130 Spine and Spinal Cord Injuries in Children: General Aspects Including Pure Ligamentous Injuries in Children

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Introduction

Spinal injury due to trauma is considered relatively uncommon in the pediatric population. It is estimated that patients with spinal trauma comprise 1–4% of children admitted to pediatric trauma centers (Anderson and Schutt 1980). Although rare, spinal trauma with or without spinal cord injury can represent a potentially

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C. Di Rocco et al. (eds.), *Textbook of Pediatric Neurosurgery*,
https://doi.org/10.1007/978-3-319-72168-2_133

devastating diagnosis with significant neurologic morbidity. The mortality rates for children with spinal trauma are substantially higher than those reported for adults (Nitecki and Moir 1994; Jones et al. 2011); these differences are explained by distinct differences in pediatric spinal anatomy and biomechanics as well as differences in the locations of spinal injury between pediatric and adult patients (Rush et al. 2013). Nearly 60–80% of all pediatric spinal injuries occur in the cervical spine (Jones et al. 2011). Children also have a higher rate of concomitant head injury with spinal trauma that contributes to higher mortality rates (Anderson and Schutt 1980; Brown et al. 2001).

This chapter discusses the current management strategies for spine and spinal cord injuries in children, including pure ligamentous injuries. It specifically highlights the importance of prehospital assessment and immobilization, epidemiology of spinal cord injuries, diagnosis of spinal injuries, and the management (surgical and nonsurgical) of spine and spinal cord injuries as well as pure ligamentous injuries in children.

Prehospital Assessment and Immobilization

The goal of prehospital assessment and management for children at high risk for spinal trauma or those in whom spinal trauma is suspected is to prevent further injury (Rozzelle et al. 2013a). After securing the airway, breathing, and circulation, the next step is spinal immobilization. Immobilization of the cervical spine in the neutral position is preferred; however, large movements or rotation to achieve a neutral position should be avoided, especially in the scenario of rotatory instability and subluxation. For children younger than 8 years of age, compensation must be made for an enlarged head-to-torso ratio; in these children, the neutral position forces the neck into flexion when the head and torso are on a flat surface (Nypaver and Treloar 1994). In a study of 40 children <8 years of age, all 40 children required elevation of the torso to eliminate positional neck flexion and achieve neutral alignment (Nypaver and Treloar 1994), and for children <4 years of age, a greater degree of elevation was required ($p < 0.05$). Thus, for children <8 years, the torso should be elevated or the head should be placed in an occipital recess to achieve a more neutral position for true immobilization. Huerta et al. (1987) evaluated the use of multiple immobilization devices and found that no collar provided "acceptable immobilization" alone; they recommended the use of a modified half-spine board, rigid cervical orthosis, and tape as an effective means of immobilizing the cervical spine in children. Although this technique can aid in immobilization, care must be taken to ensure the safety and protection of the respiratory system while doing so; Schafermeyer et al. (1991) found that the forced vital capacity is reduced when children are moved from the upright to the supine position; tape along the thoracic cavity for immobilization can further reduce the forced vital capacity by 40–90% when compared with the supine position without tape.

In summary, spinal immobilization is indicated in any traumatic setting; planning for immobilization should involve consideration of the child's age and physical maturity, specifically allowing for a large head-to-torso ratio in younger children. Careful attention should be paid to the child's airway, breathing status, and circulation while maintaining spinal alignment to prevent further injury.

Epidemiology and Socioeconomic Impact

Spinal cord injury is defined as an acute traumatic injury of the spinal cord, cauda equina, or conus medullaris that results in motor or sensory deficits, neurogenic bladder, or bowel dysfunction (Parent et al. 2010). Spinal injuries in children occur with an incidence of 1.99 per 100,000 children in the United States (Parent et al. 2010). Most spinal cord injuries in pediatric patients happen in the 15–18 years of age range; only 10% of all children who experience a spinal cord injury are younger than 15 years of age (Parent et al. 2010). The most common location for pediatric spinal cord injuries is the cervical spine, comprising 60–80% of cases.

Less commonly, the thoracolumbar region is involved, occurring in just 5–30% of cases (Dogan et al. 2007; Platzer et al. 2007; Reilly 2007).

African-American children experience the highest rate of spinal cord injuries, i.e., 1.53 per 100,000, followed by Native Americans, i.e., 1.00 per 100,000, Hispanics, i.e., 0.87 per 100,000, and Asians, i.e., 0.36 per 100,000 (Parent et al. 2010). Males are twice as likely to suffer spinal cord injuries as females. The most common mechanism of injury associated with pediatric spinal injuries is motor vehicle accidents, which account for 50–55% of injuries, and 68% of the patients are reportedly unrestrained at the time of injury (Brown et al. 2006). Additional causes of pediatric spinal cord injury include birth-related injuries, sports-related injuries, falls, diving, and gunshot wounds (Lallier et al. 1999; Caird et al. 2005; Vitale et al. 2006).

For all patients that experience spinal cord injury, there is a need for significant acute and chronic care and rehabilitation. This is especially true for children who experience spinal cord injury; in fact, a conservative estimate for lifetime costs for a 10-year-old child with a spinal cord injury in the United States can range from \$2.5 million dollars for an incomplete injury to nearly \$6 million for a high cervical complete injury (Mulcahey et al. 2004).

Imaging

The initial imaging for a child who is thought to have a spinal cord injury is often performed in the emergency department on arrival and prior to transport to a tertiary care facility. Screening imaging can be accomplished with plain x-rays, computed tomography (CT) of the cervical spine, or magnetic resonance imaging (MRI) in cases where there is high suspicion or neurological symptoms of spinal cord injury. Bohn et al. (1990) described the need for spinal imaging in pediatric trauma in patients that have unexplained hypotension or experience cardiac arrest, as these may be signs of severe cervical spinal cord injury. Laham et al. (1994) investigated the use of cervical spine x-rays (3-view series of images: anteroposterior (AP) and lateral) in 268 children with isolated head trauma; they concluded that screening radiographs are not necessary in children with no neck pain or neurological deficit if they are able to communicate.

Viccellio et al. (2001) proposed five criteria that they found indicated low risk for severe cervical spinal cord injury in the 3065 children in the National Emergency X-Radiography Utilization Study (NEXUS). The criteria included (1) absence of midline cervical tenderness, (2) absence of intoxication, (3) normal level of alertness, (4) nonfocal neurological examination, and (5) absence of other painful distracting injury. If all five criteria are met, the child is considered low risk, but if even one criterion is not met then the child is considered high risk. More than six hundred patients fulfilled the low-risk criteria and none of them had evidence of cervical spine injury by radiographic evaluation; 30 injuries (0.98%) were documented in children defined as high risk. Viccellio et al. (2001) concluded that use of the NEXUS criteria in children would reduce x-ray use by 20% and not result in missed injuries; however, the number of patients <2 years of age was small, so the sensitivity of this finding in younger children is accompanied with large confidence intervals. Thus, these Class II data "cautiously" endorse the use of the NEXUS criteria in children, in particular in children from 0 to 9 years of age.

In another Class II prospective trial, Anderson et al. (2006b) proposed a protocol in which children >3 years of age with normal radiographs who met all five NEXUS criteria were cleared, but all others required additional imaging or neurosurgery consultation. They found that use of the protocol led to a 60% increase in the number of patients that could be cleared by others rather than neurosurgery.

For children <3 years of age, Anderson et al. (2010) reported a protocol involving plain radiographs (AP and lateral views) and CT scans for inadequate findings or if there was high suspicion of injury. If the initial imaging was negative, further studies depended on airway status, neurological condition, dynamic imaging, and/or

MRI. The use of MRI was reserved for children in whom there was a high suspicion of spinal cord injury, those that were obtunded for >48 h, and children with persistent neck pain. In the 575 children under 3 years to whom this protocol was applied, there were no missed injuries; CT scans were used in 14% of cases, MRI was obtained in 10% of cases. These Class II data were limited by the small number of injuries reported in this study (28 of 575) (Anderson et al. 2010).

Garton and Hammer (2008) found that in children <8 years of age, only two injuries would have been missed by using the NEXUS criteria (sensitivity of 94%); furthermore, they reported improved sensitivity for plain x-rays in combination with limited CT evaluation (occiput-C3) versus plain x-rays with flexion/extension views (sensitivity 94% vs. 81%).

Ehrlich et al. (2009) assessed the NEXUS low-risk criteria and the Canadian C-spine Rule (CCR) in children <10 years of age and found that both methods would have missed clinically important cervical spine injuries: the sensitivity and specificity for NEXUS were 42% and 96%, respectively, and those for CCR were 86% and 94%, respectively. They concluded that neither method is suitable for use in young children, <10 years of age. Katz et al. (2010) reviewed 905 infants (<12 months of age) after low-impact head trauma (mechanism other than MVA or fall >10 feet) and discovered only two cervical spine injuries, both after nonaccidental trauma (NAT); they conclude that routine cervical spine imaging in this population is not necessary, unless there is concern for NAT.

The use of open-mouth odontoid views in pediatric trauma has been called into question. Swischuk et al. (2000) surveyed pediatric radiologists to determine how many injuries were missed on lateral imaging, but detected on open-mouth views. Twenty-eight of the 432 respondents (7%) missed a total of 46 fractures on lateral view that were subsequently detected on open-mouth odontoid views, yielding a missed fracture rate of 0.007 per year per radiologist. They concluded that open-mouth odontoid views are not routinely needed in children; thus, diagnosis could be enhanced by the widespread use of thin-cut cervical spine CT for trauma evaluation. Buhs et al. (2000) also determined that open-mouth views were not necessary for cervical spine clearance in children <9 years of age.

Dynamic imaging of the cervical spine in children can be helpful in clearance and identifying pure ligamentous injury without fracture. Lui et al. (1996) presented a series of 22 patients with C1-2 injuries and found that flexion-extension films were necessary to identify instability in 4/12 (33%) odontoid fractures and 6/9 (66%) suspected pure ligamentous injuries with resultant atlantoaxial dislocation. Ralston et al. (2001) reported on the use of flexion-extension x-rays in 129 children following initial static radiographs and concluded that dynamic imaging was valuable for confirming spinal stability when static imaging is questionable.

Scarrow et al. (1999) described the use of flexion-extension fluoroscopy, somatosensory-evoked potentials, and MRI in evaluating the obtunded child for cervical spine clearance and to rule out injury. Although their investigation involved 15 children, three of whom were believed to have a change in SSEP and one of which underwent MRI of the cervical spine that did not display injury, they were unable to make conclusions about the use of these modalities in combination as part of a protocol to aide in cervical spine clearance.

Age-related changes in maturation must be considered when interpreting imaging of the pediatric cervical spine. Normal findings that are commonplace on radiographs and CT imaging of children include pseudosubluxation of C2 on C3, overriding of the anterior atlas in relation to the odontoid on extension, exaggeration of the atlantodental interval (ADI), and radiolucent synchondrosis between the odontoid and C2 body (Rozzelle et al. 2013a). Vachhrajani et al. (2014) demonstrated age-dependent and independent findings on normal CT measurements of the upper cervical spine for the ADI, basion–dental interval (BDI), posterior atlantodental interval (PADI), lateral mass interval (LMI), and craniocervical interval (CCI). They concluded that age-dependent and independent CT measurements help to differentiate physiological and pathological states in children.

An earlier study by Hutchings et al. (2009) demonstrated a sensitivity and specificity of 100% for CT in diagnosing cervical spine injuries, but there were only six injuries in this cohort. Nonetheless, CT imaging of the cervical spine for trauma evaluation has become the standard of care due to its ease, availability, and sensitivity for recognizing traumatic spinal injuries.

Pang and colleagues (2007a, b) performed a study using CT imaging for diagnosing atlantooccipital dislocation (AOD) in the pediatric population (89 children without AOD and 16 children with AOD) (Fig. 1). They proposed the use of the condylar-C1 interval (CCI), which had a sensitivity and specificity of 100% compared with standard measurements on plain radiographs, which had a sensitivity between 25 and 50% and a specificity between 10 and 60%. This class I medical evidence for the diagnosis of AOD among pediatric patients is currently the gold standard.

The role of helical CT for imaging high-risk patients involved in severe, blunt, multisystem trauma has been previously reported (Berne et al. 1999). In a series of 58 patients, 20 cervical spine injuries were discovered; 8 of them (5 stable, 3 unstable) were undiagnosed by plain radiographs. The authors concluded that cervical spine CT should be used to assess for injury in high-risk trauma patients, although in young children in whom the entire spinal column can be visualized on plain x-rays, the need is not as great. Gargas et al. (2013) concluded, based on findings in 173 children who underwent CT and MRI, that high-resolution CT with sagittal and coronal reconstructions is comparable to MRI for the detection of unstable cervical spine injuries; in addition, they indicated that CT can be used for cervical spine clearance to prevent long-term hard collar use. For cervical spine clearance, Brockmeyer et al. (2012) found that CT had 100% sensitivity and 95% specificity, whereas MRI had 100% sensitivity and 74% specificity; thus, they also recommended using CT for initial cervical spine clearance in children (Fig. 2).

The use of MRI is common in the setting of an obtunded child or with the presence of a focal neurological deficit, but there are few reports about its efficacy and utility in the pediatric trauma literature. Keiper et al. (1998) reviewed the use of MRI in the evaluation of children with cervical spine trauma who had no evidence of fracture but did have persistent delayed symptoms or instability. Among the 52 children, there were 16 abnormal MRIs. The most common abnormalities discovered were posterior soft tissue and ligamentous changes. Four of the 52 children underwent surgical fixation, and the MRI findings

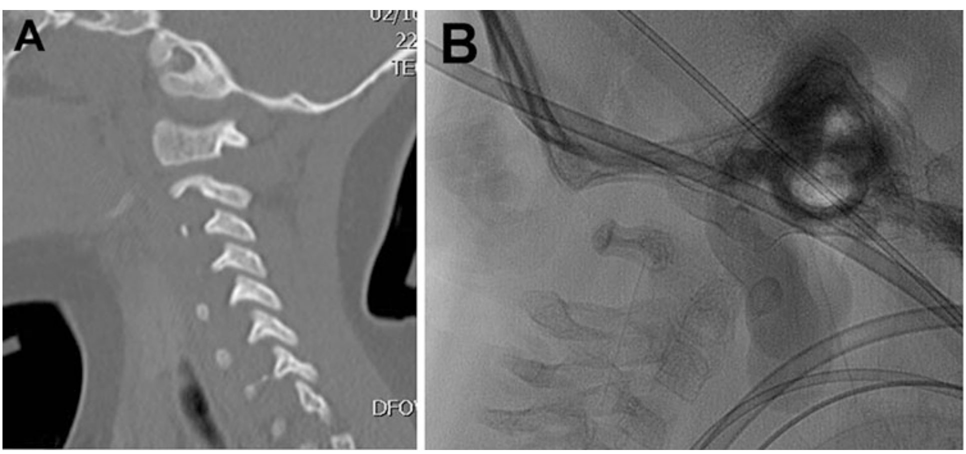

Fig. 1 (**a**) Sagittal CT demonstrating an enlarged CCI of >4 mm indicating a high likelihood of atlanto-occipital dislocation. This patient was managed surgically. (**b**) Intraoperative radiograph demonstrating the widening between the occiput and C1 with gross instability. This patient underwent an occiput-C2 posterior spinal fusion

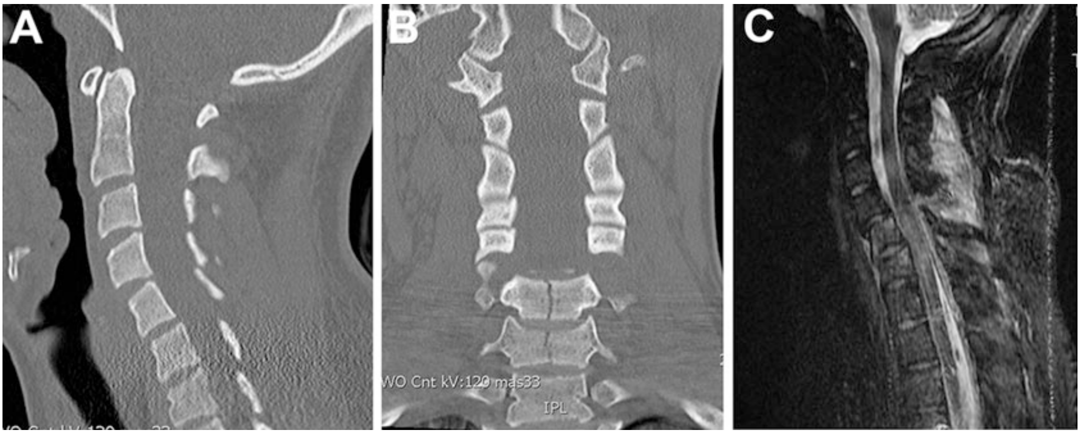

Fig. 2 Sagittal (**a**) and coronal (**b**) CT demonstrating a coronally oriented fracture through C5 and C6. Sagittal stir sequence MRI (**c**) demonstrating significant C4-5 ligamentous injury as a result of a hyperflexion mechanism

provided the surgeon with information to stabilize more levels than would have been stabilized without MRI (Keiper et al. 1998). Davis et al. (1993) also described the use of MRI in evaluating pediatric spinal cord injury in 15 patients and found that it did not reveal any lesion that would warrant surgery; however, they did observe that MRI findings correlated with neurological outcome. They also concluded that MRI findings may influence intraoperative decision making in those patients requiring fusion and could be considered as an adjunct (Davis et al. 1993). MRI can be especially helpful in the diagnosis and management of spinal cord injuries without radiographic abnormality (SCIWORA).

By definition, SCIWORA occurs in the setting of clinical findings of neurological deficit despite normal neutral and dynamic radiographs, CT imaging, and MRI (Pang and Wilberger 1982). SCIWORA has an incidence of nearly 20% of all pediatric spinal cord injuries. SCIWORA occurs nearly exclusively among younger children, particularly those 8 years or younger. SCIWORA is uncommon in adolescents and rare among adults. Cervical and thoracic spinal levels are injured with the same frequency, but lumbar levels are rarely involved. SCIWORA injury patterns differ between children of younger (0–8 years) and older (9–16 years) ages. Younger patients have a higher proportion of complete neurological injuries (Rozzelle et al. 2013b), whereas adolescents have a lower incidence of complete spinal cord injury due to SCIWORA.

SCIWORA occurs secondary to the ligamentous flexibility and elasticity of the immature spine. A young child's vertebral column can withstand elongation without evidence of injury while the spinal cord is injured. Infant spine and cadaver specimens have been shown to withstand up to 2 inches of stretch without disruption, while the spinal cord ruptures only after 0.25 inches of stretching (Wilberger 2005). This mismatch explains the higher incidence of SCIWORA injuries in young children.

Children who experience an episode of SCIWORA are at increased risk for recurrent episodes; subsequent episodes may be more severe and carry permanent sequelae. The use of external orthosis for several months to prevent further injury is common practice, but there are no standardized treatment guidelines available. Once SCIWORA is diagnosed, however, a conservative treatment approach with external orthosis is advised.

Nonsurgical Injury Management

There are several nonsurgical aspects of pediatric spinal cord injury and management that require consideration. This section discusses several categories of spinal cord injury in children. The medical management of spinal cord injuries in the adult sector is well described and studied, but no literature exists in this realm for children. For example, there is no information regarding the use of corticosteroids in pediatric spinal cord injuries; in fact, for NASCIS II and NASCIS III, which evaluated the pharmacological therapy of corticosteroids after acute spinal cord injury, children younger than 13 years of age were excluded from the study (Bracken et al. 1990). Similarly, there is no specific information with regard to mean arterial pressure goals or pressor therapy. Although adult blood pressure parameters and physiology are often applied to pediatric spinal cord injury patients, there is a paucity of Level I evidence supporting this practice.

Neonatal Spinal Cord Injury

The birthing process can result in spinal cord injury at a frequency of 1 per 60,000 births (Viccellio et al. 2001), with the most common location of such injuries being the upper cervical spine, followed by the cervicothoracic junction (MacKinnon et al. 1993). MacKinnon et al. (1993) described a series of 22 neonates with birth-related spinal cord injuries: 14 with upper cervical injuries, 6 with cervicothoracic injuries, and 2 with thoracolumbar injuries. All cervical injuries were associated with cephalic presentation and the use of forceps, whereas the cervicothoracic injuries were associated with breech presentation. All infants had evidence of spinal shock with flaccidity, no spontaneous motion, and absence of deep tendon reflexes. The neurological outcome after neonatal spinal cord injury is quite poor, with six of the seven patients with upper cervical spine injuries requiring mechanical ventilation and only two of the six with cervicothoracic spinal cord injury patients surviving, both of whom remained paraplegic.

Rossitch and Oakes (1992) reported five neonates with birth-related spinal cord injuries, four of whom were misdiagnosed with Werdnig-Hoffman syndrome, occult myelodysplasia, and birth asphyxia. Only one of the infants in this series demonstrated abnormalities on radiographs, but this was AOD. The absence of respiratory effort within 24 h of life is associated with dependence of long-term mechanical ventilation (Rozzelle et al. 2013a).

The treatment for neonatal spinal cord injury is variable and can depend on the patient's level of function, age, and weight. Pang and Hanley (1990) described the use of an external immobilization device for neonates that included a thermoplastic molded device that contoured to the occiput, neck, and thorax. Velcro straps were used across the forehead and torso to fully immobilize the infant. This, however, represents a single report as there are no large series of treatment methods to provide support for any individual measure.

Odontoid Epiphysiolysis

The dentocentral synchondrosis of C2 does not fuse completely until the age of seven and can represent a vulnerable site of injury in young children (Griffiths 1972); however, injuries to this area most commonly happen in preschool-aged children (Mandabach et al. 1993). It can be detected on plain x-ray alone, which demonstrates anterior or posterior angulation of the odontoid process (Sherk et al. 1978). Mandabach et al. (1993) described 13 children with odontoid injuries; eight of ten children who were managed with halo immobilization alone achieved stable fusion. The authors concluded that because the injury goes through the epiphysis, reduction and immobilization would result in adequate fusion over time, with a mean time to fusion of 13 weeks (range 10–18 weeks) (Mandabach et al. 1993).

Sherk et al. (1978) reported on 35 children with odontoid injuries, only one of which required surgical fixation. Fassett et al. (2006) performed a meta-analysis on 55 odontoid synchondrosis fractures and found that among 45 cases in which closed reduction and immobilization were performed, 42 resulted in stable fusion (93%). Immobilization was achieved with a halo or Minerva jacket; more importantly, surgical fusion was performed in eight cases (4 as initial treatments, 3 immobilization failures, and 1 delayed diagnosis). In all 8 cases, stable fusion was achieved without complications (Fassett et al. 2006). Posterior atlantoaxial fixation for these injuries is the most commonly performed and can be done safely (Gluf and Brockmeyer 2005; Anderson et al. 2006a), but anterior fixation with an odontoid screw has been described. Anterior fixation may have the benefit of preserving motion and obviating the need for external bracing (Godard et al. 1997); however, this must be considered carefully in the setting of other injuries, the potential benefits of avoiding external bracing, and other clinical factors.

Atlantoaxial Rotatory Subluxation or Fixation

Rotatory subluxation of C1-2 is more common during childhood and can happen after minor trauma. Additionally, it can happen spontaneously or as a sequela of an upper respiratory infection (Rozzelle et al. 2013a). The patient presents with the head rotated to one side and tilted to the other side causing the "cock-robin" appearance; the child is also unable to turn their head past the midline (Rozzelle et al. 2013a). Although a child can present with neurological deficits, most commonly there is no associated neurological compromise (Kowalski et al. 1987; Phillips and Hensinger 1989; Subach et al. 1998; Eleraky et al. 2000; Pang and Li 2004).

Fielding and Hawkins (1977) classified atlantoaxial rotatory subluxation into four categories: type I – described as unilateral anterior rotation of the atlas pivoting around the dens with a competent transverse ligament; type II – described as unilateral anterior subluxation of the atlas with the pivot being the contralateral C1-2 facet and ADI < 5.0 mm; type III – described as anterior subluxation of both C1 facets with an incompetent transverse ligament; and type IV – described as posterior displacement of C1 relative to C2 with an absent hypoplastic odontoid process. Type I and II injuries account for the vast majority of rotatory atlantoaxial subluxations.

Subach et al. (1998) reported 20 children with C1-2 rotatory subluxation, four of them reducing spontaneously. Reduction was achieved in 15/16 (94%) treated with traction for 4 days on average; six children required fusion because of recurrent subluxation (5 children) and in one case that was irreducible. Importantly, no child experienced recurrent subluxation if reduced within 21 days of symptom onset.

Nonsurgical management can be used for these injuries when the subluxation is treated early. In addition, if the subluxation is easily reduced and treated early on, the use of a rigid collar can be limited to 4 weeks and is typically sufficient for healing (Rozzelle et al. 2013a). Since C1-2 rotatory subluxation can reduce spontaneously in the first week, traction or manual manipulation and realignment can be reserved for those injuries that do not spontaneously resolve (Rozzelle et al. 2013a). More restrictive external immobilization (i.e., halo vest, Minerva brace) is used longer term, 4 months, for those presenting late or with recurrent subluxation (Phillips and Hensinger 1989). Surgical arthrodesis can be considered for those with irreducible subluxations, recurrent subluxations, or subluxations present for >3 months' time (Rozzelle et al. 2013a).

Treatment with Cervical Spine Immobilization

An injured pediatric cervical spine requires immobilization for healing. This can be accomplished through rigid external immobilization or surgical fixation internally. External immobilization may be required in conjunction with placement of temporary traction in order to restore alignment.

The body of literature on traction for restoration of alignment or providing decompression is scant in the pediatric population. The use of halo traction or Gardner–Wells tongs in children must be done carefully because of their thinner skulls and higher chance of skull penetrations. Additional concerns when performing traction maneuvers on children include lighter body weight, which in turn provides less counter traction, more elastic ligaments, and less robust paraspinal musculature, which can lead to over distraction (Rozzelle et al. 2013a). Gaufin and Goodman

(1975) reported on three infants that were treated with bilateral pairs of burr holes and the passing of a 22-gauge wire through them to provide fixation points from which to hang weight. Mubarak et al. (1989) described halo application in infants; three infants (7, 16, and 24 months) were kept in a halo device for 2–3.5 months with no obvious neurological complication and adequate healing.

Dormans et al. (1995) reviewed 37 children managed in halo immobilization; an overall 68% complication rate was reported. The most common complication was pin-site infections, although upon further evaluation these was more common in those >10 years of age. Loosening of the pins, which occurred mostly along the anterior pin sites, was the most common complication in children <10 years of age. They also reported one case of dural laceration and one case of transient supraorbital nerve injury (Dormans et al. 1995). Baum et al. (1989) concluded that the halo device appears to provide satisfactory immobilization of the cervical spine in children; it is accompanied, however, by a higher rate of minor complications in comparison with adults.

The use of thermoplastic Minerva braces has been described previously (Gaskill and Marlin 1990) and may offer a reliable alternative to halo immobilization in younger children.

Surgical Management of Spine Trauma and Spinal Cord Injury

Although spinal fixation is often necessary in the setting of spine and spinal cord injury, there is no literature regarding early versus late surgical decompression in the setting of acute pediatric spinal cord injury (Rozzelle et al. 2013a). The choice of approach, either anterior or posterior, is made based on the location of injury and degree of compression of the spinal cord (Fig. 3).

For injuries to the cervical spine requiring C1-2 fixation, either a Goel–Harms construct (Heuer et al. 2009) or transarticular screw fixation (TAS) (Gluf and Brockmeyer 2005) is acceptable for achieving arthrodesis. In the setting of an odontoid fracture, the use of an odontoid screw fixation technique is acceptable as a motion-sparing operation after about 8 years of age. For fixation of the subaxial cervical spine, lateral mass fixation as described in adults has been utilized. For thoracic and lumbar spine trauma, multisegmental pedicle screw fixation with rods is the standard treatment for cases not amenable to conservative management with external bracing. The specific treatments and technical methods for fixation are outside the scope of this chapter.

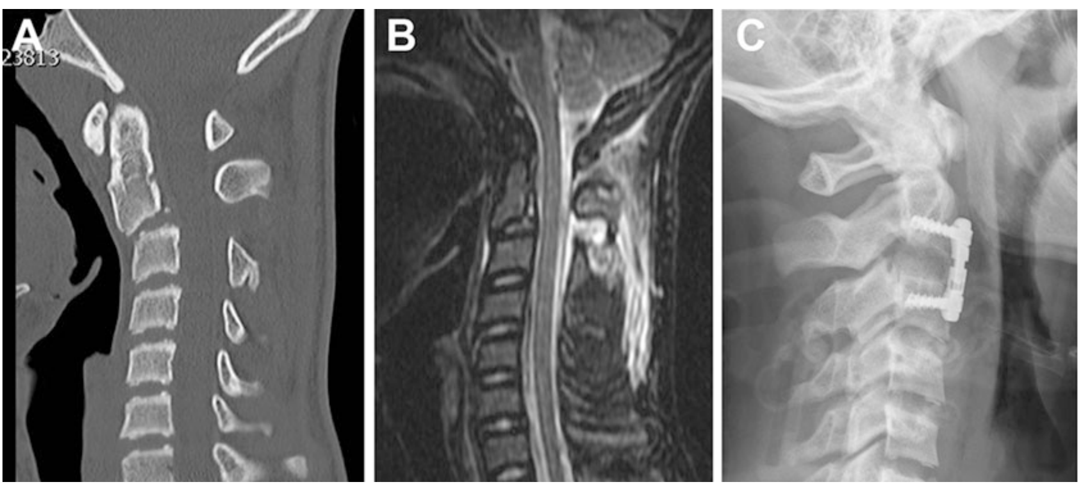

Fig. 3 (**a**) Sagittal CT demonstrating anterior subluxation of C2 on C3. (**b**) Sagittal stir sequence MRI showing posterior ligamentous injury at C2-C3. (**c**) Because of the instability, the patient was treated with a C2-3 anterior cervical discectomy and fusion

Thoracolumbar Spine Trauma

Trauma to the thoracolumbar spine in children is rare but can carry significant neurological morbidity. Fractures of the thoracolumbar spine account for 1–2% of all pediatric fractures (Akbarnia 1999; Cirak et al. 2004; Dogan et al. 2007). The most common mechanism for thoracolumbar trauma in children is motor vehicle accidents, which accounts for 33–58% of all injuries (Carreon et al. 2004; Dogan et al. 2007; Junkins et al. 2008). Additional mechanisms of injury can include fall from height, sports trauma, child abuse (King et al. 1988; Dogan et al. 2007; Junkins et al. 2008), football, skiing, and all-terrain-vehicle accidents. Children under the age of eight are less likely to suffer thoracolumbar spine injuries than older children (Parent et al. 2010) because of altered biomechanics, with large head-to-body ratio, leading to a higher incidence of cervical spine injuries. Also, the mechanisms that lead to thoracolumbar trauma affect older children more so because of their participation in these high-risk activities (Reilly 2007). The use of safety belts in all children, but in particular those above the age of 3, has provided a significant reduction in the risk of injury and death (AAP Committee on Injury, Violence and Poison Prevention, Policy Statement 2011); this is also true for prevention of significant thoracolumbar injuries, most notably Chance fractures.

As in the pediatric cervical spine, there are many differences between the pediatric and adult thoracolumbar spine. These include greater ligamentous laxity, shallower and more horizontally oriented facet joints, and decreased paraspinal muscle bulk (Carreon et al. 2004). Additional factors include the water content of the disk space and less overall collagen crosslinking leading to more elasticity and a greater ability to dissipate force (Akbarnia 1999). Patients 8 years of age or older have fracture patterns similar to those seen in adults, whereas children younger have different patterns. The location of the spinal cord also plays a role in injury states: the spinal cord ends at L3 in newborns and migrates to L1 or L2 during adolescence (Daniels et al. 2013); therefore, injuries at the level of the spinal cord may result in complete spinal cord injury, whereas injuries below may lead to a conus medullaris or cauda equina syndrome.

When evaluating a child with suspected thoracolumbar injury, a complete neurological examination should be obtained, including motor and sensory examination, rectal and genital examination, and reflex testing, including bulbocavernosus testing (Daniels et al. 2013). Palpation should be performed examining for step-offs and deformities. Physical examination can be 87% sensitive and 75% specific for detecting thoracolumbar spine fractures (Santiago et al. 2006). Additional consideration should be given to intra-abdominal and intrathoracic injuries that can accompany thoracolumbar spine fractures, which can exist in 40% of children (Louman-Gardiner et al. 2008). The most common concomitant injuries include small bowel injuries, pancreatic rupture, hemothorax, pneumothorax, lung contusion, and aortic injuries (Daniels et al. 2013); these are especially common in those wearing lap safety belts.

Imaging for suspected thoracolumbar trauma includes AP and lateral radiographs of the thoracic and lumbar spine. CT may be used in situations where there is obvious step-off and deformity with neurological dysfunction or significant osseous destruction requiring characterization; additionally, CT may be useful in pretreatment planning, either for surgical or conservative measures. MRI is being used more commonly because of its lack of ionizing radiation and the ability to assess soft tissue structures and detect ligamentous disruption, disk herniation, and spinal cord and nerve root injury (Sledge et al. 2001). It is important that urgent MRI be obtained for any pediatric patient with a thoracolumbar spine injury and neurological deficit (Dare et al. 2002).

The Thoracolumbar Injury Classification and Severity Score (TLICS) (Table 1) is used to describe thoracolumbar spine trauma and provide information about predicting surgical intervention and outcomes (Vaccaro et al. 2005); however, its

Table 1 Thoracolumbar injury classification and severity score system[1]

Characteristic	Number of points
Morphology	
Compression	1
Burst	2
Rotation/translation	3
Distraction	4
Disruption of the posterior ligamentous complex	
Intact	0
Suspended	2
Disrupted	3
Neurologic Status	
Intact	0
Nerve deficit	2
Cord, conus medullaris: complete	2
Cord, conus medullaris: incomplete	3
Cauda equina	3

[1]Non-surgical management is recommended when the sum of all categories is 0–3, and surgical intervention is recommended when the sum is greater than 4. When the total is 4, either treatment method may be considered (Adapted with permission from Vaccaro et al. 2005)

use has not been validated nor widely accepted in pediatric patients.

Compression Fractures

Compression fractures are the most commonly encountered fracture type in the pediatric spine, and most of them occur at the thoracolumbar junction (Carreon et al. 2004; Dogan et al. 2007). They result from low-energy injuries; mechanically they occur because of axial loading and flexion of the spine resulting in collapse of the anterior cortex of the vertebral body, resulting in <20% loss of height (Akbarnia 1999; Daniels et al. 2013). Neurological compromise is rare and management entails nonsurgical treatment in a thoracolumbosacral orthosis (TLSO) (Daniels et al. 2013). For single-level compression fractures not close to the thoracolumbar junction, bracing can be used as a comfort measure only and can be avoided completely if the patient does not have discomfort without immobilization.

Burst Fractures

Burst fractures occur in axial loading injuries where the nucleus pulposus is driven into the vertebral body, leading to fracture and displacement of the anterior and middle columns (Daniels et al. 2013). These injuries most commonly occur at the thoracolumbar junction (Dogan et al. 2007). The patient may experience neurologic compromise due to retropulsion of the posterior elements resulting in biomechanical instability and dural tear. The higher along the thoracolumbar spinal column the injury and burst fracture are experienced, the higher the propensity for neurological injury (Vander Have et al. 2009).

Burst fractures may be biomechanically unstable if there are focal kyphosis, significant retropulsion (>50%), fracture through the laminar arch, or facet subluxation with or without neurological injury (Daniels et al. 2013). Stable burst fractures without neurologic injury may be managed in a TLSO brace for 8–12 weeks, but unstable burst fractures are treated with screw fixation and rod constructs with or without arthrodesis (Daniels et al. 2013).

Flexion–Distraction Injuries

Flexion–distraction injuries can include Chance fractures or seat belt injuries and are caused by distractive forces where the posterior column fails in tension and the anterior column fails in distraction or compressive flexion (Fig. 4) (Smith and Kaufer 1969; Rennie and Mitchell 1973). Injuries of this type can be purely osseous, purely ligamentous, or a combination of both. Concomitant visceral and head injuries occur in 40% of pediatric patients with flexion–distraction injuries (Santiago et al. 2006), so a high level of suspicion should be maintained for patients with multiple solid organ injuries requiring exploratory laparotomy (Daniels et al. 2013).

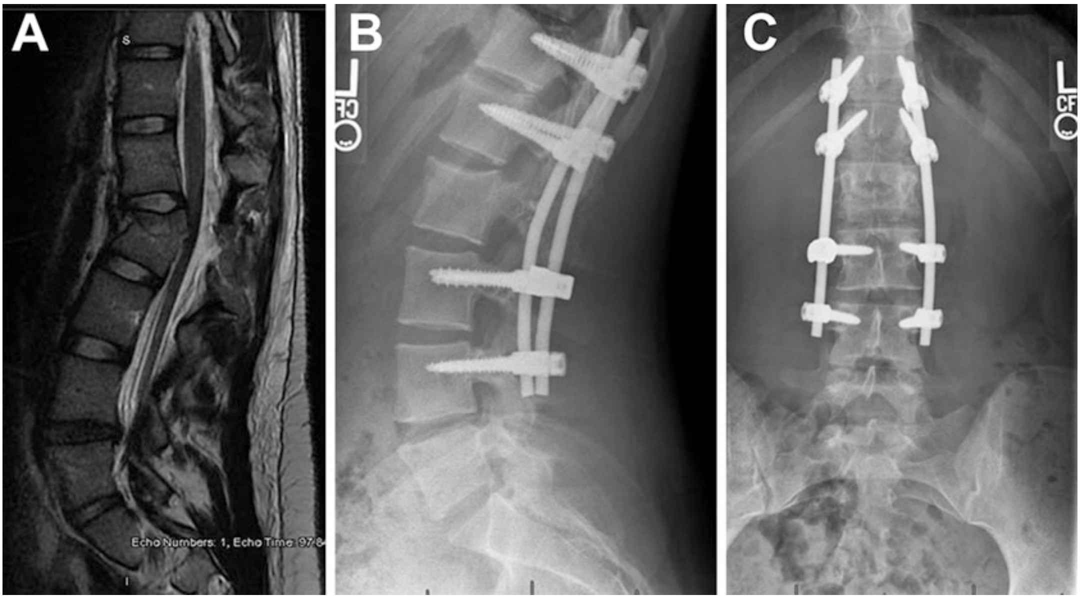

Fig. 4 (**a**) Sagittal T2 MRI demonstrating a Chance fracture through L2. The patient was managed surgically with posterior spinal fusion and arthrodesis from T12 to L4. Postoperative lateral (**b**) and anteroposterior (**c**) x-ray

Purely osseous flexion–distraction injuries may be managed in a TLSO brace with immobilization, but flexion–distraction injuries with a ligamentous disk component may require pedicle screw fixation either one or two levels above and below the injured level (Daniels et al. 2013).

Combined Fracture–Dislocations

Blunt trauma with high-energy mechanisms may lead to combined fracture patterns. These uncommon injuries may be associated with nerve root injury or avulsion, spinal cord injury, or cauda equina syndrome; often they must be manually reduced and stabilized surgically (Daniels et al. 2013).

Apophyseal Fractures and Herniation

Apophyseal fractures and herniations can occur in children aged 10–14 as a result of the open physes in the vertebral column (Shirado et al. 2005; Chang et al. 2008). This injury is analogous to intervertebral disk herniations in adults, given the apophyseal herniation into the spinal canal or neural foramen. It occurs because of the separation of the vertebral apophysis from the spongiosa layer of the vertebral body; the resultant fracture crosses the hypertrophic zone of the physis (Daniels et al. 2013). This injury can spontaneously reduce and may be difficult to detect on conventional imaging. MRI could be obtained to qualify the location and size of the herniation. Patients often present with radicular pain after strenuous activity or weightlifting. Although surgical decompression is rarely needed (Shirado et al. 2005; Chang et al. 2008), treatment in the absence of neurological deficits involves anti-inflammatory drugs and bracing.

Spinous Process/Transverse Process Fractures

Fractures of the spinous process or transverse process may occur in the thoracic and lumbar spine secondary to blunt trauma. Rarely lumbar spinous process fractures may be associated with unstable pelvic injuries or avulsions of the iliolumbar ligaments (80). Pain control is the most common treatment for these injuries, and no bracing or surgical intervention is necessary.

Pure Ligamentous Injury in Children

In children <10 years of age with cervical spine injuries, the majority of patients will have ligamentous injuries without fracture (Hadley et al. 1988; Dickman et al. 1989; Hamilton and Myles 1992; Osenbach and Menezes 1992; Dormans et al. 1995). In children >10 years of age, however, the incidence of fracture is much greater than that of ligamentous injury without fracture (80% vs. 20%) (Givens et al. 1996; Viccellio et al. 2001). Thus, the absence of fracture on CT imaging or plain radiographs should not be used to exclude injury in the pediatric cervical spine.

Schleehauf et al. (1989) reported on two false-negative CT studies with C1-2 ligamentous injuries in a study of the use of CT evaluation in the cervical spine in high-risk trauma patients; they concluded that CT should not be relied on in excluding ligamentous injuries of the pediatric cervical spine. The authors did state, however, that CT may be used to evaluate for osseous injury and difficult-to-image regions, such as the cervicothoracic junction.

Pennecot et al. (1984) described 16 children with ligamentous injuries of the cervical spine in whom they were able to manage minor ligamentous injuries (ADI of 5.0–7.0 mm or interspinous widening without dislocation or neurological deficit) with reduction and immobilization. Primarily ligamentous injuries of the cervical spine may heal with external immobilization alone, but can be associated with a high rate of persistent or progressive deformity when treated non-operatively (Rozzelle et al. 2013a).

Conclusions

Spine trauma is rare in children but can represent a potentially devastating diagnosis. Management and diagnosis of children with potential spinal cord injuries is important as early recognition can improve neurological outcomes. Recognizing pediatric-specific conditions including neonatal spinal cord injury, odontoid epiphysiolysis, and atlantoaxial rotatory subluxation or fixation can also aid in the triage, diagnosis, and treatment of children with traumatic spinal injuries. Further studies are needed to delineate pediatric-specific parameters for optimal medical management and timing for surgery.

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