Cervical Spine Injury

Julie C. Leonard, MD, MPH

KEYWORDS
- Pediatric • Children • Cervical spine injury

KEY POINTS
- Cervical spine injury is rare, especially in children younger than 8 years.
- Motor vehicle crashes are the most common cause of blunt cervical spine injury in children, although sports-related injuries and falls are also important.
- Violence, including penetrating trauma, is the third leading cause of spinal cord injury in children.
- Altered mental status, focal neurologic deficit, neck pain, torticollis, substantial torso trauma, high-risk motor vehicle crash, diving, and predisposing conditions are factors associated with blunt cervical spine injury in children, and can be used to develop screening guidelines.
- Manual in-line cervical stabilization should be used during intubation of the victim of blunt trauma.
- A rigid collar is an adequate precaution for the cervical spine following blunt trauma.
- The rigid long board should be used as an out-of-hospital extrication and transfer device for those children who are significantly injured. Use of the rigid long board should be discontinued as soon as possible because of its associated risks.
- Three-view plain cervical radiographs are good for screening children who have normal mental status and no focal neurologic findings.
- Children younger than 8 years are more likely to injure their upper cervical spine.
- There is a wide variety of cervical spine injury patterns; the most common injury is atlanto-axial rotary subluxation.
- Spinal cord injury without radiographic association is also common, but may be overreported.
- Mortality in children who sustain cervical spine injury is high.

EPIDEMIOLOGY

Cervical spine injury is uncommon in children, occurring in less than 1% of those evaluated following blunt trauma.\(^1,2\) Furthermore, the age distribution among children with cervical spine injury is skewed toward older children and teenagers, with less than 5%
of injuries occurring in children younger than 2 years. Similar to other types of injury, boys are almost twice as likely to be injured as girls.

Mechanisms of blunt cervical spine injury are diverse. Similar to adults, the most common cause of injury in children is a motor vehicle crash. Another frequent mechanism in children, especially those at younger ages, is being hit by motor vehicles while walking or riding recreational equipment. However, mechanisms with lower biomechanical forces, such as falls in younger children and sports and recreational impacts in older children, can also result in injury. Of recreational activities, diving puts children at greatest risk for cervical spine injury. Child abuse is a rare, but perhaps underreported cause of cervical spine injury. When penetrating spine injury is considered, however, violence is the third most common cause of spinal cord injury among youth.

Furthermore, one-third of outcomes following cervical spine injury are poor in general, with up to one-third of children sustaining neurologic injury. Mortality is directly related to the level of injury, with upper cervical spine injuries carrying 23% mortality versus 4% mortality in the lower cervical spine. The long-term prognosis for those children who sustain cervical spinal cord injury and survive the first 24 hours is poor; life expectancy is reduced by anywhere from 6 to 45 years depending on the level and completeness of injury.

**DEVELOPMENTAL ANATOMY**

Anatomically, the cervical spine is divided into 2 distinct regions: the axial (occiput, C1 and C2) and subaxial (C3–C7). The developmental anatomy of the axial vertebrae is distinct from the subaxial anatomy. The atlas (C1) has 3 primary ossification centers (1 anterior and 2 neural arches), which are associated with cartilaginous joints (synchondroses). The anterior center fuses by the age of 3 and the neural centers fuse by age 7 years, thus forming a solid, bony ring structure. The body of the axis (C2) has the same 3 primary ossification centers as the atlas; however, there is a fourth ossification site at the base of the dens, which fuses by age 11 years.

All of the vertebrae of the subaxial cervical spine (C3–C7) follow the same developmental pattern. Three primary ossification centers occur at each level: a centrum for the body (which fuses by age 6 years) and 2 neural arches (which fuse by age 3 years). Understanding this anatomy helps clinicians to distinguish between pathologic fracture and lucency associated with a synchondrosis.

Secondary ossification centers in the transverse and spinous processes of all vertebrae are present by puberty. Additional growth occurs along the epiphyseal plates of the vertebral bodies. Secondary ossification sites fuse during early adulthood. Compared with those of adults, pediatric vertebrae have anterior wedging of the bodies, absent uncinate processes, and shallow, horizontally oriented facets. Additional developmental considerations that influence the patterns of cervical spine injury in children are a relatively large head size in comparison with the remainder of the body, immature neck and paraspinal musculature, and underdeveloped ligaments. These developmental characteristics result in hypermobility and a fulcrum of motion at the C2 to C3 level, which renders the upper cervical spine more prone to injury. By age 14 years the spine has sufficient support, and soft tissues have sufficiently matured such that the fulcrum migrates to the C5 to C6 level; injuries sustained at this age are similar to those in adults.

**CLINICAL PRESENTATION**

Cervical spine injury is a heterogeneous disease (see the section on injury patterns), therefore so are the clinical characteristics (Fig. 1). Presenting complaints range
**Fig. 1. Clinical signs and symptoms of acute cervical spine injury.**

| Vital signs | • Apnea or hypopnea caused by diminished respiratory drive from injury at C5 or higher.  
| Mental status | • Hypotension without associated bradycardia caused by loss of sympathetic tone from cervical cord injury.  
| Sensory | • Altered mental status: decreased cerebral perfusion and oxygenation from hypopnea and hypotension.  
|         | • Change in pain and temperature sense indicates injury to the anterior cord.  
|         | • Change in position and vibratory sense as well as pinpoint discrimination indicates posterior cord injury.  
|         | • Complete sensory loss is caused by cord transection or nerve root disruption.  
|         | • Paresthesia is an aberrant sensation described as “burning, electric shocks or pins and needles” that is caused by nerve root compression or injury to the posterior spinal cord.  
|         | • L’hermitte’s sign is paresthesia elicited by hyper-flexing/extending the neck.  
| Motor | • Loss of strength or muscle action due to injury or disruption of the efferent pathways in the posterior/lateral spinal cord.  
| Reflexes | • A bulbocavernosus reflex is elicited by a finger into the rectum and squeezing the glans of the penis or the head of the clitoris. A normal response is a reflex contraction of the anal sphincter. Absence represents a complete cord injury.  
|         | • Priapism is associated with complete cord injury thus accompanies absolute motor and sensory paraplegia.  
|         | • Deep tendon reflexes are diminished or absent initially.  
|         | • Babinski present (up going great toe upon stimulation of plantar stimulation).  
| Neck findings | • Neck pain or tenderness localized to the posterior midline neck.  
|         | • Decreased range of motion or torticollis.  
|         | • Cock-robin deformity is a form of torticollis where the head is turned in one direction and tilted toward the other and is associated with atlantoaxial rotatory subluxation.  

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from cervicalgia to respiratory arrest. The findings at presentation help localize the level of injury and degree of spinal cord involvement. In general, findings that are localized to a dermatome indicate injury to a nerve root, whereas sensory and motor loss involving a cervical level and lower indicate injury to the spinal cord. In addition, there are characteristic spinal cord syndromes (Fig. 2).

CLINICAL SCREENING CRITERIA

Given that neck irradiation in childhood leads to tumors in adulthood, especially thyroid cancer, clinicians should limit radiographic imaging to those children at risk for cervical spine injury. The following factors have been identified as being associated with cervical spine injury in children: altered mental status, focal neurologic deficit, neck pain, torticollis, substantial torso trauma, high-risk motor vehicle crash, diving, and predisposing conditions. Although not prospectively validated, these factors are highly sensitive for cervical spine injury and, along with validated adult screening criteria, should serve as the basis for developing clinical guidelines for children. Fig. 3 is a suggested guideline for determining which children warrant diagnostic testing for cervical spine injury following blunt trauma.

INITIAL MANAGEMENT

Those children presenting in traumatic cardiopulmonary arrest should be managed according to Advanced Trauma Life Support (ATLS) guidelines, with prompt attention to gaining control of the airway while observing cervical precautions by maintaining in-line manual cervical stabilization. Once the airway is secured, a rigid cervical collar should be placed. Use of a rigid long board for ease of extrication and transition is appropriate for the immobile or unconscious child in the out-of-hospital setting; however, the child should be removed from the board as soon as possible to avoid adverse effects such as decubitus ulcers. For children who are alert and have more subtle signs of cervical spine injury, a rigid cervical collar alone is sufficient for providing protection against potential worsening of injury. Immobilization of alert and stable children on rigid long boards may cause pain that leads to unnecessary testing.

Use of corticosteroids in the management of pediatric cervical spinal cord injury remains controversial. Although a large, randomized controlled trial in adults found that a regimen of high-dose methylprednisolone (30 mg/kg) over 1 hour followed by a 23-hour infusion (5.4 mg/kg/h) improved neurologic outcome when initiated within 8 hours of injury, this finding has not been replicated and no comparable studies have been conducted in children younger than 13 years. Corticosteroid therapy for spinal cord injury is a therapeutic option, but is not without risk and should be initiated only after consultation with a spine surgeon.

DIAGNOSTIC TESTING

The approach to diagnostic evaluation should take into consideration the clinical presentation (see Fig. 3). Plain radiographs, computed tomography (CT), and magnetic resonance imaging (MRI) are the mainstays of diagnostic evaluation for cervical spine injury. Routine plain radiographs alone are greater than 90% sensitive for bony cervical spine injury and are usually sufficient for screening the alert patient who has a normal neurologic examination. Flexion-extension plain radiography plays a role in evaluating ligamentous stability, but is not useful in screening for acute injury. CT is nearly 100% sensitive for bony cervical spine injury, and is the imaging modality of choice for critically injured children. However, CT may miss up to 4% of
| Anterior Cord Syndrome | Complete motor paralysis  
|------------------------|--------------------------|
|                        | Loss of pain and temperature sensation  
|                        | Preservation of position and vibration sensation  
|                        | Associated with severe flexion injury  
| Central Cord Syndrome  | Diminished or absent upper extremity function  
|                        | Preserved lower extremity function  
|                        | Associated with extension injury  
| Posterior Cord Syndrome| Very rare  
|                        | Associated with spinal artery injury  
|                        | Loss of position and vibratory sensation only  
| Brown-Séquard Syndrome | Hemisection of the spinal cord  
|                        | Ipsilateral loss of motor function and position and vibratory sensation  
|                        | Contralateral loss of pain and temperature sensation  
| Spinal Shock            | Flaccid below level of lesion  
|                        | Absent reflexes  
|                        | Autonomic dysfunction including hypotension and bradycardia  
|                        | Sensation may not be preserved; if absent indicates total cord transection  

Fig. 2. Spinal cord syndromes.
Fig. 3. Guideline for diagnostic evaluation of potential cervical spine injury in children.
ligamentous injuries, some of which are clinically relevant. MRI is nearly 100% sensitive for acute cervical spine injury, including bony, ligamentous, and cord injuries.

Clinicians who routinely evaluate children following blunt trauma should become familiar with plain cervical radiographs. Fig. 4 presents the 3-view series. The lateral view is the most important single view, as it picks up nearly 80% of injuries (see Fig. 4). The anterior-posterior (AP) view allows additional assessment of the overall alignment, the alignment of the spinous processes, and evaluation of the lateral masses, as well as evaluation for subtle signs of fracture and subluxation. The open-mouth view allows evaluation of the dens, and the alignment of the lateral masses of C1 to C2. There are several common pediatric variants that can be mistaken for injury on a plain radiograph. The most common of these are pseudosubluxation and physiologic wedging of the vertebrae (Fig. 5). In addition, given the aforementioned developmental anatomy of the cervical spine, a normal synchondrosis can be mistaken for fracture (Fig. 6A).

INJURY PATTERNS

Because of developmental and structural differences, injuries of the cervical spine are best described by axial and subaxial regions. Young children (less than 8 years) are more prone to injury in the axial region in comparison with older children and adults.

The most fatal of these, atlanto-occipital and atlantoaxial dislocations, occur from high-energy mechanisms that induce acceleration-deceleration motion, which results in excessive motion of the head relative to the cervical spine (Fig. 7).

The most common injury involving the axial region is atlantoaxial rotatory subluxation (Fig. 8), which was first described in the setting of upper respiratory and pharyngeal infections (Grisel syndrome) and later in the settings of trauma and head and neck surgery. "Cock robin" torticollis, characterized by chin rotation to the contralateral side and flexion of the neck, is the characteristic physical examination finding in atlantoaxial rotatory subluxation. Children are in a good deal of discomfort and may have C2 radiculopathy or myelopathy. The ligamentous laxity and robust synovium that are inherent in the pediatric spine predisposes children to these injuries. Because atlantoaxial rotatory subluxation is usually self-limiting, a conservative approach can be taken to evaluating these injuries. For children in whom injury is suspected, screening with plain radiographs is appropriate. If these are normal aside from asymmetric positioning of the dens relative to the lateral masses, and the child does not have focal neurologic findings, a trial of rigid collar, analgesia, and muscle relaxant is warranted. For those children whose symptoms do not spontaneously resolve within 2 weeks, evaluation for atlantoaxial rotatory subluxation requires referral to a spine specialist and dynamic CT (images taken in 3 positions: at rest, in neutral position, and rotated to the opposite side).

Fractures to the atlas (C1) are usually the result of axial-loading compressive force, which causes a burst fracture (typically 4 fracture lines), otherwise known as a Jefferson fracture. Neurologic injury is uncommon with these injuries because the diameter of the spinal canal is large at this level, and burst fragments tend to project outward away from the spinal cord. These fractures are usually stable unless the axis is also fractured or the transverse ligament is disrupted. These injuries are usually detectable on plain radiographs by noting the atlanto-dens interval (ADI) on lateral view. The ADI is normally 5 mm or less in pediatric patients; ADI values in excess of 5 mm indicate disruption and instability of the transverse ligament. The open-mouth view can also be used to assess stability of the transverse ligament: a lateral mass
Fig. 4. Evaluation of routine 3-view plain radiographs.

**Lateral**
- All 7 vertebrae are visible and free of fractures
- All 4 lordotic curves are aligned: anterior vertebral line (anterior margin of vertebral bodies), posterior vertebral line (posterior margin of vertebral bodies), spinolaminar line (posterior margin of spinal canal), posterior spinous line (tips of the spinous processes)
- Atlanto-dental interval ≤0.5mm
- Intervertebral and interspinous spaces are not more than 11° at a single space and no fanning of spinous processes
- Prevertebral soft tissue is less that 6mm at C2 and 5mm at C3-C4
- Atlanto-occipital joint aligned*

*This subject has straightening of their cervical spine due to supine positioning

**Anterior-posterior (AP)**
- Assess longitudinal alignment and symmetry of the vertebral bodies, facets, pillars and spinous processes
- Look for evidence of linear compression fractures, step-offs, subluxations and malalignment

**Open-mouth**
- Assess alignment of the atlantooccipital and atlantoaxial joints
- Evaluate margins for alignment of the lateral masses of C1 with C2
- Assess the odontoid and verify central position between the lateral masses of C1
- Difficult view to obtain in children < 8 years
The overhang of C1 over C2 greater than 6.9 mm indicates disruption of the transverse ligament (the rule of Spence).26,27

The weakest point in the axis (C2) is the cartilaginous subdental epiphysis, which is present until the age of 7 years.26,27 These fractures are infrequently displaced and may be difficult to distinguish from normal anatomy; anterior angulation with fracture helps distinguish the two (see Fig. 6B). Significant displacement of the fractured dens can result in neurologic deficit. True fractures of the odontoid process are seen in older children and adolescents, and are usually caused by mechanisms that cause forceful head and neck flexion.26,27 True dens fractures are classified by their location: type I involve the superior portion of the dens as a result of avulsion of the alar ligament; type II involve the base of the neck, and are rarer and usually associated with C1 fracture (see Fig. 6C); and type III odontoid fractures extend into the body of C2.26,27 Hyperextension of C2 can result in pars interarticularis fractures or “hangman’s fracture.”26,27

Subluxation of C2 on C3 can occur; however, this must be distinguished from pseudosubluxation in this region, which is a common physiologic variant in children (see Fig. 5). In addition, os odontoideum, a congenital anomaly that results in a bony fragment with smooth cortical margins located cranially to the body of the axis with associated small or hypoplastic dens, may be confused with healed type I or type II dens fracture (see Fig. 6D).28 Os odontoideum can be unstable if the cruciate ligaments are disrupted.28

Subaxial injuries are less common until the age of 8 years.2 The structure and biomechanics at these levels (C3–C7) are similar. Compression or burst fractures of the vertebral body are usually the result of axial load mechanisms (Fig. 9).26,27 Compression fractures are usually stable and heal without surgical intervention (see Fig. 9A).26,27 Burst fractures, however, involve retropulsion of bone into the spinal canal, and more frequently require surgical intervention (see Fig. 9B).26,27 Teardrop fractures are avulsion fractures involving the anteroinferior aspect of the vertebral...
body,\textsuperscript{26,27} which result from hyperflexion and involve disruption of the facet joints, the anterior and posterior longitudinal ligaments, and the disk. When identified on radiographs, these injuries should be evaluated for stability using flexion-extension radiographs and/or MRI to assess ligamentous integrity.\textsuperscript{6,7,20} Hyperflexion/extension can result in a variety of other fractures including spinous process, lateral mass,
transverse process, and uncinate, laminar, and pedicle fractures. Physeal fractures or separation of the vertebral body from the end plate through the epiphysis is an injury unique to children, and may require surgical intervention depending on the Salter-Harris type.

Hyperflexion with or without distraction and rotation may result in unilateral or bilateral facet dislocation. Occult ligamentous injury can also occur in the subaxial cervical spine as a result of ligamentous disruption without fracture. Plain radiograph findings suggestive of posterior ligamentous disruption include subluxation movement on flexion-extension views and increased interspinous distance on lateral radiograph. In the acute setting, it may be difficult to distinguish ligamentous injury. For patients with persistent posterior neck pain, it is appropriate to continue cervical precautions for 2 weeks and then reassess.
Fig. 7. Atlantooccipital dislocation (AOD) (A) Lateral plain radiograph status-post emergent halo placement and (B) Sagittal CT image. These images (see arrows) illustrate findings consistent with AOD including displacement of C1 anterior and inferior to the clivus and occipital condyle; and widening of the Occiput-C1-C2 spinous process interspaces. (C) Sagittal T2 MRI demonstrates (see arrow) prevertebral edema, epidural hemorrhage, and disruption of the apical odontoid and transverse ligaments.

Fig. 8. Atlantoaxial rotatory subluxation (AARS) (A) CT reconstruction of a child with AARS involving the right lateral mass; C1 is subluxed anterior to C2 (see arrow). (B) Axial image through the C1-C2 complex illustrating the dens of C2 (see arrow) malaligned posterior and lateral. (C) Axial image caudal to prior image illustrating the arch of C1 (see arrow) subluxed anterior to C2.
Fig. 9. (A) The arrow identifies compression fractures of C5 and C6. Important findings on this lateral plain radiograph include loss of contour and height of the vertebral body and subtle anterior subluxation with preservation of the posterior elements indicating with no retropulsion of fracture fragments into the spinal canal. (B) Burst fracture of C7 illustrated on lateral plain radiograph (left arrow) and sagittal CT image (right arrow). Important findings on the lateral plain radiograph include decreased contour and height of the vertebral body and loss of alignment indicating compromise of the anterior and posterior elements. This also demonstrates the importance of clear visualization of C7 on plain radiographs. The sagittal CT image shows retropulsion of the fracture fragments with clear spinal canal compromise.
Spinal cord injury without radiographic abnormality (SCIWORA) was originally used to describe traumatic myelopathy in individuals with evidence of vertebral injury on plain radiography (including flexion-extension views), myelography, or CT. It is speculated that SCIWORA occurs because the inherent hypermobility of the pediatric spine allows for transient deformation of the spinal column without fracture or ligamentous disruption at the expense of the spinal cord. The reported incidence of SCIWORA ranges from 4% to 66% among all children with spinal cord injuries. Emerging evidence suggests that clinicians may inappropriately label patients who have very transient neurologic complaints as SCIWORA, thus resulting in overreporting. As MRI has improved and become universally available, clinicians have been able to identify spinal cord injuries that correlate to the neurologic findings. Nonetheless, SCIWORA is a diagnosis of exclusion, and clinicians must be vigilant to rule out persistent ligamentous incompetence that may place the patient at risk for further injury.

SUMMARY

Cervical spine injury is an uncommon and heterogeneous disease in children. Mechanisms of injury, clinical presentation, and injury patterns are diverse, and an understanding of this diversity aids clinical decision making. Previously identified risk factors for cervical spine injury in children can be used to create a sensible clinical guideline that meets the dual aims of prompt recognition, stabilization, and diagnosis for those children who are at greatest risk of cervical spine injury, while avoiding unnecessary and potentially harmful interventions for those at negligible risk.

REFERENCES