section briefly covers management of 2 extremes of TBI: (1) those with minor injuries warranting discharge and (2) those with severe injuries that may require immediate intervention on the part of the pediatric surgeon to minimize secondary injuries as well as death or serious disability due to ICH and the risk of subsequent herniation.

Minor traumatic brain injury

In the absence of concern for NAT, asymptomatic patients may be safely discharged home from the ED if imaging reveals the following[33–39]:

- Normal imaging
- An isolated, linear, nondisplaced skull fracture not involving the skull base

These patients, however, likely benefit from neurocognitive evaluation both prior to ED discharge and as an outpatient.[40]

Severe traumatic brain injury

A major cause of secondary brain injury in trauma patients is brain hypoperfusion and hypoxia due to systemic hypotension. Although CPP goals for pediatric patients have been established, it is unlikely that an ICP monitor will have been placed when the patient is first evaluated by a pediatric surgeon. Therefore, maintenance of normal blood pressure is the goal. Adult literature has suggested that traditional SBP goals are inadequate, and target SBP should be approximately 120 mm Hg.[41,42] Unfortunately, equivalent values are not available for pediatric patients. Therefore, the recommendation is to maintain SBP near the upper limit of normal for a patient's age group.

Furthermore, ICH can raise the ICP and is another significant cause of secondary brain injury, herniation, and death. The gold standard for measurement of ICP is the placement of an invasive monitor into one of the lateral ventricles.[14] This luxury is often not afforded in the trauma bay and, therefore, presumptive diagnosis, and subsequent treatment, of ICP is initially based on physical examination, imaging, and clinical suspicion. The brain herniation syndromes (subfalcine, tonsillar, and uncal) are traditionally associated with increased ICP and may occur independently of ICH.[43] There are no rigorous criteria or thresholds for treatment of suspected ICH in the ED or trauma bay setting; however, initial management includes the following[44]:

- Intubation for children with severe TBI or GCS less than 8
- Avoiding hypoxia
- Avoiding hypercarbia
- Avoiding hypotension

- Avoiding hypothermia
- Pediatric ICU admission

There is no consensus on ICP treatment thresholds, even in children who have an invasive monitor; however, level 3 recommendations were made to support an ICP treatment threshold of 20 mm Hg and a CPP threshold greater than 40 mm Hg in children.[45,46] A survey of ED physicians demonstrated that a majority would administer a hyperosmotic solution for severe TBI with reactive mydriasis, midline shift on head CT, or compression of the skull base cisterns on head CT.[47]

In adult patients, hypertonic saline in is the first-line pharmacologic therapy for management of ICH. Unfortunately, solution concentrations (3%–23.4%) and doses vary and pediatric experience is more limited.[43,48–51] If treatment is administered in the setting of impeding herniation, hypertonic saline (3% saline 3–10 mL/kg bolus) should be the first-line agent administered in addition to 30° head of bed elevation and midline head placement.[44] Emergent neurosurgical consultation should be obtained and the use of additional hyperosmolar agents, sedatives, analgesics, and anticonvulsant therapy should be discussed with the neurosurgeons and intensivists involved in a patient's care.

A Cochrane Library review of the literature concerning adults with TBI recommends against the routine use of corticosteroids in patients with TBI.[52] Pediatric guidelines also recommend against the use of steroids for ICP management, because it has been demonstrated that they have no effect on ICP, CPP, or outcome and are associated with an increase in infections.[44]

Clinical Outcomes

Clinical outcomes in pediatric TBI are clouded by varied study methodologies and limited standardization for categorizing postinjury function. Furthermore, few studies were conducted in a longitudinal fashion and publications have drawn conflicting conclusions.

A meta-analysis from Babikian and Asarnow[53] of 28 pediatric TBI publications revealed that patients who experienced mild TBI tend to not suffer any neurocognitive impairments in the short term or long term (24 months or greater). Those with moderate TBI tended to have persistent deficits and had worse outcomes than those with mild TBI but fared better than the severe TBI group. The analysis did not capture a difference in outcomes based on age at injury. There were studies included, however, in the meta-analysis that demonstrated worse outcome in those suffering TBI at an earlier age. Compared with adults, children 15 years of age or younger who suffered a TBI had improved mortality and functional outcomes.[3]

A longitudinal study conducted by Rivara and colleagues[54] demonstrated that patients who have persistent disability at 24-month postinjury follow-up do not show interval improvement at 36-month evaluation.

Several studies have demonstrated the impact of home life and background on patient outcome, independent of injury severity. Negative prognostic factors include low household income, lack of parent formal education, Medicaid insurance, Hispanic ethnicity, mental health of the caregiver, and functionality of the family.[55,56]

Not only are pediatric TBI patients at risk for failing to return to their preinjury baseline neurologic function, they also are at risk for development of postinjury psychiatric disorders.[57] Severity of illness is correlated with the likelihood of development of psychiatric disorder, but even children with mild TBI were at risk of psychiatric disorder development compared with a cohort of patients with an orthopedic injury.

Finally, patients who suffered TBI as a result of NAT experienced higher morbidity and mortality than those injured via unintentional mechanisms.[58,59]

Summary

- TBI is a significant source of morbidity and mortality in children.
- Indications for noncontrast head CT in the ED to evaluate for TBI include GCS less than 13, lower-energy mechanisms when combined with neurologic deficits or evidence of basilar skull fracture, high-energy mechanisms, and suspected or confirmed NAT.
- Patients with normal imaging and examination may be discharged from the ED and do not require observation.
- Immediate management of severe TBI includes maintenance of normal P_{CO_2}, normal oxygenation, and normal blood pressure with possible administration of hypertonic saline for signs of ICH. Corticosteroids should not be given.
- Outcomes in pediatric TBI patients are related to injury severity, presence of NAT, and socioeconomic background.

CERVICAL SPINE EVALUATION

Introduction

CSIs are estimated to occur in 1% to 2% of all pediatric trauma patients.[60–62] The incidence in very young patients, less than or equal to 5 years old, is estimated to be much less (0.4%).[63] Although unusual, CSIs can have serious consequences, including death and permanent disability[64]; 5% to 10% of patients with missed injuries develop worsening of neurologic symptoms or complete disability, reinforcing the importance of accurate diagnosis of CSI.[65] Anatomic differences between the adult and pediatric cervical spine pose a unique challenge during the evaluation and management of CSIs in children. In children without neurologic deficits, clearance of the cervical spine is not an emergency and, if unable to be cleared on arrival, children should be maintained in a properly fitted cervical collar, awaiting resolution of the urgent atmosphere that accompanies a trauma evaluation prior to reexamination. This strategy allows clinical clearance of many children without imaging. This article examines the characteristics of pediatric CSIs and an approach to the diagnostic evaluation of the pediatric cervical spine.

Relevant Anatomy and Pathophysiology

Pediatric anatomy

The cervical spine is the most common location for spinal injuries in children, accounting for 60% to 80% of spinal injuries compared with 30% to 40% of spinal injuries in adults.[60,66] Patient age also affects the location of injury. Injuries to the cervical spine in children less than 8 years of age are more likely to occur in the upper cervical spine, from the occiput to C3, and are more likely to be ligamentous as opposed to bony fractures.[67,68] In younger patients, the hypermobile and elastic cervical vertebral column can stretch as much as 2 inches without fracturing, whereas the spinal cord can only stretch 0.25 inches, predisposing children to a greater proportion of dislocations and spinal cord injury without radiographic abnormality (SCIWORA).[69,70] After the age of 8 to 10 years, the pediatric spine completes its maturation process and begins to take on adult characteristics and patterns of injury, including fractures and injuries to the lower cervical spine.[60,70,71] **Table 1** illustrates the unique characteristics of the pediatric cervical spine.[60,67,68,72,73] Certain conditions, including Down syndrome, mucopolysaccharidosis, achondrodysplasia, and os odontoideum (a congenital abnormality where the odontoid process is separated from the body of the axis by a transverse gap), are associated with spine abnormalities and an increased risk of CSI.[66,74]

Table 1
Unique characteristics of the pediatric cervical spine injuries

Structure	Anatomic Considerations in Children Greater Than 8 y of Age
Occiput	Larger occiput-to-body ratio, smaller occipital condyles, more horizontal orientation of atlanto-occipital joints
Musculature	Weak nuchal muscles
Fulcrum	Fulcrum of motion at C2–C3 in comparison to C5–C6 in mature cervical spine
Ligaments, joints, and joint capsules	Incomplete ossification, more lax and stretchable ligaments and joints, susceptible to pseudosubluxation
Facets	Shallow and angulated facet joints
Vertebral bodies	Physiologic anterior wedging of vertebral bodies
Uncinate processes	Absent uncinate processes
Spinous processes	Underdeveloped spinous processes

Data from Refs.[60,67,68,72,73]

Normal variants

Familiarity with the pediatric vertebral architecture is important to differentiate fusion abnormalities or incomplete ossification from pathologic fracture. Common ossification sites and time to normal fusion are presented in **Table 2**.[67] Unlike epiphyseal plates, which appear sclerotic, smooth, and in predictable locations, fractures are irregular in appearance, nonsclerotic, and in unusual locations.[67]

Clinical Presentation and Examination

Mechanism of injury

Adults and children less than 8 years old with CSI are more frequently injured in motor vehicle crashes (MVCs) and falls, whereas sports-related injuries predominate in older children.[60,61,75,76]

Table 2
Embryologic considerations in imaging the developing pediatric spine

Level	Ossification Centers	Time to Maturation
C1	3 Ossifications sites: anterior arch and 2 neural arches	Anterior arch ossification: 1 y Posterior fusion of neural arches: 3 y Anterior arch and neural arch fusion: 7 y
C2	4 Ossification sites: 2 odontoid and 2 neural arches, 1 body	Odontoid process: fuses midline in 7th fetal month. Second ossification center at apex (os terminale) appears between 3 y and 6 y and fuses by age 12 Posterior fusion of neural arches: 2–3 y Fusion of neural arches and body: 3–6 y
C3-7	3 Ossifications sites: 1 body and 2 neural arches	Posterior fusion of neural arches: 2–3 y Fusion of neural arches and body: 3–6 y Secondary ossification sites: tips of transverse processes and at the superior and inferior vertebral bodies may persist into adulthood

Data from Lustrin ES, Karakas SP, Ortiz AO, et al. Pediatric cervical spine: normal anatomy, variants, and trauma. Radiographics 2003;23(3):539–60.

NAT must be in the differential diagnosis when evaluating young patients with CSI. Abuse should be suspected in any child with a whiplash mechanism of injury.[61] In a retrospective review of 342 children with spinal injuries admitted to a level 1 trauma center, Knox and colleagues[77] evaluated the characteristics associated with spinal trauma secondary to NAT. NAT accounted for 3.2% of spinal trauma, and all children with spinal injuries secondary to NAT were under the age of 2 years. In this series, NAT and MVC were equally common mechanisms of injury in children less than 2 years old. A majority of these children (73%) sustained injuries to the cervical spine, and ligamentous injuries predominated. In addition, 91% had at least 1 other significant injury, with head injuries predominating.[77] It is important that NAT is not overlooked as a potential cause of CSI in very young patients, and other injuries are investigated in the evaluation of these patients.

Prehospital management

All unconscious children, children with injuries cephalad to the clavicles, or children involved in a high-speed MVC, are assumed to have a CSI.[72] Proper immobilization of the cervical spine is of key importance in the prehospital management of children with suspected CSI to prevent further injury. Children should be placed in a cervical collar and backboard immobilization and have their torso elevated or the head placed in a cervical recess to maintain neutral cervical alignment (see **Fig. 1**).[73,75,78]

Clinical examination

It is essential to perform a thorough history and physical examination, including a complete neurologic examination, in any child who presents with concerns of a CSI. Patel and colleagues[69] emphasized the importance of the physical examination in a retrospective review of 1098 children with CSIs. In this series, 50% of children with symptomatic spinal cord injury identified on physical examination had no radiographic findings (SCIWORA), highlighting the importance of a timely and complete neurologic examination to identify spinal cord injury early and prevent the extension of a partial neurologic deficit to a complete one. Furthermore, certain history and physical examination findings may alert a physician to the possibility of CSI in children. Leonard and colleagues[79] reviewed 540 cases of children less than 16 years of age across 17 hospitals in the Pediatric Emergency Care Applied Research Network and identified 8 factors associated with CSI, which are detailed in **Box 3**. The presence of 1 or more factors had a 98% sensitivity (95% CI, 96%–99%) in detecting CSI.[79]

Box 3
Risk factors associated with pediatric cervical spine injury

Altered mental status

Focal neurologic findings

Neck pain

Torticollis

Substantial torso injury

Preexisting conditions predisposing to CSI

Diving mechanism

High-risk MVC

Data from Leonard JC, Kuppermann N, Olsen C, et al. Factors associated with cervical spine injury in children after blunt trauma. Ann Emerg Med 2011;58(2):145–55.

Diagnostic Evaluation

Clinical prediction rules

There are several well-validated clinical prediction rules in adult cervical spine trauma that, when applied correctly, can identify patients that are at low risk for a CSI and do not need additional imaging. Applying these decision-making tools to children, especially very young children, poses a unique challenge to the examining physician. Fear and anxiety may be confused with pain, and a child may not be developmentally able to follow instructions or communicate with a provider, further complicating the picture. Additionally there is no single, well-defined clinical prediction rule for children.

The most commonly cited clinical adult decision tools are the National Emergency X-Radiography Utilization Study (NEXUS) decision tool and the Canadian C-Spine Rule (CCR). NEXUS consists of 5 low-risk criteria that, when absent, make CSI unlikely and usually obviate additional imaging in adult patients, with a sensitivity of 99% (95% CI, 98%–99.6%).[80] The CCR asks 3 questions, none of which relies on physical examination findings and, when applied in hemodynamically stable and alert adult patients, had a 100% sensitivity (95% CI, 98%–100%) in detecting clinically significant CSI.[81] A comparison of the NEXUS low-risk criteria and the CCR is presented in **Table 3**. Stiell and colleagues[82] compared the NEXUS decision tool to the CCR and found that the CCR was more sensitive (99.4% compared with 90.7%) and specific (45.1% compared with 36.8%) than the NEXUS criteria when applied to stable, alert adults. Furthermore, the CCR was superior to NEXUS on secondary analysis of indeterminate patients.

In 2001, Viccellio and colleagues[83] applied the NEXUS decision tool to children less than 18 years old. Of the 3065 patients examined, 30 were found to have a CSI. Of the 603 patients who met the low-risk criteria, none had a CSI, resulting in a sensitivity of 100% (95% CI, 87.8%–100%). Unfortunately, when further examining the sensitivity of the tool, the CI was wide, and, in addition, there were only 4 injured children who were less than 9 years old and none less than 2 years old. The investigators cautioned the application of this tool in infants and children, despite the initial apparent success in the pediatric population.

Table 3
A comparison of the National Emergency X-Radiography Utilization Study low-risk criteria and the Canadian C-Spine Rule

National Emergency X-Radiography Utilization Study Criteria	Canadian C-Spine Rule
No midline cervical tenderness	Is there any high-risk factor present that mandates radiography (ie, dangerous mechanism)?
No focal neurologic deficit	Is there any low-risk factor present that allows safe assessment of range of motion (ie, position in ED, ambulatory at any time since injury)?
Normal alertness	Is the patient able to actively rotate neck 45° to the left and right?
No intoxication	
No painful distracting injury	

Data from Hoffman JR, Mower WR, Wolfson AB, et al. Validity of a set of clinical criteria to rule out injury to the cervical spine in patients with blunt trauma. National Emergency X-Radiography Utilization Study Group. N Engl J Med 2000;343(2):94–9; and Stiell IG, Wells GA, Vandemheen KL, et al. The Canadian C-spine rule for radiography in alert and stable trauma patients. JAMA 2001;286(15):1841–8.

Several years later, Ehrlich and colleagues[84] applied the NEXUS low-risk criteria and the CCR to case-matched patients less than 10 years old. They concluded that neither rule was sensitive or specific enough for that age group.

To address the challenge of clinical clearance in young patients, Lee and colleagues[85] recruited a multidisciplinary team to design a cervical spine clearance algorithm for children less than 8 years old. Ten criteria were defined:

1. Unconscious patient or patient with abnormal neurologic examination
2. High-risk mechanism of injury (high-speed motor vehicle collisions [MVC], falls greater than body height, and so forth)
3. Neck pain
4. Focal neck tenderness or inability to assess secondary to distracting injury
5. Abnormal neurologic examination findings after complete examination
6. Transient neurologic symptoms suggestive of SCIWORA
7. Physical signs of neck trauma
8. Unreliable examination secondary to substance abuse
9. Significant trauma to the head or face
10. Inconsolableness

Presence of 1 or more of these criteria resulted in cervical spine imaging. The application of the clearance algorithm resulted in no missed injuries and a reduction in the time to cervical spine clearance in both intubated and nonintubated children.[85]

Nonverbal infants and toddlers pose an even greater challenge when it comes to clinical clearance. Pieretti-Vanmarcke and colleagues[86] sought to determine if there were any clinical indicators of CSI in children less than 3 years old and were able to identify 4 independent predictors, which are presented in **Table 4**. Each predictor was assigned a score, and a total score of 0 or 1 had a negative predictive value (NPV) of 99.93% (95% CI, 99.85%–99.97%) and a sensitivity of 92.9% (95% CI, 85.1%–97.3%) in ruling out CSI without additional imaging. CSI were identified in 83 of the 12,537 patients in this study. Of these, 5 children with significant injuries scored less than 2, which would have been missed with this prediction model; however, all children with missed injuries had neck splinting or evidence of facial or skull fractures on physical examination.[86] This study reinforced that well-applied clinical prediction rules are efficacious, even in infants and toddlers, but they cannot take the place of a well-performed clinical examination.

In summary, it is possible to rule out CSI clinically in many but not all children. A combination of the NEXUS and CCR can be used. At minimum, screening cervical

Table 4
Independent clinical predictors of cervical spine injury in children less than 3 years of age and assigned score*

Clinical Finding	Score
GCS <14	3 Points
GCS_{EYE} = 1	2 Points
Motor vehicle accident	2 Points
Age 2 y or older (24–36 mo)	1 Point

* A score of 0–1 points was associated with a low risk of CSI.
Data from Pieretti-Vanmarcke R, Velmahos GC, Nance ML, et al. Clinical clearance of the cervical spine in blunt trauma patients younger than 3 years: a multi-center study of the american association for the surgery of trauma. J Trauma 2009;67(3):543–9. [discussion: 549–50].

spine imaging should be obtained in all unconscious children and conscious children who present with the following[78,84,86]:

- After a fall from 10 feet or greater (or body height if <8 years)
- MVC
- Suspected NAT
- GCS <14 (GCS_{EYE} = 1 if <3 years)
- Neurologic deficit
- Significant head, face, or neck trauma
- Neck pain or torticollis
- Distracting injury or intoxication

Plain radiographs

After clinical stratification, the ideal imaging strategy in pediatric CSI identifies injuries while minimizing cumulative radiation dose and subsequent risk of malignancy. Plain radiographs are the initial screening tool of choice for children who cannot be clinically cleared. There is controversy over what films should be obtained. In small children, the sensitivity of a lateral film alone is 73% but increases to 93% in children over 8 years of age.[70] Because of this, the anteroposterior (AP) film is often included and has resulted in an increase in sensitivity to greater than 90%, although other reports indicate that the addition of the AP film is unlikely to increase sensitivity.[68,70,87] The role of the odontoid view is also controversial and likely unnecessary in children less than 9 years of age, because most dens fractures in this age group re visible on the lateral film.[68] It is important to visualize the entire cervical spine on lateral film (C1–C7) to avoid delays and the associated untoward consequences of a missed CSI. There is little role for oblique or flexion/extension films acutely in the setting of normal lateral and AP films.[64,68,70]

Computed tomography

The use of CT to screen for CSI is associated with high doses of ionizing radiation, and the risk of malignancy is not inconsequential. Children, especially girls, are disproportionally more sensitive to the adverse effects of ionizing radiation, and this risk decreases linearly with age.[88,89] Although CT has been reported to be more sensitive in detecting CSI compared with plain films, most clinically significant injuries in children found on CT are also noted on plain film.[70] Additionally, young children are more likely to have ligamentous injury, which is not identified on CT. A focused CT can limit radiation and may be indicated to clarify abnormalities identified on plain films.[90] MRI may be the imaging modality of choice for children less than 8 years of age, because the incidence of identifying a clinically significant fracture on CT not present on radiograph is low, and there is an increased risk of developing radiation-induced cancer, particularly to the thyroid gland.[76,91,92] **Fig. 2**A depicts a C2 fracture in a 16-month-old who was involved in an MVC. The patient then underwent MRI (see **Fig. 2**B), which revealed an unstable C2 fracture with disruption of the interspinal ligament and the anterior and posterior longitudinal ligaments from C2 to C3 as well as cord contusion from C2 to C7, which was not apparent on CT. The patient was placed in halo traction and review of the postoperative lateral film (see **Fig. 2**C) reveals the C2 fracture that would have easily been identifiable had this patient had an initial screening lateral cervical spine film.

MRI

MRI of the cervical spine is the best imaging modality for the diagnosis of soft tissue injuries, such as ligamentous injuries, cord edema or hematoma, cord transections, and cord compression.[93] In a meta-analysis of adult blunt trauma patients, Muchow and colleagues[94] demonstrated a high sensitivity (97.2%, 95% CI, 89.5%–99.35%)

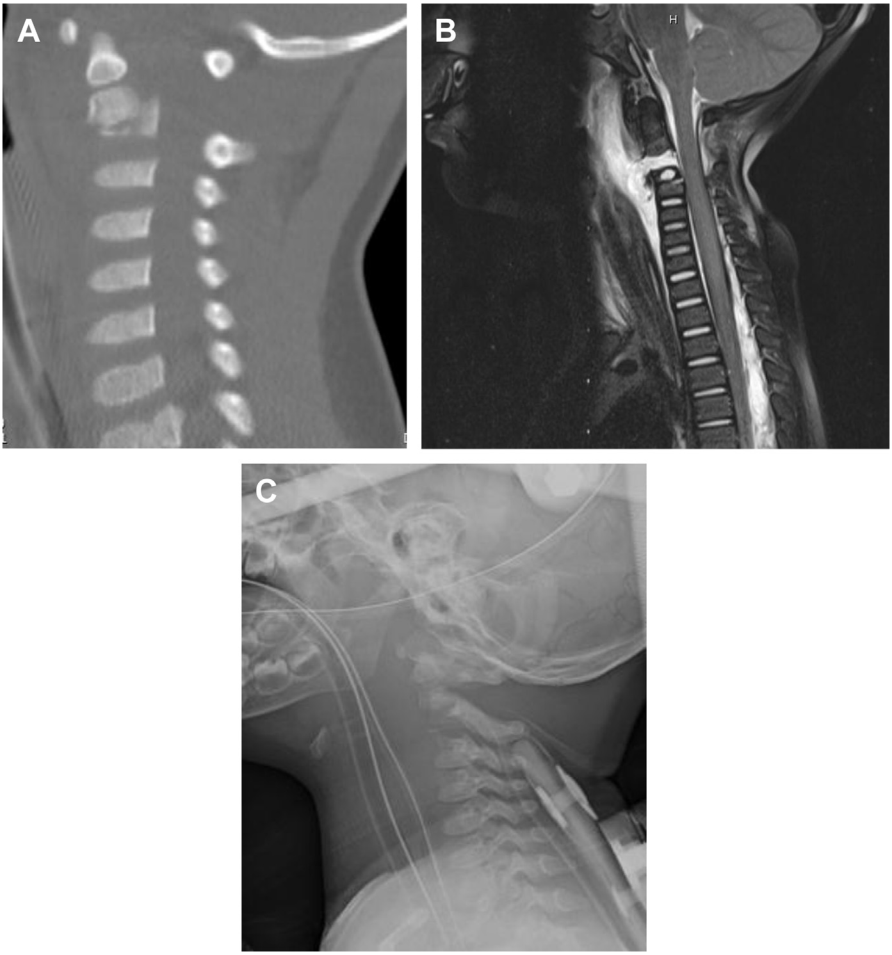

Fig. 2. (*A*) C2 cervical spine fracture depicted on initial CT obtained in a 16-month old girl after a motor vehicle accident. (*B*) An MRI was obtained in this child that further revealed an unstable C2 fracture with disruption of the interspinal ligament, anterior and posterior longitudinal ligaments from C2 to C3, and cord contusion from C2 to C7, which was not apparent on CT. The fracture was also identified. (*C*) This is a lateral film after halo stabilization, and the cervical spine fracture is clearly seen in this film, highlighting the importance of screening cervical spine films in children, because most bony injuries are identified.

and specificity (98.5%, CI, 91.8%–99.7%) with a 100% NPV, allowing the safe discontinuation of cervical spine precautions without adverse neurologic outcomes. MRI has a sensitivity of 100%, specificity of 97%, and NPV of 75% and, when compared with CT, has a superior sensitivity for the detection of soft tissue injuries.[65] **Fig. 3**A is an example of the importance of a through neurologic examination for identification of soft tissue injuries, regardless of CT findings. The initial cervical spine CT scan on this 3-year-old who was involved in an MVC was normal. The patient, however, had right-sided paresis and an MRI was obtained (see **Fig. 3**B) that revealed a C1–C2 cord contusion and ligamentous injury, and the patient was placed in halo traction the following day.

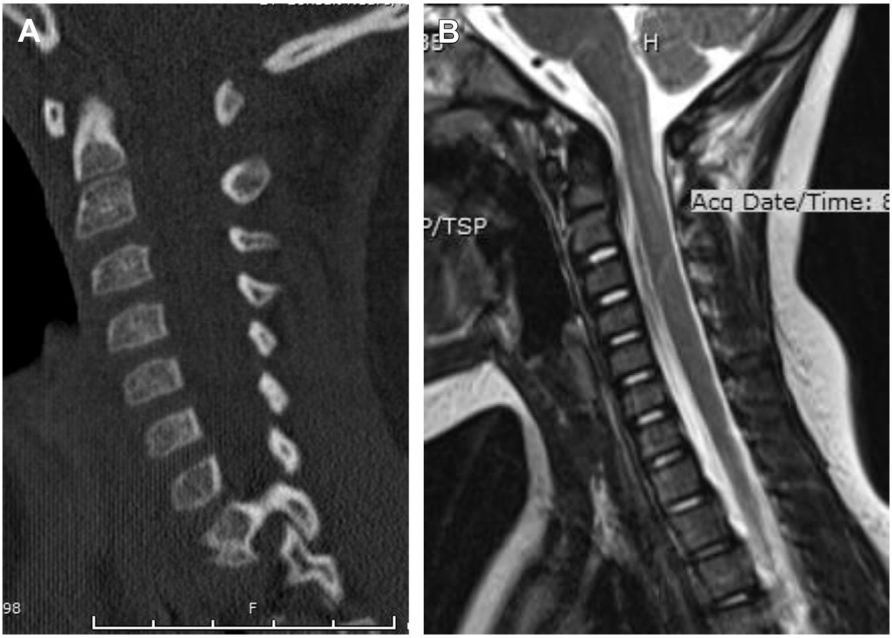

Fig. 3. (*A*) Normal cervical spine CT in a 3-year-old after a motor vehicle accident. (*B*) An MRI was obtained in this patient due to right-sided neurologic findings and revealed a C1–C2 cord contusion and ligamentous injury, underscoring the point that CT scans can be normal and miss the ligamentous injuries that are most common in young pediatric trauma patients. All patients with neurologic findings should undergo MRI.

MRI has a defined role in the clearance of CSI intubated or obtunded children. Frank and colleagues[95] found a decrease in time to cervical spine clearance and a reduction in the duration of ICU and hospital stay with the use of MRI. In any child who is likely to remain intubated or obtunded, an MRI within the first 72 hours is the best way to ensure no clinically significant CSI, even in the presence of normal plain radiographs.[72,96] If the cervical spine is unlikely to be cleared within 72 hours, and the child will undergo brain MRI for trauma, obtaining a cervical spine MRI at that time may also be useful.[61] All children with neurologic symptoms should undergo urgent MRI examination to rule out injuries that would warrant intervention.[64,75]

In 2000, Boston Children's Hospital instituted a cervical spine clearance algorithm for both conscious (**Fig. 4**) and the unconscious pediatric patients (**Fig. 5**) with possible CSI. Over a 10-year study period, the algorithm sensitivity was 94.4% and the NPV was 99.9%. There was only one missed injury that was a stable CSI found in a patient who remained in a collar at hospital discharge. These algorithms, or one similar, can be used in the evaluation children with suspected CSI while minimizing the risk of ionizing radiation (Arbuthnot M, Mooney, DP. Cervical spine clearance in pediatric trauma: a single institution's experience, submitted for publication).

MANAGEMENT

Table 5 outlines common CSIs in pediatric patients.[67] The management of injuries is beyond the scope of this article, but urgent consultation with a spine specialist and traumatologist is required in the setting of diagnosed CSI.

CLINICAL OUTCOMES

Traumatic spinal cord injury in children is a rare event. As discussed previously, the anatomic differences in the cervical spine result in a different pattern of injury in children and there is some evidence that children have a better neurosurgical recovery compared with adults.[97]

The mortality rate associated with spinal cord injury varies from 4% to 41%, and, of survivors, as many as 67% have neurologic deficits.[68] TBI is the most common concomitant injury.[98] Shin and colleagues[99] reviewed a decade of pediatric CSI from the Kids' Inpatient Database and found a 22.05% rate of TBI and determined the mortality rate was 11.07% in children with TBI and 3.14% in non-TBI patients.

In a large retrospective review by Leonard and colleagues,[66] children less than 2 years old had the poorest outcomes with the highest incidence of permanent neurologic damage and death. Patients with atlanto-occipital dislocations or C1–C2 dislocations were the most devastated, and children with axial injuries were 5 times more likely to die than those with subaxial injuries.[66]

Finally, there is insufficient evidence to recommend the use of steroids in CSI.[100] Steroid administration has been associated with worse clinical outcomes, and steroid administration is not recommended in children with spinal cord injuries.[66]

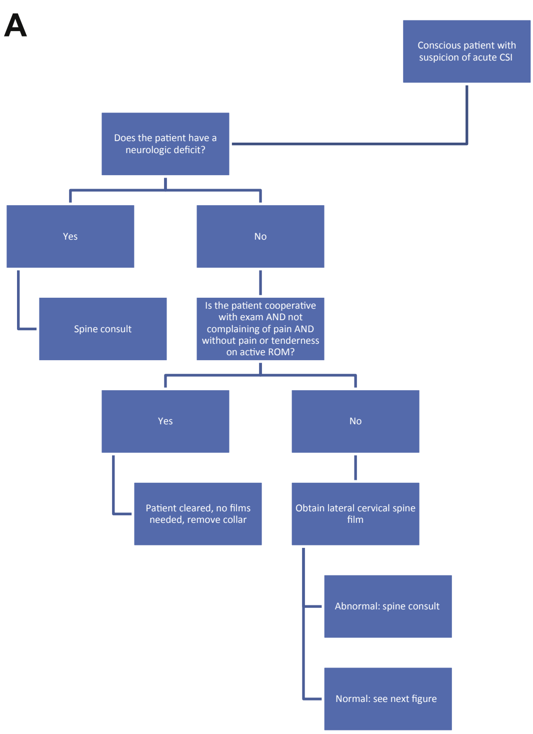

Fig. 4. (*A, B*) Cervical spine clearance algorithm for the conscious patient with concern for CSI. ROM, range of motion.

B

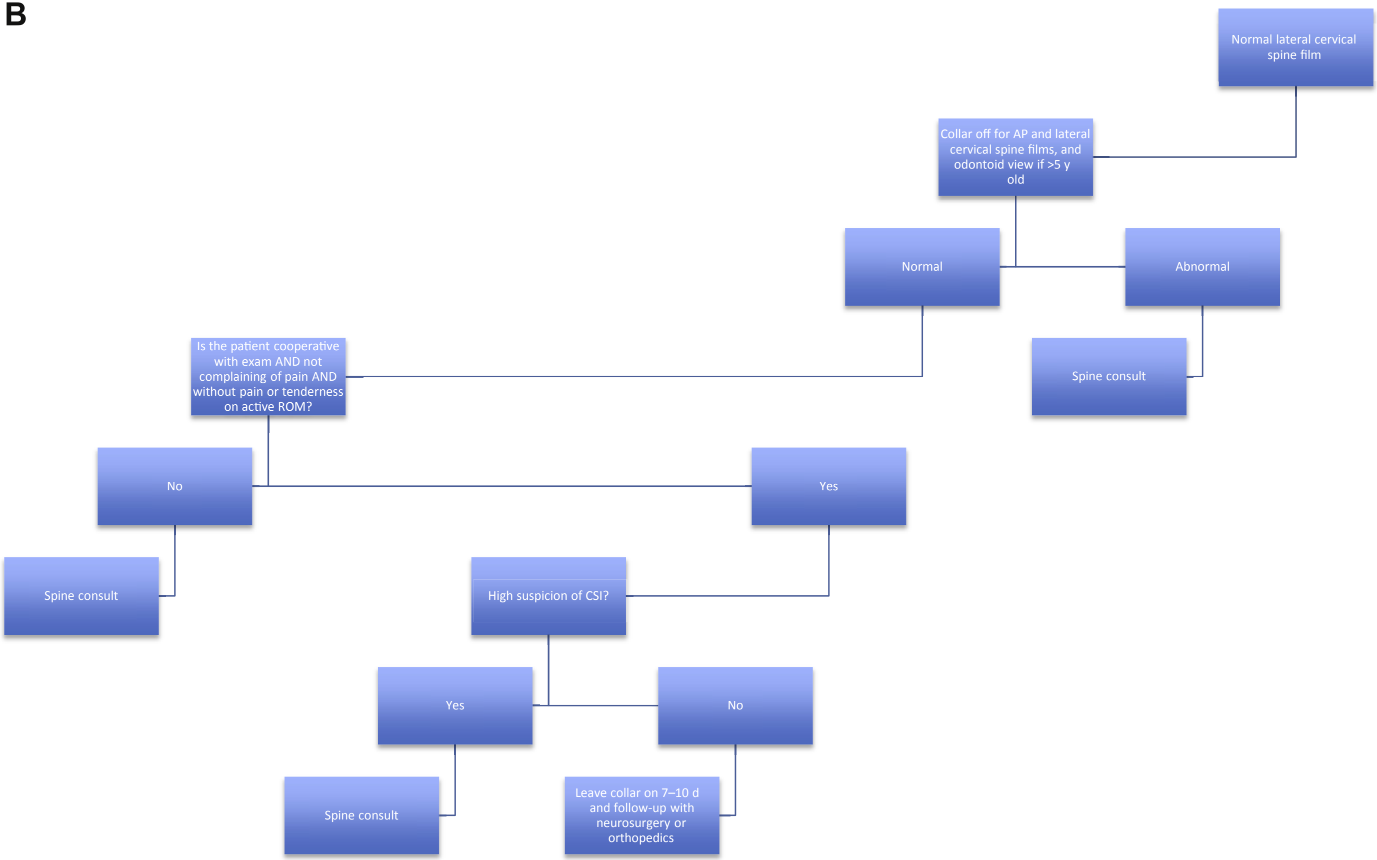

Fig. 4. (*continued*)

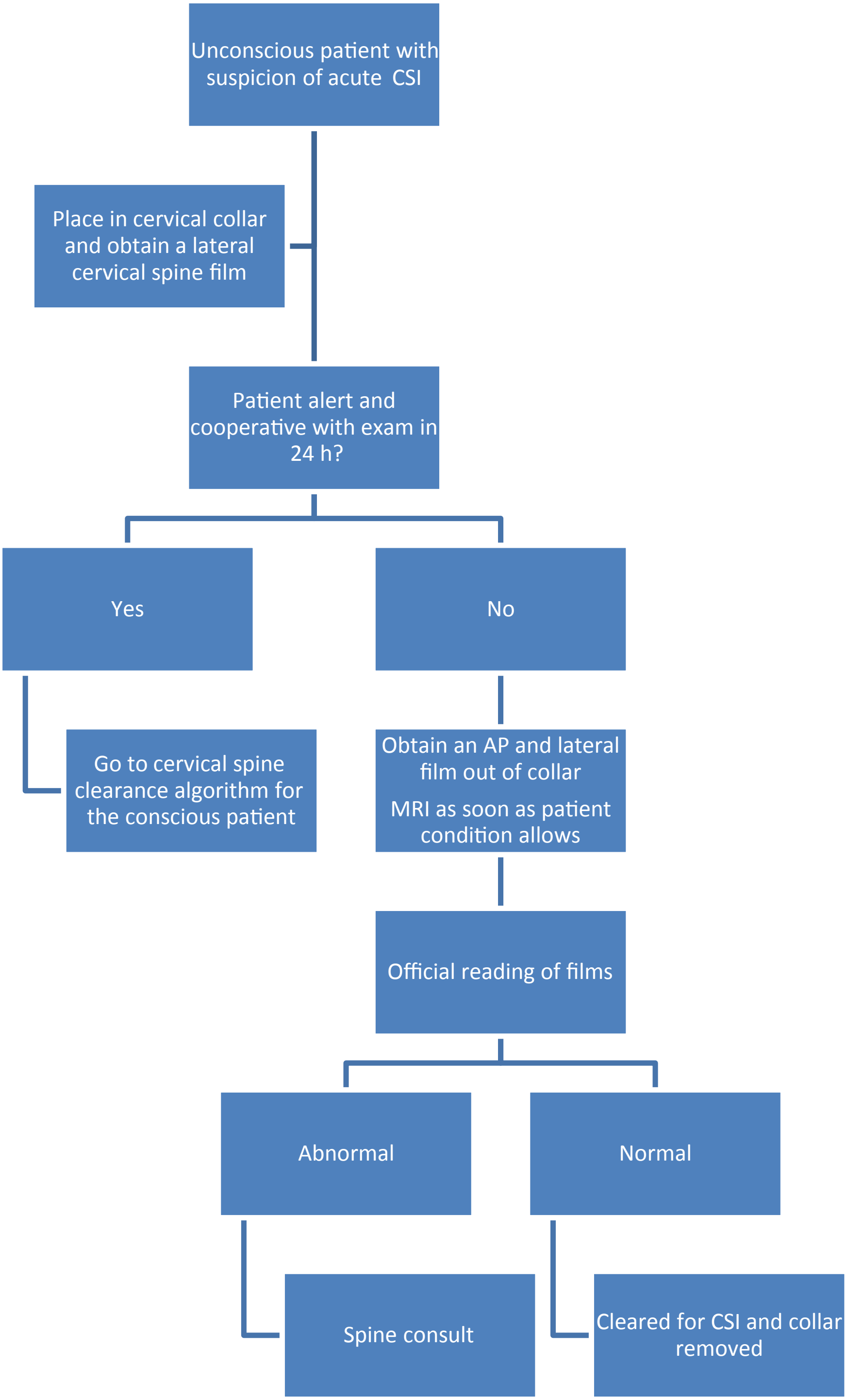

Fig. 5. Cervical spine clearance algorithm for the unconscious patient with concern for CSI.

Table 5
Cervical spine injuries in pediatric patients

Injury	Description
SCIWORA	• SCIWORA is likely related to transient deformation of the spinal column without bony fracture. • Requires MRI to evaluate
Atlanto-occipital injuries	• Associated with deceleration injuries, can be fatal. Atlanto-occipital dislocation is 2.5× more common in children than in adults. • Crucial to evaluate the craniocervical junction on imaging
Jefferson fracture	• Fracture of the ring of C1, due to axial loading injury • Stable when transverse ligament is still intact
Atlantoaxial injuries	• C1–C2 injuries can be due to ligamentous disruption, rotary subluxation, or odontoid separation • Can result in excess cervical rotation and spinal cord injury
Hangman fracture	• Hyperextension injury that results in fractures through the pars interarticularis of C2 and is associated with anterior subluxation of C2 on C3 • Important not to confuse with the normal variant of subluxation in children
Subaxial injuries	C3–C7 injuries are more common in older children and associated with MVC and sport-related injuries
Posterior ligamentous injuries	Diagnosed with MRI and often require operative intervention (posterior fusion)
Wedge compression fractures	• Associated with axial loading and flexion injuries resulting in loss of vertebral height • Usually stable fractures that heal easily
Facet dislocations	• Can be associated with facet fractures • Are unstable when bilateral and often associated with spinal cord syndromes

Data from Lustrin ES, Karakas SP, Ortiz AO, et al. Pediatric cervical spine: normal anatomy, variants, and trauma. Radiographics 2003;23(3):539–56.

SUMMARY

- Children younger than 8 are more likely to have ligamentous injuries located to the upper spine. After the age of 8, the pediatric spine starts to resemble the adult spine and there is an increased incidence of fractures and multilevel injuries.
- MVC, sports-related injuries, and falls are common mechanisms of injury. NAT should be in the differential diagnosis in children less than 2 years old with CSI.
- All unconscious patients and conscious patients who present after a significant mechanism of action or significant trauma to the head should be assumed to have a CSI and placed in proper cervical immobilization.
- Clinical clearance is possible in many children, although in older children it is easier due to improved ability to communicate. All children should undergo a complete neurologic examination.
- Plain radiographs (lateral ± AP) are the screening tool of choice in children who cannot be clinically cleared. The odontoid view can be reserved for children greater than or equal to 9 years old. There is little acute role for the oblique, flexion, or extension views.

- CT is associated with an increased malignancy risk and should not be used as a screening tool for pediatric CSI. It is good at evaluating fractures but cannot diagnose soft tissue or ligamentous injury and, as such, cannot be used solely to clear the cervical spine.
- In children less than 8 years old, an MRI may be the modality of choice to clear the cervical spine if it cannot be cleared clinically. Furthermore, an MRI should be obtained in all patients with neurologic symptoms. In patients who are expected to remain obtunded or intubated for greater than 24 to 48 hours, an MRI within the first 72 hours can be used to clinically clear the spine.
- Outcomes in spinal cord injury are related to age and type of injury. Generally, children have better neurologic outcomes compared with adults. Corticosteroids are currently not recommended in the treatment of pediatric spinal cord injury.
- A cervical spine clearance algorithm may assist in safe cervical spine clearance with a low missed injury rate.

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