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CASE-BASED UPDATE

Absence of MRI soft tissue abnormalities in severe spinal cord injury in children: case-based update

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Abstract
Introduction Occult spinal cord injury should be suspected based not only on the mechanism of trauma but also on the age of the patient. The pediatric spine has unique biomechanical and anatomical properties that must be considered carefully when evaluating spinal cord trauma. For instance, the hypermobility and elasticity of the spinal column in children often lead to self-reducing injuries that can mask spinal cord injury.
Case illustration We present the case of a 22-month-old male patient who was found to have ligamentous injury detected by magnetic resonance imaging (MRI) in the upper cervical spine but missed by MRI in the lower thoracic spine. Furthermore, there was no spinal cord injury in the upper cervical spine, but indeed a serious insult in the thoracic region. Since the advent of MRI, spinal cord injury without radiographic abnormality (SCIWORA) has become increasingly rare but not altogether extinct.
Conclusions We present a noteworthy example of the inadequacy of MRI in revealing SCIWORA, a term that is antiquated as we combine the latest imaging techniques with a better understanding of the biomechanics of trauma and spine injury. Based on the literature and our case illustration, we believe that the biomechanics of the pediatric spine must be considered when children who may have sustained a SCIWORA are examined.

Keywords Spinal cord injury · Pediatric spine · Tomography · MRI · Radiography · SCIWORA · Children · Trauma · Biomechanics

As defined by White and Punjabi, cervical spine instability is loss of the ability of the spine to maintain its orientation so that there is no neurological injury, no deformity, and no incapacitating pain during normal activity [25]. As evidenced by the literature and clinical experience, it is not always obvious when the posttraumatic cervical spine is unstable. Other regions of the spine can also be unstable without radiographic evidence.

Clearing the cervical spine is challenging, especially in the pediatric population. Current guidelines require three-view radiography and thin-cut computed tomography (CT) [10]. Yet occult spine injuries, which account for 40 to 70% of pediatric cervical spine trauma, remain a major concern in pediatric trauma cases [12, 15]. Spinal cord injury without radiographic abnormality or SCIWORA is a term that was coined before the advent of magnetic resonance imaging (MRI). It refers to injuries that are most commonly found in children.

Although the pathophysiology of SCIWORA may be unique in the pediatric population, abnormalities on MRI are common features seen in adults and children. Moreover, MRI is now a routine method for the evaluation of traumatic spine trauma (Table 1) [22]. Most patients with a spinal cord injury will exhibit some type of radiographic abnormality. Because MRI is sensitive in identifying injuries to the spinal cord or surrounding soft tissues,

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Table 1 Magnetic resonance imaging protocol and detection of spinal cord abnormalities

Pathology	Imaging technique[a]
Acute cord hemorrhage	Sagittal T2-weighted gradient-recalled echo [6]
Acute posttraumatic disc herniation	STIR
Cervical spine alignment Vertebral body integrity	Sagittal T1-weighted spin-echo [14, 22]
Spinal cord swelling	
Spinal cord edema Compression	Sagittal T2-weighted spin-echo [14, 22, 26]
Ligamentous hemorrhage	
Paraspinal ligamentous injury Bone marrow edema	STIR [14, 22, 26]

STIR short tau-inversion recovery

[a] Axial T1- and T2-weighted spin-echo sequences can be used to confirm all sagittal imaging findings

contusions and hemorrhages, herniations, hematomas, and ligamentous injury, it is a useful adjunct for the diagnosis of traumatic spinal cord injury.

Detecting a pediatric spine injury presents numerous challenges that range from difficulty in performing neurological examinations to poor detection of ligamentous injury on static radiographs to insufficient imaging studies. Occult injuries in SCIWORA are often discovered on MR images. However, we present a case in which ligamentous injury was detected in the upper cervical region but not in the lower thoracic region of the same pediatric patient.

Case illustration

History

A 22-month-old Hispanic boy was ejected as an unrestrained passenger in a motor vehicle accident. He was extricated by bystanders and brought to our facility by the paramedics as a level 1 trauma patient. Initially, he was unable to move his upper right extremity, but he soon regained movement and localizing ability. At presentation, he could move neither lower extremity; this deficit has remained and palpable pulses exist in both lower extremities. Extensive MRI showed a significant thoracic cord contusion without an associated fracture or ligamentous injury. Spleen and kidney lesions and an unstable pelvic fracture were also present.

Examination and imaging studies

The patient was intubated and sedated, which precluded a good neurological examination. His rectal tone was decreased, and he was not moving his lower extremities. At presentation, he reportedly localized purposefully with his upper left extremity but only withdrew on the right. Eventually, he regained purposeful movement with his upper right extremity although still less than on his left side. He did not withdraw or react to pain in the lower extremities. His pupils were pin point bilaterally. No blood or cerebrospinal fluid was present in the ears, nose, or throat. His paraplegia failed to improve.

CT of the head was negative for trauma, and the predental interval was normal. CT of the thoracic and lumbar spine was negative; there was no evidence of epidural hematoma in any region of the spine. MRI showed the following neurological findings: a small amount of subarachnoid hemorrhage (SAH) over the convexities and within the interpeduncular cistern, opacification of the mastoid air cells and paranasal sinuses, ligamentous injury at the atlanto-occipital and atlantoaxial junctions, a spinal cord hematoma and edema at T10–T11 without evidence of ligamentous or bony injury of the thoracic or lumbar spine, and SAH within the lumber spinal canal.

Contrast-enhanced MRI of the entire spine showed normal alignment of the anterior and posterior spinal elements and no evidence of subluxation. The vertebrae and disc spaces were normal, and no compression-type fractures were identified anywhere in the spine. At the craniocervical junction, a marked short tau-inversion recovery (STIR) hyperintensity was present within the bilateral joint spaces between the occipital condyles and the lateral masses of C1. At T10–T11, a left eccentric hematoma was surrounded by edema (Fig. 1). There was no significant STIR intensity within the thoracic vertebral bodies or the thoracic paraspinous soft tissues (Fig. 2). Hyperintense STIR signals were also noted within the atlantoaxial articulations bilaterally and within the interspinous interval at C1–C2 (Fig. 3). Some layering of SAH was present within the dependent portions of the lumbar spinal canal. All films were reviewed by neuroradiologists.

The patient was placed on steroids to treat his neurological complications. No further treatment was provided.

Discussion

Various features of the pediatric spine must be considered when a patient is evaluated for instability and spinal cord

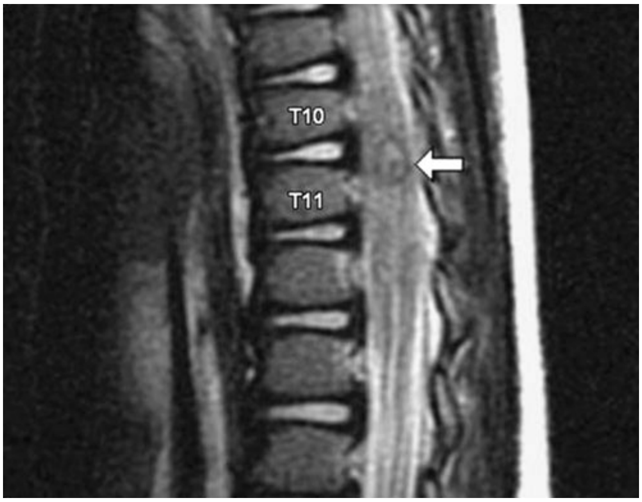

Fig. 1 Sagittal T2-weighted MRI of the thoracic spine demonstrating traumatic hematomyelia at the T10–T11 level (*white arrow*)

injury. Our patient illustrates important aspects of the young spine that lead to unique injuries. In the immature spine, the vertebrae have special characteristics that heighten intersegmental mobility [13]. The vertebral bodies are wedged anteriorly, a configuration that enhances flexion and forward translation [3, 6, 21]. Compared to the adult spine, the shallow facets are oriented more horizontally, contributing to hypermobility during flexion, extension, and rotation [4, 6, 24, 25]. The uncinate processes, present in adult vertebrae, are missing in children younger than 10 years old [5, 23].

Compared to the adult spine, the stabilizing forces of the paraspinous musculature are reduced in the pediatric spine.

Fig. 2 STIR sequence demonstrating lack of soft tissue injury at the level of the thoracic spinal cord injury

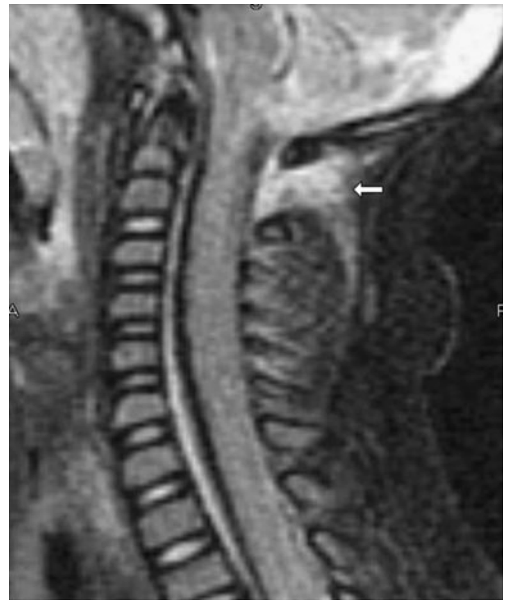

Fig. 3 Sagittal MRI showing significant ligamentous injury on the STIR sequence at the upper cervical region (*arrow*)

The spinous and transverse processes are less developed in children. Therefore, the musculature cannot transmit the same forces allowed by the longer mechanical levers represented by adult processes. The intervertebral discs are also different; they help allow some motion between the bodies and the development of secondary lordoses. In the adult, they can attain 25% of the height of the vertebral body. In neonates, however, they are almost equal in height to the vertebral body.

In a child, the disc is rubbery and firm, more like that of a degenerated disc in an adult. With its tenacious attachment to the end plates, the disc frequently remains intact after severe spinal trauma in children. The weak point is the interface between the end plate and vertebral body. A shear injury involving this site can cause the disc to penetrate the marrow of the vertebral body. The hypervascular growth zone in the endplate is brittle and easily splits from the primary centrum [2, 11]. Finally, the large head of the infant overwhelms the underdeveloped nuchal musculature, a notable cause of hyperextension and hyperflexion injuries [17].

The elasticity of the ligaments of the spine, which connect the vertebrae, varies. For instance, the elasticity of the interspinous ligament is inversely proportional to a child's age. The interspinous ligament also appears to generate little intervertebral tension, further contributing to hypermobility of the young spine until about 8 years of age [19]. Altogether, the biomechanics of the immature spine inherently increase the mobility of the spine at the expense of its protective function. In children, the elastic interspinous ligament combined with the malleable spinal column can cause a self-reducing injury associated with a severe SCIWORA.

Atlanto-occipital dislocations are often associated with a high-energy mechanism of trauma and are usually fatal. Recent advances in emergency medicine, however, have increased the frequency with which this type of injury reaches medical attention [19]. In children, the occipital condyles are poorly developed, preventing stable atlanto-occipital articulation and stability. Consequently, the propensity for dislocation is high [12, 27].

C1–C2 dislocations related to trauma have various causes and may be associated with fractures. They are classified as either anterior, posterior, or rotatory. Because traumatic displacements of the atlantoaxial joint are associated with severe ligamentous injury and head injury [7], they are rarely seen in clinical settings. In fact, the atlantoaxial region is the level most commonly injured in children.

The types of injury seen in the pediatric population reflect the maturation of the extraneural components of the spine with age. For instance, the instability of the upper cervical spine in children leads to more upper spinal cord lesions, especially in children under 9 years of age [16]. Thoracic lesions without radiographic abnormality seem to lack a discernible age distribution. However, Pang et al. found a small predilection for SCIWORA at T1–T6 in children under the age of 8 years [17].

The neurologic findings associated with SCIWORA vary, but most children present with a complete injury, especially if the trauma is localized to the thoracic spine [20]. Older children are less likely to suffer complete injuries. When they do, the lesions are more likely to be in the cervical region [9]. The hypermobility and elasticity of the pediatric spine produce a transient subluxation followed by a strong recoil of the spine. Despite the presence of a spinal cord injury, the result is normal alignment, which often masks the injury itself [8, 18]. A sad example is infants who are quadriplegic after breech extraction—the spinal cord and meninges rupture while the vertebral column remains totally intact [1]. Thus, imaging studies must include the patient's age as a primary determinant of the possible neurological complications associated with a traumatic spinal injury.

Based on the literature and our case, we believe that the biomechanics of the pediatric spine must be considered when children who may have sustained a SCIWORA are examined. Our case serves as an internal control because the MRI showed ligamentous injury in the upper cervical spine but not in the lower thoracic spine. To our knowledge, a similar case has not yet been reported. In our patient, we postulate that the thoracic injury was likely accompanied by ligamentous injury and spinal column instability with subluxation that was self-corrected. The discrepancy in the sensitivity of MR imaging in detecting the cervical and thoracic injuries deserves further investigation and should prompt more careful imaging protocols. Fusion was not considered based on this special case and regarding the age of the patient.

The alignment of the thoracic spinal cord is evidence of the self-reducing capacity of the pediatric spine. The spinal cord hematoma may have been caused by dislocation and immediate reduction or by a distracting injury, which classically is associated with motor vehicle accidents. In either case, MRI would be expected to reveal occult spinal instability associated with SCIWORA (i.e., ligamentous injury of the thoracic spine). Because it relies on past radiological and professional protocols, SCIWORA can be a misleading term. MRI has reduced the number of SCIWORA cases, but understanding pediatric pathophysiology should reduce this number further. This case highlights the inadequacy of MRI in detecting ligamentous injury in a patient with severe spinal cord injury. Further studies are needed to identify clinical scenarios and biomechanical factors that can help diagnose spinal instability when no radiographic abnormalities are present.

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