

Pediatric Spinal Cord Injury

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Department of Orthopaedic Surgery, Stony Brook School of Medicine, Stony Brook, NY, USA

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Pediatric spinal cord injury is a complex process that is associated with significant morbidity and mortality. While this injury is rare, knowledge of the unique aspects of the pediatric spine can aid in making a prompt diagnosis which can lead to faster treatment and functional recovery.

Keywords: Pediatric spine; Spinal cord injury; Dislocation; Vertebral column

Overview

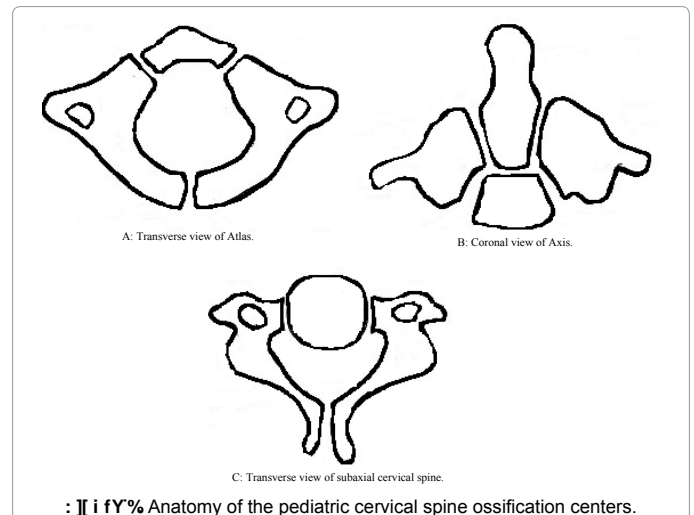
Spinal cord injury (SCI) is a devastating diagnosis widely thought to have a poor prognosis. These injuries are less common in the pediatric population; however, it is crucial for treating providers to understand the morphologic differences in the pediatric spine, compared to adults, in order to promptly diagnose and manage these complex injuries.

Anatomy

One function of the vertebral column is to protect the spinal cord from injury. The pediatric spine, unlike the adult spine, is in a state of growth and development. Morphologic and physiological differences can be used to explain different injury patterns seen in pediatric compared to adult patients (Table 1).

The pediatric vertebral column has ossification centers, which are points of weakness that sometimes are confused with fractures (Table 2 and Figure 1) [1-3]. The atlas has three ossification centers: one body and two lateral masses. The synchondrosis that forms the posterior arch fuses by age 3 to 4 while the synchondrosis linking the lateral masses to the body fuse by 6 to 8 years [2].

The axis forms from five primary ossification centers: one body, two lateral masses, and two in the dens. The dentocentral synchondrosis connects the dens to the body and can be open in children up until age 3 [2]. The remaining levels in the cervical spine arise from three ossification centers: one for the body and one for each neural arch. The



synchondrosis fuses posteriorly between 2 to 3 years and anteriorly between 3 to 6 years.

The morphology of the vertebra also changes with growth. In the young child, the vertebral body has a characteristic wedge shape with horizontal facet joints [4,5]. The orientation of the cervical facet joint increases from 0° to 30° at birth to 60° to 70° at age 8 [2]. This more vertical orientation increases stability of the facet joint. Furthermore, ossification of the uncovertebral joints, which occurs by age 7, increases the stability of the cervical spine [6]. Dynamic stabilization of the spine also follows this developmental pattern. In the young child, paraspinal muscle reflexes are underdeveloped and do not protect the spine from sudden trauma [7].

Physiologically, the pediatric spine has properties making it more flexible than the adult spine. Spinal ligaments have a higher elasticity compared to adults, which allow traumatic forces to be transferred to the spinal cord [4,7]. The annulus also has increased water content which increases the elasticity of the disc [8]. The presence of synchondroses increases the flexibility of the cervical spine allowing for potentially more motion compared the rigid vertebral column in the adult [4,7].

Presence of primary and secondary ossification centers
Horizontal cervical facet joints
Wedge shaped vertebral bodies
Lack of ossification of the uncovertebral joints
Underdevelopment of secondary stabilizers
Increased elasticity of ligaments
Increased elasticity of annulus
Greater head-to-torso ratio

HU'Y% Unique anatomic and morphologic characteristics of the pediatric cervical spine contributing to instability.

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Atlas (C1)	Anterior neurocentral	6 to 8
	Posterior neural arch	3 to 4
Axis (C2)	Dentocentral	3 to 6
	Anterior neurocentral	3 to 6
	Posterior neural arch	2 to 3
	Odontoid neural arch	2 to 3
Subaxial (C3-7)	Anterior neurocentral	3 to 6
	Posterior neural arch	2 to 3

HU'Y& Age of fusion of cervical spine Synchondroses.

17 cffYgdcbXJb['U h cf. James Barsi, Stony Brook University Hospital, HSC 18-030 Stony Brook, NY 11794, USA, Tel: 631.444.3482; Fax: 631.444.3403; E-mail: james.barsi@stonybrookmedicine.edu

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From a morphologic perspective, pediatric patients are at higher risk of cervical spine injury because of the larger head to torso ratio and the alteration in flexion fulcrum with development. The large head to torso ratio predisposes the head to large flexion and extension moments. The fulcrum of cervical flexion shifts caudally from C2-C3 in early childhood to C5-C6 by age 10 years [2,7].

Epidemiology

Pediatric SCI is rare among trauma admissions, with an overall prevalence of 1-2% [8-11]. The overall mortality rate has been listed in the literature as 4.9%; however, in the subgroup of patients under age 3, mortality peaks at 10.8% which is thought to be due to the presence of concomitant head injury [4]. The highest incidence of pediatric SCI occurs in early adolescence and young adulthood during the ages of 14-17 years, and is associated with male patients who reside in urban areas [4,9,11-14]. The most common mechanism of injury is motor vehicle accidents, accounting for 81% of pediatric spinal injuries [15].

The distribution of injuries is also correlated with age. There is a higher frequency of upper cervical (C1 and C2) injuries in younger patients with a greater association of mortality and neurologic morbidity [8,11,16]. This can be attributed to the anatomic changes during childhood development. After age 8, the cervical spine takes a more adult anatomy and lower cervical spine injuries become more common [9].

Classification

Pediatric spine injury can be broadly classified into two groups: those with radiographic abnormalities and those without radiographic abnormalities. Included in the former are fracture, dislocation and subluxation. Spinal cord injury without radiographic abnormality (SCIWORA) was defined in the pre-MRI era as the presence of myelopathy without evidence of fracture or ligamentous instability [17].

The mechanism of SCIWORA is thought to be due to the flexibility of the pediatric spine. While the vertebral column can stretch up to 2.5 cm, the spinal cord may rupture when stretched to 1 cm [17,18]. Theories of how this stretch can cause spinal cord injury include damage to blood vessels feeding the spinal cord and injury to the nerve fibers themselves [19].

In the modern MRI era, the pathology of SCIWORA is better defined. Up to 55% of MRIs in the SCIWORA patient can be normal [20]. When the MRI is positive, the most common finding is T2 spinal cord hyperintensity occurring nearly 42% of the time [20]. Five MRI injury patterns have been described: complete spinal cord disruption, major spinal cord hemorrhage, minor spinal cord hemorrhage, edema, and no abnormality [21].

Evaluation

History and physical

Any child presenting after sustaining trauma should initially be managed by ATLS guidelines. Upon presentation, the spinal column should be considered unstable until proven otherwise. The cervical spine should be properly immobilized with a rigid cervical orthosis. The pediatric spinal column should be immobilized on a pediatric spinal board, or an adult spinal board equipped with an occipital recess or thoracic elevation, so as to not place the child's neck into flexion [22].

The ability to perform a complete neurologic exam could be limited for many reasons. The unconscious or the uncooperative child can be very difficult to properly examine. For these children, examination

findings that do not require patient cooperation such as palpation, deep tendon reflexes, and abnormal (Babinski, Hoffman) reflexes are useful.

Pediatric SCI patients can present with a wide variety of neurologic deficits ranging from transient paresthesias to complete cord injury [17]. 52% of children will present with delayed paralysis, and nearly all will have transient paresthesias [17].

As in adult spine trauma, it is useful to classify the neurologic injury. The American Spinal Injury Association (ASIA) impairment scale classifies neurologic function alphabetically. Complete absence of sensory and motor function is termed grade A. Having sensory preservation, but no motor function below the level of injury is termed grade B. Grade C is defined as having less than a motor strength grade 3, and ASIA grade D is having 3 or greater motor strength.

The greatest predictor of long-term function has been shown to be neurologic status at presentation [17]. Neurologic improvement is also correlated with injury. Patients with complete spinal cord injury rarely improve, whereas those with incomplete lesions improve. In patients specifically with SCIWORA, the improvement in ASIA grade with treatment has been shown to be 0.89 [20].

Imaging

Imaging of the pediatric cervical spine for evaluation of possible injury can be challenging with the presence of synchondroses, secondary ossification centers, and un-fused apophyseal rings that can be mistaken for fracture. Understanding the time these synchondroses appear and fuse are essential in evaluating pediatric cervical spine radiographs. A common location for confusion is the synchondrosis between the odontoid and body of C2, which may be apparent until the age of 5-6, whereas the epiphysis of the dens can be un-fused until the age of 6-8 years [23].

Traditionally, AP, lateral and open-mouth odontoid has been considered the standard-of-care in screening for cervical trauma, but recent studies have questioned this (Figure 2). In a recent study of 51 pediatric patients sustaining cervical spine trauma, 13 of the 15 patient aged under 8 had their diagnosis from by AP and lateral radiographs, with the open-mouth odontoid view contributing to none of the diagnoses [14]. Many clearance protocols recommend CT of the upper cervical spine in place of the open-mouth odontoid view.

Evaluation of specific cervical plain film parameters helps to aid in the diagnosis of the pediatric cervical trauma. The atlantodens interval (ADI) is the distance between the posterior aspects of the atlas and the anterior aspect of the dens. In patients younger than 8 years, this distance can be between 3-5 mm. An increase in ADI above this suggests atlantoaxial injury. With increasing ADI, injury to the transverse ligament should be suspected, and with values greater than 10 mm, injury to the alar and apical ligaments should be suspected, as well [23].



Figure 2: AP, Lateral, and Odontoid view in a 9-year-old patient demonstrating asymmetry of the atlanto-dens interval.



: II i fY' . Lateral radiograph of the cervical spine in a 5-year old child showing pseudosubluxation of C2 on C3 and anterior vertebral wedging.

The Power ratio is the ratio of the distance between the basion to the posterior laminar line of the atlas compared to the distance from the opisthion to the posterior surface of the anterior ring of the atlas. A ratio greater than 1.0 suggests anterior subluxation.

The basion-dens interval (BDI) can be measured on the lateral cervical spine radiograph to assess for atlanto-occipital (AO) dissociation. This measurement is made from the basion to the superior tip of the odontoid. Values greater than 12.5 mm are indicative of AO dissociation. This measurement is less reliable in children under age 5 because of the variability in dens ossification.

Pseudosubluxation is a common anatomic variant of the pediatric spine due to the wedge shaped vertebral bodies and horizontal facet joints. It is seen most commonly at C2-C3 followed by C3-C4 (Figure 3). It can be differentiated from pathologic subluxation by the spinolaminar line which is drawn along posterior arch from C1 to C3. Translation of the anterior aspect of the posterior arch greater than 1.5 mm suggests an injury [24].

CT screening for pediatric cervical trauma may be less useful. A recent study demonstrated that CT scans detected injuries already seen on radiographs [25]. As there are soft tissue and ligamentous injuries in the pediatric patient, MRI would be more useful to examine the extent of injury. Indications for obtaining an MRI are the presence of a neurologic injury on examination, to assessment of ligamentous integrity, and aid in cervical spine clearance in obtunded patients.

Treatment

Treatment for pediatric spinal cord injury falls into three categories: immobilization, steroid therapy, or surgery. Immobilization can be performed externally with either a collar or a halo vest. Halo vest application in pediatric patients is unique because of the thin bony skull and presence of open suture lines, which requires a greater number of pins placed at less torque compared to adults. A typical recommendation is to use 8–12 pins set at 2 to 4 in/lb.

Steroid use in spinal cord injury has been recommended by some; however, its use remains controversial [26]. While some studies have shown a trend towards a clinical benefit in improving neurologic function, the data is inconclusive [27]. The benefits of steroid use have to be weighed against potential complications such as wound breakdown, sepsis, and gastric ulcers.

Surgical management of pediatric spinal cord injury can be thought of as either stabilizing a spine with ligamentous or bony instability or decompressing the neural elements from hematoma or disk herniation.

The choice of approach depends on the pathology being treated. Often for upper cervical injuries, a posterior approach is used to gain access to the occiput if necessary. Historically, instrumentation consisted primarily of wires, but with the advent of screw anchors, higher fusion rates have been obtained.

Rehabilitation

Pediatric patients with spinal cord injuries face several unique challenges compared to adults. Rehabilitation efforts must be representative of these differences and recognize the impact of the spinal cord injury on the complex developmental process of the child. The approach to the patient should be family-centered, accounting for the fundamental role of parents in child development. Care should also be age-appropriate.

Spinal cord injury can result in spasticity which is an upper motor neuron syndrome resulting in velocity-dependent resistance to passive range of motion [8]. Spasticity is best managed with an incremental approach where less invasive modalities such as physical therapy and oral medications are utilized before more invasive treatment.

Physical therapy plays a crucial role in the management of spasticity. Modalities include range of motion exercises as well as prolonged passive stretching. Though there is limited evidence for its efficacy, it has been suggested that prolonged passive stretching may be helpful in the reduction of spasticity and the improvement in range of motion [16]. Hydrotherapy has also been shown to decrease spasticity and to lower the amount of anti-spasmodic medicine used.

A variety of pharmacologic agents have been described in the treatment of spasticity. Oral therapy has been used with varying degrees of success. Baclofen is considered first line therapy for spasticity and acts as a GABA agonist through the blood brain barrier [28]. Patients with focal hypertonicity without joint contracture may benefit from intramuscular injections of Botulinum toxin which acts to block the release of acetylcholine from the presynaptic axon at the neuromuscular junction [12]. While shown to be efficacious, the decrease in spasticity is short-lived lasting on average 12-16 weeks [29].

Pediatric SCI patients face several unique orthopaedic challenges during the rehabilitation process secondary to the effect growth and development has on the skeleton. Neuromuscular scoliosis can develop in children sustaining a SCI prior to skeletal maturity, with up to two-thirds of these patients requiring surgical intervention [30]. Another common orthopaedic sequela of pediatric SCI is spastic hip subluxation or dislocation. Greater than 90% of children with SCI with an onset prior to age 10 will develop this [31].

Summary

Pediatric spinal cord injury is a complex process that is associated with significant morbidity and mortality. Knowledge of the unique aspects of the pediatric spine can aid in making a prompt diagnosis which can lead to faster treatment and functional recovery.

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1. Aufdermaur M (1974) Spinal injuries in juveniles. Necropsy findings in twelve cases. J Bone Joint Surg Br 56B: 513-519.
2. d'Amato C (2005) Pediatric spinal trauma: injuries in very young children. Clin Orthop Relat Res : 34-40.
3. Jones TM, Anderson PA, Noonan KJ (2011) Pediatric cervical spine trauma. J Am Acad Orthop Surg 19: 600-611.
4. Carreen LY, Glassman SD, Campbell MJ (2004) Pediatric spine fractures: a review of 137 hospital admissions. J Spinal Disord Tech 17: 477-482.

5. McPhee IB (1981) Spinal fractures and dislocations in children and adolescents. *Spine (Phila Pa 1976)* 6: 533-537.
6. Ogden JA (1983) Skeletal injury in the child. *Br J Sports Med* 17: 23.
7. Huisman TA, Wagner MW, Bosemani T, Tekes A, Poretti A (2015) Pediatric spinal trauma. *J Neuroimaging* 25: 337-353.
8. Akbarnia BA (1999) Pediatric spine fractures. *Orthop Clin North Am* 30: 521-536, x.
9. Chafetz RS, Gaughan JP, Vogel LC, Betz R, Mulcahey M (2009) The international standards for neurological classification of spinal cord injury: intra-rater agreement of total motor and sensory scores in the pediatric population. *J Spinal Cord Med* 32: 157-161.
10. Bracken MB, Collins WF, Freeman DF, Shepard MJ, Wagner FW, et al. (1984) Efficacy of methylprednisolone in acute spinal cord injury. *JAMA* 251: 45-52.
11. Sayama C, Chen T, Trost G, Jea A (2014) A review of pediatric lumbar spine trauma. *Neurosurg Focus* 37: E6.
12. Bracken MB, Shepard MJ, Collins WF, Holford TR, Young W, et al. (1990) A randomized, controlled trial of methylprednisolone or naloxone in the treatment of acute spinal-cord injury. Results of the Second National Acute Spinal Cord Injury Study. *N Engl J Med* 322: 1405-1411.
13. Bracken MB, Shepard MJ, Holford TR, Leo-Summers L, Aldrich EF, et al. (1997) Administration of methylprednisolone for 24 or 48 hours or tirilazad mesylate for 48 hours in the treatment of acute spinal cord injury. Results of the Third National Acute Spinal Cord Injury Randomized Controlled Trial. National Acute Spinal Cord Injury Study. *JAMA* 277: 1597-1604.
14. Buhs C, Cullen M, Klein M, Farmer D (2000) The pediatric trauma C-spine: is the 'odontoid' view necessary? *J Pediatr Surg* 35: 994-997.
15. Brown RL, Brunn MA, Garcia VF (2001) Cervical spine injuries in children: a review of 103 patients treated consecutively at a level 1 pediatric trauma center. *J Pediatr Surg* 36: 1107-1114.
16. Anderson RC, Kan P, Vanaman M, Rubsam J, Hansen KW, et al. (2010) Utility of a cervical spine clearance protocol after trauma in children between 0 and 3 years of age: Clinical article. *J Neurosurg Pediatr* 5: 292-296.
17. Pang D, Wilberger JE Jr (1982) Spinal cord injury without radiographic abnormalities in children. *J Neurosurg* 57: 114-129.
18. Pang D (2004) Spinal cord injury without radiographic abnormality in children, 2 decades later. *Neurosurgery* 55: 1325-1342.
19. Pastorelli F, Di Silvestre M, Plasmatti R, Michelucci R, Greggi T, et al. (2011) The prevention of neural complications in the surgical treatment of scoliosis: the role of the neurophysiological intraoperative monitoring. *Eur Spine J* 20: 105-114.
20. Carroll T, Smith CD, Liu X, Bonaventura B, Mann N, et al. (2015) Spinal cord injuries without radiologic abnormality in children: a systematic review. *Spinal Cord* 53: 842-848.
21. Grabb PA, Pang D (1994) Magnetic resonance imaging in the evaluation of spinal cord injury without radiographic abnormality in children. *Neurosurgery* 35: 406-414.
22. Herzenberg JE, Hensinger RN, Dedrick DK, Phillips WA (1989) Emergency transport and positioning of young children who have an injury of the cervical spine. The standard backboard may be hazardous. *J Bone Joint Surg Am* 71: 15-22.
23. Eubanks JD, Gilmore A, Bess S, Cooperman DR (2006) Clearing the pediatric cervical spine following injury. *J Am Acad Orthop Surg* 14: 552-564.
24. Swischuk LE (1977) Anterior displacement of C2 in children: physiologic or pathologic. *Radiology* 122: 759-763.
25. Hernandez JA, Chupik C, Swischuk LE (2004) Cervical spine trauma in children under 5 years: productivity of CT. *Emerg Radiol* 10: 176-178.
26. Pettiford JN, Bikhchandani J, Ostlie DJ, St Peter SD, Sharp RJ, et al. (2012) A review: the role of high dose methylprednisolone in spinal cord trauma in children. *Pediatr Surg Int* 28: 287-294.
27. Wang MY, Hoh DJ, Leary SP, Griffith P, McComb JG (2004) High rates of neurological improvement following severe traumatic pediatric spinal cord injury. *Spine* 29: 1493-1497.
28. Davidoff RA (1985) Antispasticity drugs: mechanisms of action. *Ann Neurol* 17: 107-116.
29. Kaji R, Osako Y, Suyama K, Maeda T, Uechi Y, et al. (2010) Botulinum toxin type A in post-stroke lower limb spasticity: a multicenter, double-blind, placebo-controlled trial. *J Neurol* 257: 1330-1337.
30. Ruge JR, Sinson GP, McLone DG, Cerullo LJ (1988) Pediatric spinal injury: the very young. *J Neurosurg* 68: 25-30.
31. Frankel HL, Hancock DO, Hyslop G, Melzak J, Michaelis LS, et al. (1969) The value of postural reduction in the initial management of closed injuries of the spine with paraplegia and tetraplegia. I. Paraplegia 7: 179-192.

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