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Although cervical spine injuries (CSIs) are uncommon in children, a missed or delayed diagnosis may have devastating consequences for the patient. A thorough understanding of normal pediatric anatomy, injury patterns, and children who are at increased risk for injury is critical for the physician caring for the acutely injured child. The author provides an overview of the unique features of the pediatric spine, and fracture patterns that occur commonly in children. The author also offers guidelines on instances when a child is at increased risk for sustaining a CSI.

—The Editor

Pediatric Cervical Spine Injuries: Avoiding Potential Disaster

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Introduction

The diagnoses of CSIs in children deserves special attention and distinction from injuries in adults. The anatomy, biomechanics, and injury pattern of the infant are different than those of the school-age child and the adolescent. By adolescence, the cervical spine has assumed the same mechanical response as the adult spinal column. This review will describe the anatomy of the cervical spine from infancy through adolescence and discuss the varying injury patterns that may occur through childhood. A general sense of the biomechanical tolerance of the pediatric spine will be developed through a review of injury-producing impacts. Additionally, limitations of data will be acknowledged that will necessitate practical management recommendations.

Anatomy of the Cervical Spine

The cervical spine is composed of seven vertebrae, each separated by an intervertebral disc. The cranium rests upon the atlas (C_1) while C_7 rests upon the first thoracic vertebra (T_1). See Figure 1 for the landmarks of the lower cervical vertebrae.

Tethering ligaments and their associated attachments are listed in Table 1. The transverse ligament is unique to C_1 and maintains the relationship between C_1 and C_2. This ligament attaches to the posterior dens (odontoid process of C_2) from the inner, lateral aspect of C_1. The other tethering ligaments, as well as the facets and interfacet joints, limit horizontal motion between the vertebral bodies. Additionally, the tethering ligaments limit axial, or vertical, elongation of the spinal column. When the mechanical properties of these structures are overcome by the forced neck motion of impact, an injury will result.

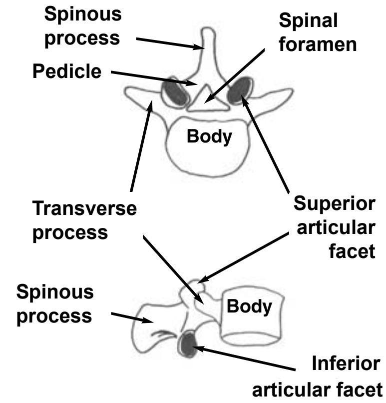
Developmental Biology of the Cervical Spine

The ossification centers of the vertebral bodies appear during the second month of gestation as sclerodermal mesoderm migrates and thickens into the vertebral column. The vertebral bodies are formed by two lateral neural arches and a centra. The centra and the anterior portion of the lateral arches fuse to form the vertebral body. The posterior portions of the neural arches fuse to form the transverse processes, facets, and spinous process. The anterior and posterior arches are radiographically evident at birth, while the spinous, articular, and transverse processes do not fuse until approximately 8 years of age.

Ossification of the dens is not complete until 6-8 years of age. The dens is formed by union of two lateral globular masses, achieving a conical shape at an age of viability.[1] This ossified dens retains a cartilaginous association with the body of C_2 until fusion occurs at age 6-8 years. The tip of the dens is formed by a separate ossification center. The superior portion of the dens is calcified by age 4 years.

In the newborn cervical spine, the facet joints are flatter than those in the mature teenage spine, therefore, anterior-posterior relative motion is not limited in the newborn's cervical spine as well as it is in the mature spine. One study found that the facet joint angle does not assume an adult angle until age 10 years.[2] Additionally, potential voluntary anterior-posterior motion of one vertebral body upon another is increased until age 12 years.

Figure 1. Anatomy of the Cervical Vertebra



Although no biomechanical data exist to quantify the difference, the musculature supporting the pediatric cervical spine is assumed to be laxer than in adults. In addition to a weaker neck, infants have a relatively larger head, per body weight, than adults do. In summary, in young children, a weaker neck that has less restriction to mechanical motion must support a heavier head. Being at an anatomic disadvantage, the cervical spine in infants and children may be at risk for injury at lower impact energies than would cause injury in adults.

Cervical Spine Malformations and Anomalies. As described above, embryologic formation of the vertebral column starts during the third to fourth week of gestation. Additionally, the major structures of the face and neck develop between weeks 4 and 12.[3] Children who have abnormal embryologic development of facial or neck features are at risk for abnormal cervical spine development as embryologic development of these two structures occurs simultaneously.[4] See Table 2 for a list of associated abnormalities. While the emergency physician often will not be able to identify the specific malformation syndrome, patients with face and neck anomalies should be considered at risk of having a congenitally abnormal cervical spine.

When examining cervical spine radiographs, it is necessary to look for any signs of congenital abnormality. Fusion of adjacent posterior elements commonly is associated with fusion of the vertebral bodies. Identification of the posterior fusion will appear earlier, as the complete ossification of the vertebral bodies is delayed in children. Fusions are most common above C_4, yet can occur throughout the cervical spine. Other common abnormalities include occiptoatlantal fusion, hypoplastic or anomalous portions of the atlas, ligamentous laxity, and malformations of the dens.[3,5]

Studies of U.S. football players have demonstrated that congenital cervical stenosis commonly is detected in athletes with transient neuropraxias. However, this anomaly does not predispose athletes to catastrophic neurological injury.[6]

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Table 1. Tethering Ligaments in the Cervical Spine

Vertebral bodies and discs	Anterior and posterior longitudinal ligaments
Facets	Interfacet capsular ligaments
Spinous processes	Interspinous and supraspinous ligaments
Transverse processes	Intertransverse ligaments
Adjacent lamina	Ligamentum flavum

Even though it would seem logical, neuromuscular disorders typically do not affect the cervical spine. Instead, neuromuscular disorders tend to result in thoracolumbar scoliosis.[7] Examples of these disorders include cerebral palsy, muscular dystrophy, spinal muscular atrophy, and Rett's syndrome.

Cervical Spine Injury Distribution (Age/Location)

CSIs are less common in pediatric trauma patients than in adult patients. The NEXUS group found 30 injuries in 3065 (1%) pediatric patients, compared to injuries in 2.5% of adult patients (788/31,004).[8] Approximately two-thirds of pediatric CSI occur in patients older than 8 years of age.[9] These data reflect patients who arrived to emergency departments, and do not include those who died prior to transport. In a series of 102 patients, 42% of those younger than 10 years of age arrived neurologically intact, 42% had an incomplete spinal cord injury and 16% had a complete lesion.[10] Of those between 10 and 16 years, 41% (26 of 64 patients) arrived neurologically intact, 47% had partial spinal cord lesions, and 12% had complete spinal cord injury on arrival.

Types of injuries to the pediatric cervical spine include fractures, dislocations, or SCIWORA (Spinal Cord Injury Without Radiographic Abnormality). In one review of the National Pediatric Trauma Registry, 25-30% of all CSI were SCIWORA in children younger than 11 years.[11] In patients between 11 and 18 years, 15-20% of all CSI were SCIWORA. Fractures accounted for 35-40% of CSI in children younger than 7 years, 45-50% between 7 and 11 years, 60-70% from 12 to 16 years, and 70-75% in those older than 16 years. Dislocations caused 30-40% of the injuries in those younger than 7 years, 20-30% in those 7-11 years, and 15-25% in those 12-16 years. In summary, fractures are the most common injury seen and increase in frequency through childhood. Dislocations also are more common in younger children, but the difference between young and old is not as dramatic. SCIWORA is common in younger children, but may occur in any age group.

Younger children with CSI most commonly are injured in the upper cervical spine. *(See Figure 2.)* By the end of the teenage years, injuries are distributed more evenly between the upper and lower cervical spine. In children younger than 11 years of age, 15-20% of all CSI are below C_4. In the ages 11-15, 35-40% of CSI are below C_4. Upper and lower CSI are equally as likely in the child older than 15 years.[11] Series published through individual institutions have presented differing distribution of injuries, but one paper[11] included 408 children, the largest data set of pediatric CSI.[12-22]

Some data exist regarding the prevalence of CSI as an isolated injury. In a group of 72 children with CSI from Utah, one study notes that the median Glasgow Coma Score (GCS) was 15.[22] Fourteen percent of the children had a GCS less than 13. The mean injury severity score was 15, with a range of 4-54.[22] In another series, 37 children younger than 9 years had a mean injury severity score of 26, while the 36 children older than 8 years had a mean injury severity score of 12.1.[18] These data suggest that children may sustain an isolated CSI .

Combining the data presented in two studies allows some description of outcomes in children with CSI.[12,19] Eleven of 18 children younger than 5 years with CSI died. Fourteen of 19 children between the ages of 5 and 10 died. Of those older than 10 years, four of 42 children died. In one of the two studies, all children survived if they had an isolated cervical spine fracture. One child out of nine with a fracture/subluxation died. All 15 children with distraction injuries died (eight of which were occipito-cervical injuries).

Injury Etiology

CSI in young children tends to result from motor vehicle collisions (MVCs), falls, pedestrian injuries, or child abuse. Older children are more active in sports and activities and may endure a CSI due to MVCs, sports, falls or bicycle accidents.[9-12,16-18,20-22]

To further clarify the force of impact necessary to cause CSIs in children, it is tempting to read injury reports regarding specific mechanisms of trauma. Many authors have published series of papers dealing with the injuries seen after specific types of trauma, including falls,[24-27] crashes,[28-31] and animal attacks.[32] These data series tend to reinforce to the clinician that a specific impact may be an injury-producing impact. Potentially more useful are series that emphasize mechanisms that did not result in a CSI from a specific type of trauma. CSI did not occur in any child in a series of 432 falls down stairs reported in two series.[33,34] One child died after a fall down stairs in a walker after suffering a CSI, skull fracture, and subdural hematoma.[35,36]

Similarly, a CSI did not occur in any child after falling from bed (207 children),[37] high chairs (103 children),[38] or shopping carts (62 children).[39] One author reported 151 falls from heights, none resulted in CSI.[40] Another group reported a series of 101 children admitted to the hospital with a skull fracture. None of these children had a concurrent CSI.[41]

One author published a series of eight children who sustained CSI after short falls.[42] All were symptomatic at the time of presentation (although the time from injury to symptom onset is not reported). In this series, a 4-year-old had a C_1-C_2 subluxation after falling out of bed. A 9-month-old fell while pulling herself up and suffered a subluxation of C_1-C_2 with an odontoid fracture. A 3½-year-old fell while running and suffered a fracture of the neural arch of C_2 with subluxation of the inferior articulating facet. The other children had rotary subluxations after falling or somersaulting.

Table 2. Malformation Syndromes with Associated Cervical Spine Abnormalities

SYNDROME	SIGNS	CERVICAL SPINE ABNORMALITIES
Klippel-Feil	Short, webbed neck; low posterior hairline; sensorineural hearing loss	Cervical fusion, cervical ribs
Turner Syndrome	Female; short stature; webbed neck; low posterior hairline; small mandible; epicanthal folds; high arched palate; broad chest, cardiac abnormalities	Cervical hypoplasia
Goldenhar Syndrome	Hyperplasia of malar, maxillary, and mandibular face; ear abnormalities; hearing loss; cleft lip or palate	Cervical fusion, vertebral malformations (including posterior fusion); Chiari malformation
Crouzon Syndrome	Premature craniosynostosis; hypoplasia of maxilla; hypertelorism; proptosis; cleft lip and palate	Cervical fusion; foramen magnum stenosis w/Chiari malformation
Apert's Syndrome	Asymmetric face; proptosis; syndactyly of hands and feet; hypoplastic midface; beak nose; cleft palate	Cervical fusion; progressive calcifications; foramen magnum stenosis
VATER*	Anal atresia; tracheo-esophageal fistula; radial side malformations; renal defects	Cervical defects
Larsen's	Prominent forehead; flat face; hypertelorism; multiple dislocations; cleft palate; kyphosis	
Mucopolysaccharidosis	Coarse features; corneal clouding and other ophthalmologic abnormalities; short stature; hirsutism; hydrocephalus; macroglossia	Joint laxity with cervical instability- (especially MPS type IV); vertebral anomalies
Ehlers-Danlos	Skin hyperelasticity; fragile skin and blood vessels	Cervical ligament instability
Fetal Alcohol Syndrome	Short palpebral fissures; epicanthal folds; maxillary hypoplasia; micrognathia; thin upper lip; cardiac defects; delayed cognitive development	Cervical fusion

* VATER = Vertebral defects, Anal atresia, Tracheo-esophageal fistula with Esophageal atresia, and Radial and renal anomalies.

A general summary of the above data is necessary to give the clinician a sense of the type of impact that may cause a spine injury. Collisions in which a child impacts an object with a closing speed faster than a child can run or more than twice the child's height are greater-risk impacts. This is especially true in situations where the child may initiate contact with the skull, as is common in sports injuries. While falls can result in CSI, the injury-producing falls tend to be higher, or there are extenuating circumstances. One such circumstance occurs when a child falls down stairs with the extra weight of a walker attached. Unfortunately, as demonstrated by one group,[42] these guidelines are not completely reliable, and CSI may result from minimal trauma.

Diagnostic Evaluation

After understanding the epidemiology of CSI and the pertinent anatomy, it is necessary to discuss the appropriate evaluation of the potentially injured child. The evaluation of a child with a potential neck injury involves a clinical and radiographic evaluation.

Clinical Evaluation. When faced with a child who has sustained a traumatic impact, the clinician must determine whether the child is at risk for having sustained a CSI. The clinician must make a decision regarding the need for immobilization of the child and the need to pursue diagnostic radiographic evaluation of the cervical spine. Recent work has narrowed the focus of physical examination findings that are present in adults with CSI.[43,44] Two published series identify low-risk criteria that include a normal physical examination of the neck and no history from the patient of neck complaints. The Canadian group characterized low-risk clinical criteria as being the victim of a low-speed rear end crash, being ambulatory prior to transport, or sitting in the department. The U.S. group included criteria requiring a clear sensorium and absence of a distracting injury (as defined by the treating physician). These clinical criteria did well in excluding the likelihood of an unstable cervical spine fracture in adults.

Unfortunately, there are no data in children to identify low-risk patients who do not require cervical spine radiographic evaluation. The Canadian study did not enroll children. The U.S. study identified 30 children with CSI (none younger than 2 years old, and four children younger than 9 years), and thus, lacks the power to support clinical guidelines. Therefore, while these clinical criteria are very similar to published guidelines and recommendations made after retrospective study of injured children, there are no prospective data to validate these recommendations.[15,25,26,45]

Emergency physicians continuously are faced with injured children and must make decisions regarding immobilization, imaging, and management, despite a paucity of clear criteria to use to evaluate these patients. Therefore, careful clinical judgment and evaluation are required. It is hoped that the emergency physician can refine clinical judgment by reviewing the aggregate of clinical presentations of published series of children with CSIs.

In the 30 pediatric patients with CSI from the U.S. trial, all

Figure 2. Severe Upper Cervical Spine Injury (AO and C_1-C_2)

Table 3. Suggestions for Radiographic Evaluation

PRE-VERBAL OR PRE-COOPERATIVE CHILD AT RISK OF CSI

High Risk

- Fall in which the body weight lands on the head
- Head-on motor vehicle crash with child in a forward-facing seat
- Abnormal posture of the head and neck
- Anomaly of the face, head, or neck
- Any suspicion of non-accidental trauma
- Evidence of intracranial injury or significant facial trauma
- High speed, rear-end impact with an infant in a rear-facing seat
- Risky mechanism with distracting pain
- Neck tenderness
- Neurologic deficit
- Fall while in an infant walker

Low Risk

- Head-on motor vehicle crash with child in a rear-facing seat
- Short fall in which impact is evenly distributed between trunk and head
- Unwitnessed short fall with no scalp hematoma or soft-tissue injury
- Lateral impact motor vehicle crash with the child in appropriate restraint and no evidence of intracranial injury or concussion

VERBAL AND COOPERATIVE CHILD AT RISK FOR CSI

- Neck tenderness
- Neurologic abnormality
- Distracting pain with adequate mechanism
- Altered mental status
- High-energy impact involving a child younger than 8 years

were not low-risk by clinical criteria.[8] Twenty-one of 25 (five were unable to be evaluated for this criterion) patients had midline neck tenderness. Eleven of 28 had a distracting injury. Only eight of 27 had neurologic findings, while none had SCIWORA.

A retrospective review of 72 patients included information on the neck examination of 61.[22] Thirty had radiographically apparent CSI (RACSI) and 30 had SCIWORA. Sixteen of the 31 (51%) with RASCI reported midline neck tenderness, while 24 of 30 (80%) of those with SCIWORA had midline neck tenderness documented.

One review of 50 children with CSI noted that all 30 of the children awake at the time of ED arrival had neck pain or tenderness.[12] Another author reported the retrospective review of 25 children with CSIs.[23] She reported that the criteria of any history of neck pain or vehicle crash with head injury identified all children with CSI.

The retrospective review of children with low falls described eight children who had CSI after a low fall.[42] All eight patients had neck symptoms at the time of diagnosis. Unfortunately, the time of onset of these symptoms was not reported in the series.

Additionally, the data on SCIWORA reveal that any neurologic symptoms can be markers of SCIWORA. The data from one group report that all 32 patients in that series with SCIWORA had symptoms upon initial presentation, although some were isolated sensory deficits.[22] The data by another author note a percentage of children with SCIWORA that had a normal examination on presentation yet had neurologic deterioration days later.[46,47]

In summation, a review of all the significant published series of children with CSI does not identify any criteria or criterion that will assure that a child, especially a pre-verbal or pre-cooperative child, is at low risk of an unstable CSI. Because SCIWORA exhibits a spectrum of presentations, the clinician must maintain diagnostic vigilance in any child with any neurologic symptoms. This is in contrast to the adult, in which one may consider transient, painful, radicular symptoms to be markers of peripheral nerve injury due to neck loading (i.e., the football player with a "stinger").

While noting from the above information that neck tenderness and possibly pain suggest a high-risk group, the converse is not true. How shall the clinician identify a high-risk group deserving radiographic evaluation among those without neck symptoms, those without neurologic symptoms, or those who are pre-verbal or pre-cooperative? The clinician must have a rough idea of the type of impact necessary to cause CSI, especially in the infant and toddler. Table 3 combines an arbitrary definition of high impact with somewhat arbitrary clinical criteria to produce guidelines for identifying children who may need radiographic evaluation of the cervical spine.

Radiographic Evaluation. Once the decision is made to obtain radiographic imaging, what are the appropriate studies to obtain? Authors vary on the routine studies for evaluation of the

Figure 3. C_6-C_7 Ligamentous Injury

Figure 4. C_5 Fracture with Subluxation

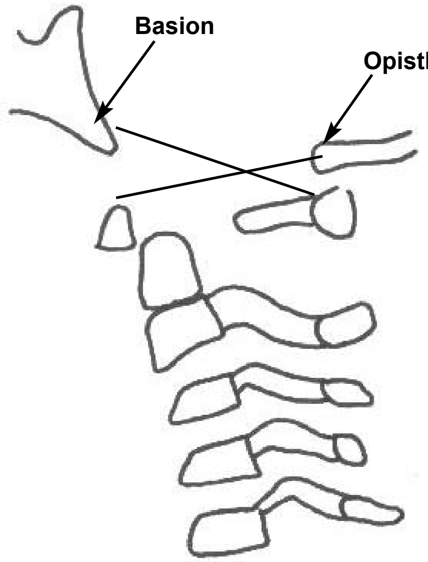
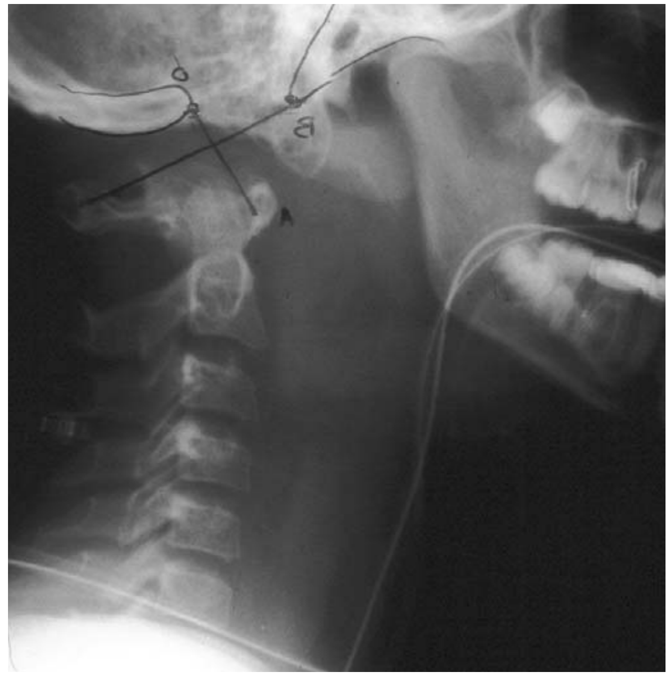
A lateral cervical spine radiograph identifies a C_5 fracture with subluxation.

cervical spine. Some authors recommend a lateral view that visualizes the atlanto-occipital joint to the C_7-T_1 joint, an antero-posterior (AP) view, and an open-mouth odontoid in the cooperative patient.[12,48] Others advocate the three-view series for all patients.[10] A recently published survey of 432 pediatric radiologists notes that 40% of responders do not obtain the odontoid view in children younger than 5 years of age.[49] Another 25% only make one attempt at obtaining that view. Older recommendations suggested a five-view series for all patients, which included oblique views in addition to the standard three views.[50]

New data are available that suggest that computed tomography (CT) scanning of the cervical spine may be faster than obtaining plain films, especially in the patient who is to have a post-traumatic CT scan of another body region.[51-53] However, the role and accuracy of this technique have not been defined outside the multiple trauma patient.

The use of flexion-extension (FE) radiographs in evaluating alert trauma patients remains controversial. The FE views are imaging techniques that are used to delineate the endpoints of the patient's active neck flexion and extension that would radiographically identify any ligamentous injury. *(See Figure 3.)* The concern with FE views is that the patient will injure his or her spinal cord during performance of the test. Therefore, the utility of and indications for FE views are not clear. Data by two authors demonstrate that static radiography is adequate to diagnose CSI in 95% of patients.[12,22] *(See Figure 4.)* Three retrospective series suggest that FE films do not identify injuries in patients with normal static radiographic series.[48,54,55] In patients with subtle spine abnormalities, there was some diagnostic value to performing FE radiographs. In the only study of injury caused during FE studies, one patient of 129 had transient tingling in the upper extremities during positioning that resolved spontaneously after relaxation.[48]

When ordering FE radiographs in the trauma patient, it is important to clarify whether the patient demonstrated adequate neck motion (FE) during the study.[56] In case of an inadequate study, a patient should be immobilized pending repeat radiographic evaluation in five days. Providing time for pain and muscle spasm to resolve should allow for a repeat, adequate radiographic study. However, it is unclear how often an FE study is inadequate. Up to one-third of FE radiographs ordered in adults acutely after trauma may be inadequate.[57] These data note that angular motion of approximately 40º is necessary between C_2 and C_7 for an adequate study. There is no clear definition of adequate motion on pediatric FE films. Specifically, the normal degree of tilting and relative motion between vertebral bodies changes throughout childhood. One author has demonstrated that tilting angles during flexion decrease with age at the C_{2-3} and C_{3-4} junctions.[2] Extension tilting increases with age at the C_{4-5} and C_{5-6} joints. These tilting changes are changes of approximately 3-5º throughout childhood. Sliding motion during flexion decreases with age at the C_{2-3}, C_{3-4}, and

Figure 5. Calculating Powers Ratio	Figure 6. An AO Injury Diagnosed by Powers Ratio
 Powers ratio is determined by the ratio of distance from the basion to posterior arch of C_1 to the distance from the opisthion to the anterior arch of C_1.	

C_{4-5} joints. This motion decreases from 18-25% down to 5-10% of vertebral width.

Acute FE magnetic resonance imaging (MRI) may have a role in identifying pediatric operative candidates sustaining ligamentous injury.[58]

Specific Injuries that Occur in Children

Occipitoatlantal Dislocation. The outcome of children with occipitoatlantal dislocation is uniformly poor.[12] This injury usually results from a high-energy impact, as seen in motor vehicle crashes. Examination of the cervical spine radiographs must include assurance of an appropriate relationship between the occiput and the atlas. The distance between the basion and the dens should not exceed 10 mm in children and 5 mm in adults.[59] It is not uncommon for normal patients to exceed these criteria.[60] The Powers ratio can be calculated. The ratio of the distance from the basion to the anterior edge of the posterior arch of the atlas divided by the distance from the opisthion to the posterior portion of the anterior arch of the atlas should be less than 0.9. A ratio greater than 1.0 is abnormal. The Wackenheim clivis line is another technique to inspect for integrity of the atlanto-occipital joint. In this test, a line drawn along the posterior clivus should intersect or be tangential to the odontoid.[61-63] *(See Figures 5 and 6.)*

Atlas Fractures. Burst fractures of the C_1 ring can occur in children, just as in adults. The fracture may occur through the synchondroses, which may remain unfused until age 7.[64] CT scan may assist in securing the diagnosis.

Atlantoaxial Injuries. Authors differ over the relative frequency of transverse ligament injuries compared to dens fractures. Although fractures through the base of the dens do occur at the synchondrosis, transverse ligament tears also are commonly seen. An atlantodens interval of 5 mm may suggest injury to the transverse ligament.

Surprisingly, children with dens fractures frequently are neurologically intact upon presentation. One series quotes seven of 15 children without weakness on presentation. Four of 15 had thoracic level symptoms, and three had low cervical symptoms (C_6 and C_7).[65] Thirteen of the 15 had anterior displacement ranging from 10-100% (mean 40%). One patient had a fracture, C_2 tetraplegia, and no displacement of the dens. Two patients with 20% displacement had a delay in diagnosis of four and six months. Tomograms may show widening of the growth plate not evident on plain radiographs.[7] CT scans require coronal and sagittal plane reconstruction because axial scanning may miss fractures.[66,67] As the growth plates close, it is important not to confuse the epiphyseal scar at the base of the dens with an acute fracture.

Os Odontoideum. Os odontoideum refers to an oval or round ossicle of variable size with a smooth cortical border located in the position of the odontoid process. Authors differ, but suspect that this is an acquired lesion after an undiagnosed odontoid fracture. These lesions commonly are unstable.[68,69]

Hangman's Fracture. Hangman's fracture, or C_2 pedicle fractures, can occur in children with a hyperextension injury, just as with adults. *(See Figure 7.)* The diagnosis of a hangman's fracture may be confused with physiologic subluxation of C_2 on C_3. Evaluating the alignment of the posterior laminar line can assist with clarifying the diagnosis.

Atlantoaxial Rotary Subluxation. Atlantoaxial rotary subluxation may occur spontaneously (Grisel's syndrome) or after minor trauma. The classic clinical presentation is torticollis in the "cock-robin" position, with the head rotated to one side and tilted

Figure 7. Hangman's Fracture

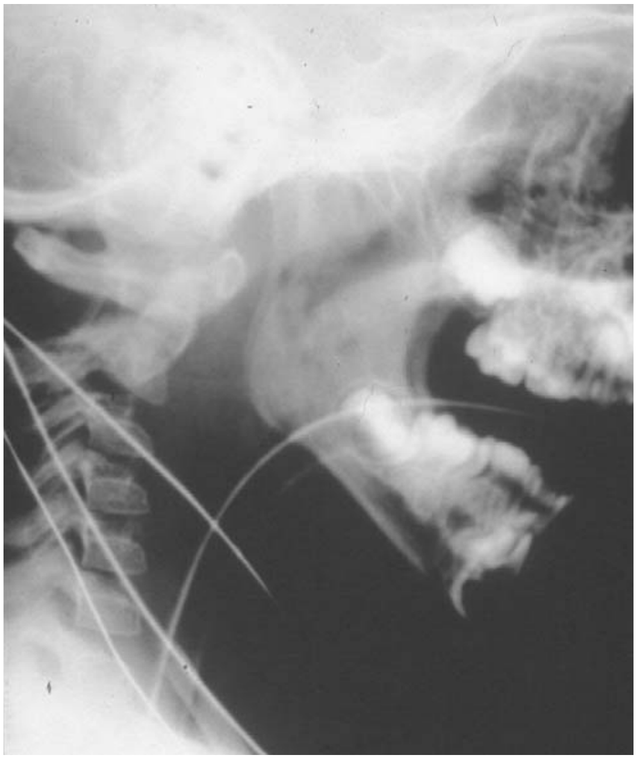


Figure 8. Apparent Anterior Vertebral Wedging

to the other, like a bird listening for a worm.[70] This usually stable injury is truly a pediatric injury, as up to 80% of these injuries occur in children younger than 13 years of age.[71,72] This type of rotary subluxation occurs most frequently at the C_1-C_2 joint, where most of the rotation of the neck occurs. The facets are flatter at this joint than at any other joint.

The diagnosis of rotary subluxation is difficult to secure with plain films alone. The abnormalities seen can be present in patients with torticollis not due to subluxation and in volunteers holding their head in the "cock-robin" position.[7,73,74] CT scanning, with 3D reconstruction, often is necessary to make the diagnosis.

Normal Radiographic Variants Simulating Injury

There are several common variations in the pediatric cervical spine radiograph that may simulate injury. This section will describe the pattern of variation and describe how to distinguish it from pathology.

Pseudosubluxation. Anterior displacement of C_2 on C_3 of up to 4 mm is common in children younger than 7 years, but frequently can be noted in children up to 16 years of age. A line drawn from the anterior cortex of the spinous process of C_1 to C_3 should come within 1.5 mm of the anterior spinous process of C_2. This misalignment may improve with FE views, but certainly isn't exaggerated by FE study. Pseudosubluxation also can occur at the level of C_3-C_4.

Apparent Anterior Vertebral Wedging. Anterior wedging of the vertebral body may be seen on pediatric radiographs. This wedging represents non-uniform calcification of the vertebral body, not an asymmetric shape. Wedging is most common at C_3 and may account for up to 3 mm difference between the anterior and posterior height of the vertebral body. The vertebral bodies should assume an adult shape by age 8. This variant can be noted in Figure 8 at C_3 and C_4.

Overriding Anterior Arch of C_1. Up to two-thirds of the anterior arch of C_1 may override the tip of the dens. This occurs in up to 20% of children younger than 7 years.[75]

Increased Predental Space. The predental space in children can be up to 5 mm. Ligamentous laxity (of the transverse and anterior atlanto-axial ligaments) may allow for an increased gap compared to the adult measurement of 3 mm.

Apical Odontoid Epiphysis. The odontoid tip has an epiphysis that usually is present at age 7, but may persist through age 16.[75,76]

Persistent Synchondrosis of the Dens. The growth plate at the base of the dens persists beyond age 7. This linear scarring may be confused with a fracture. This line is typically linear, occurs in a predictable location, and may have associated sclerosis. A fracture more commonly presents in an unpredictable location without sclerosis and with irregular edges.

Non-uniform Angulation During Flexion. There may be non-uniform angulation between adjacent vertebral bodies during flexion. This may appear as marked flexion at a single joint. Although this can be a normal variant, it is difficult to distinguish from acute trauma in the correct clinical setting.[75]

Asymmetric Odontoid. The odontoid may be centered asymmetrically between the lateral masses of C_1. Ligamentous laxity may cause this variant. While this can be a normal variant, it may be difficult to distinguish from an acute fracture in the correct clinical setting.[77]

Delayed Calcification of Anterior Arch of Axis. The anterior arch of C_1 frequently is not visible on plain film radiographs until 6 months of age. Before this, the axis is calcified insufficiently to be visible radiographically.

Treatment and Disposition

When treating patients with CSIs, emergency medicine physicians must remain focused on three goals. First, the emergency medicine physician must identify all significant injuries, including the CSI. The emergency physician, as the initial physician contact, must keep the complete patient clinical picture in mind to allow subspecialists to concentrate on specific injuries. Second, the emergency medicine physician must take steps to prevent worsening of any neurologic function associated with the spinal cord injury. Basic fundamentals must be addressed to complete this goal. Spinal immobilization of unstable injuries is imperative. Care must be taken during intubation to prevent further cord injury. Identification and treatment of shock is important to maintain adequate perfusion to the injured spinal cord. Finally, the emergency physician must expedite therapy for any CSI and associated spinal cord injury. Adult data suggest that urgent release of spinal cord compression may improve outcome. Urgent MRI may be necessary to identify cord compression. Intravenous steroids may be indicated for treatment of a spinal cord injury.

Steroids in Children. The use of steroids has been advocated for the treatment of patients with acute spinal cord injuries.[78,79] The indication for treatment in the quoted NASCIS trials was "having a spinal cord injury" as defined by study physicians. Approximately 8% of patients had normal neurologic function on enrollment in NASCIS 3.[79] No patient younger than age 14 was enrolled in this series. Patients with gunshot wounds were excluded, but patients with other forms of penetrating trauma were not excluded from study. Outcomes were not reported according to the type of cord injury sustained.

While steroid dosing in adults with acute spinal cord injuries may or may not provide benefit, the benefit and indications of this therapy in young children has not been proven. Centers should establish a consensus for the treatment of children after spinal trauma. Communication between emergency physicians and accepting subspecialists should be done so that all members of the treatment team will have a common understanding when a patient arrives in the ED. Controversy may arise about the treatment of a child with sensory deficits of an isolated cervical level or the treatment of a very young child with an apparently normal neurological examination with an abnormal cervical spine radiograph.

Conclusion

Evaluation of the pediatric patient with a potential CSI is a complicated process. The emergency physician must exercise thoughtful clinical judgment in evaluating a pre-cooperative patient at a low risk of a potentially catastrophic injury. A complete understanding of the pertinent anatomy, radiographic features, and biomechanical tolerance of the pediatric spine is necessary to provide this care.

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CE/CME Questions

1. At what age is ossification of the dens usually complete in a pediatric patient?
   A. 1 year
   B. 3 years
   C. 4 years
   D. 5 years
   E. 6-8 years

2. Which of the following increases a child's risk for abnormal cervical spine development?
   A. Neuromuscular diseases
   B. Cerebral palsy
   C. Apert's syndrome
   D. Muscular dystrophy
   E. Rett's syndrome

3. A 4-year-old child presents after falling off a horse and landing on his head. The child has midline cervical pain with a normal neurologic examination. What would be your radiographic recommendation?
   A. No radiographs are necessary
   B. Flexion extension views only
   C. MRI of the spine
   D. Lateral cervical spine radiograph

4. Significant CSI does not occur as an isolated injury.
   A. True
   B. False

5. Which of the following is true regarding occipitoatlantal dislocations?
   A. Outcome usually is poor.
   B. The injury usually results from a high-energy impact.
   C. The Powers ratio is useful for assessing the existence of this type of injury.
   D. The Wackenheim clivus line also may be used to diagnose this injury.
   E. All of the above

6. An atlantodens interval of 5 mm may suggest injury to the transverse ligament.
   A. True
   B. False

7. Which of the following is *not* true regarding flexion extension films in pediatric patients?
   A. There is no clear definition of adequate motion of pediatric flexion extension films.
   B. Up to one-third of adult flexion extension films may be inadequate.
   C. In adults, approximately 40 degrees of motion between C_6 and C_7 is necessary for an adequate film.
   D. Flexion extension films may result in spinal cord injury.
   E. The normal degree of tilting and relative motion between vertebral bodies changes through childhood.

8. A Powers ratio of greater than 1.0 is abnormal.
   A. True
   B. False

9. Which of the following is true regarding Os odontoideum?
   A. It usually is a rectangular-shaped, irregularly margined bone fragment.

CE/CME Instructions

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

B. It usually is located in the position of the odontoid process.
C. It is a congenital lesion.
D. These lesions commonly are stable.

10. Which of the following is *not* true regarding atlantoaxial rotary subluxation?
   A. It usually is associated with major trauma.
   B. Patients classically present with torticollus.
   C. Up to 80% of these injuries occur in children younger than 13 years of age.
   D. The injury most frequently occurs at the C_1-C_2 joint.
   E. The diagnosis may be difficult to make with plain radiographs.

Answer key:

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

CME Objectives

Upon completing this program, the participants will be able to:
a.) Quickly recognize or increase index of suspicion for occult spinal trauma in pediatric patients;
b.) Be educated about how to correctly and quickly stabilize, and then to manage, cervical spine trauma;
c.) Understand various diagnostic modalities for cervical spine injuries; and
d.) Understand both likely and rare complications that may occur.

In Future Issues:

Recognizing Child Abuse