Pediatric Spinal Cord Injuries

Anatomical differences bring different challenges with kids

On a warm, pleasant August morning, Waushara County (WI) EMS was dispatched to a diving accident. A 12-year-old female dove from the pier at her family’s remote country cabin and came up from the water screaming that she’d felt a snap in her neck. The girl and her family waited anxiously for the 20-plus minutes the closest ambulance took to arrive, knowing it was at least 45 minutes to the closest hospital.

When the EMS crew arrived, the patient complained of feeling neck pain since the snap but showed no neurological deficit. Knowing they had an extended drive to the hospital plus a 30-foot hill from the lake to the driveway to traverse, the crew spent several minutes carefully immobilizing their wet and shivering patient with blankets. After carefully padding a backboard and securing her tightly, they slowly carried her up the steep hill and to the ambulance for the 45-minute drive to the local ED.

I watched this entire call unfold, and when my cousin was diagnosed with a C2 body fracture and then driven, fully immobilized, three hours to the children’s trauma center for neurosurgical repair, the importance of careful and complete spinal immobilization took on a new meaning for me.

Scope of the Problem

According to the CDC, as many as 20,000 new spinal cord injuries occur annually.1 Depending on the year, up to 10% of spine injuries occur in pediatric patients.2 Spinal cord-injured patients face lifetimes of increased medical costs that can be as high as $30,000 a year. When these injuries occur in children who have many years to live, the lifetime costs for a single patient can exceed $3 million.1

Fortunately, in the scope of pediatric patients seen, fewer than 1% who present for trauma evaluation have cervical spine injury.3 Even so, almost all pediatric patients presenting to emergency departments with traumatic injuries are immobilized for transport. This practice
is not without a downside: immobilization increases the risk for pain, pressure ulcers, respiratory distress, and radiation from x-rays and CT scans. No provider wishes to fail to immobilize a child when a spine injury is present, particularly when 80% of pediatric spine injuries occur in the cervical spine. Fortunately these risks can be minimized with proper screening and careful immobilization. This article explores the anatomy of the pediatric spine and the management of pediatric spinal cord injury.

Anatomical Variations

Spinal column development begins early during embryonic growth. By the sixth week of fetal growth, a cartilaginous vertebral column forms. Throughout the remainder of fetal growth, ossification (bone growth) occurs. By birth there are definable vertebral bodies as well as cartilaginous vertebral arches that form the posterior aspect of the spinal canal. These cartilaginous arches strengthen into bone and become the lamina and pedicles during the first 5 years of life. By age 6 the pedicles have generally ossified to the point where they are called bone. Bones then continue to grow and strengthen until a child is fully grown. A spine doesn’t completely take on adult characteristics until at least age 9. Even after this age the column continues to add cartilage at the growth plates as it builds size and strength. Injury at the growth plates can result in long-term impairment of vertebral growth.

Like adults, the spinal column in children has 7 cervical, 12 thoracic and 5 lumbar vertebrae, followed by the sacral and coccygeal vertebrae, which are fused into the pelvis. Picture all the in-vitro images of fetuses you’ve seen. In each of these the fetus is curved, not flat. Beginning at development the spine takes on a curved form, as curves provide greater strength than straight lines. However, unlike with adults, the fetal spinal column is one smooth arch; with adults, the cervical and lumbar spine are concave in relation to the convex thoracic vertebrae. At birth the newborn’s spine is one smooth convex arch. The cervical spine’s concave formation develops in the first months after birth when children begin gaining the strength to pick their heads up. The concave c-spine becomes more defined as the child gains strength. Later in development, the lumbar spine slowly begins transitioning to its adult concave formation when an infant begins to walk. In the absence of spine malformations, the thoracic column remains convex for an individual’s entire life. This alternating concave/convex concave spinal curving provides strength and stability for both the spine and the body. These curves also cause gaps between the patient and a longboard during the immobilization process. Padding along the cervical and lumbar spines improves patient comfort and helps maintain natural spine alignment.

Each vertebra has several structures. The anterior and largest region is the spinal body, which is also the weight-bearing structure. Extending posteriorly at an angle off the vertebral body are two pedicles. The pedicles connect to two laminae to form the vertebral canal for the spinal cord. The spinous process protrudes posteriorly from the junction of the laminae, while a transverse process extends from each pedicle-lamina junction (Figure 1). Between each vertebral body is a cartilage disk, and longitudinal ligaments on the anterior and posterior sides of the spinal column hold the vertebrae together.

The spinal cord originates at the medulla oblongata and exits the skull through the foramen magnum. Travelling through the vertebral foramen of the spinal column, the cord ends in the lumbar spine. By adulthood this terminal end occurs around the L1–L2 junction; however, in children the spinal cord extends lower to the L3 region.

The incomplete spinal column ossification in children 8 and younger results in a weak spinal column. This weakness is particularly pronounced in the cervical spine and contributes to the high potential for spinal cord injury. This incomplete growth also leads to an increased frequency of multisite injury, which in children is at a rate of 22%. Such a high frequency of multiple-site injury highlights the need for...
stabilization of the total spine, not just the cervical, when column and cord injury are suspected in pediatric patients.

Children have much larger heads than adults in comparison to the rest of their bodies. Increased head mass, particularly on a developing and weak cervical spine, puts children, particularly under age 8, at risk for craniofacial disruption. Fortunately, craniofacial disruption is not that common. Its other name is internal decapitation, and it occurs when the cervical spine is completely separated from the brain.

Additionally, a larger head increases the forces against the neck when the child is exposed to sudden acceleration and deceleration. Until at least age 8 or 9, the child's cranium sticks out posteriorly past the back. When these children are placed on a spine board, the head's posterior extension will cause the neck to be flexed forward unless proper padding is placed under the patient's shoulders and back.

Mechanisms of Injury

Injuring the pediatric patient's spine takes significantly less force than injuring an adult spine. Recall that the child's large head puts the neck at risk for whipping-force injuries, particularly when speeds change suddenly. Maintain a higher index of suspicion for column injury with children. A fall that for an adult is unlikely to produce a column injury may cause one in a child.

Motor vehicle accidents are the leading cause of spinal injuries for children under 10. “

and deceleration. Until at least age 8 or 9, the child's cranium sticks out posteriorly past the back. When these children are placed on a spine board, the head's posterior extension will cause the neck to be flexed forward unless proper padding is placed under the patient's shoulders and back.

Mechanisms of Injury

Injuring the pediatric patient's spine takes significantly less force than injuring an adult spine. Recall that the child's large head puts the neck at risk for whipping-force injuries, particularly when speeds change suddenly. Maintain a higher index of suspicion for column injury with children. A fall that for an adult is unlikely to produce a column injury may cause one in a child.

Motor vehicle accidents are the leading cause of spinal cord injuries for children under 10, and cause as many injuries as sporting accidents for children 10–14. Overall mechanisms for pediatric spine injuries are summarized in Figure 2.

There are three primary forces that lead to spinal injury. Longitudinal compression forces, also known as axial loading, literally compress the vertebrae against one another. These are typically seen in falls from heights and often cause vertebral body fractures. When extreme bending occurs, the patient experiences hinging forces, and transverse fractures become common. Hinging forces are common in whiplash, from bending over seat belts and when the body is exposed to sudden direction changes. Finally, shearing forces combine longitudinal and hinging forces, such as when a patient is twisted/thrown in a sporting accident or when a child is struck by a car.

Assessment Techniques

Completing an accurate spine assessment of pediatric patients with potential spine injury is important for many reasons. First, it may identify the presence of column or cord injury at the beginning of patient care. Second, a thorough exam allows for changes in the patient's neurological condition to be monitored over time. Third, it may allow for the presence of spinal column and cord injury to be ruled out.

As with the evaluation of any other trauma patient, first focus on the critical systems and stabilization of the airway, breathing and circulation. Patients who have mental status changes or require control of severe bleeding, airway or breathing are unlikely to be candidates to have their spines closely evaluated; they will benefit from rapid transport to a trauma center.

When patients, even pediatric patients, present with a mechanism for spinal column injury but otherwise without obvious injury, it may be beneficial to spend additional time performing a thorough on-scene evaluation. This may help identify more subtle symptoms of a spine injury, thus creating a heightened sense of awareness and care during the immobilization process. There are six predictors of cervical spine injury:

- Neck pain
- Torticollis
- Substantial torso injury
- Conditions predisposing to cervical spine injury
- High-risk MVCs (ejection, high speeds, etc.)
- Shallow-water diving accidents

These six are 98% sensitive for injury and 28% specific, meaning that one of the six predictors is present in 98% of cervical spine injuries, but the presence of one of the six signifies only a 28% chance of injury. Torticollis is a stiff neck that is generally associated with one-sided muscle spasm. Patients with torticollis often have their heads tilted toward the injured side. When this develops following an accident, it suggests muscle or ligament injury. Any bone-density disorder can increase the patient's injury potential. In children, osteogenesis imperfecta is a hereditary disorder that causes bones to become brittle and fracture easily. Osteogenesis imperfecta is often mistaken for multiple fractures associated with child abuse until a diagnosis is made. Other conditions that increase a child's risk of spine injury include previous child abuse, premorbid birth (first year), osteomyelitis, and deficiency of calcium, copper or Vitamin D.

During the physical exam of a child, begin at the feet and work toward the chest and head. Allow the patient to be as much a part of their own exam as they can, and move slowly to build their trust. In children, positive findings during a complete spine assessment are reliable as an indicator for spine injury; however, because of the immature bone structures of the child's spinal column, the absence of positive findings is not always reliable as a sign of no injury. General signs and symptoms of spinal cord injury include flaccid extremities, paralysis, numbness, paresthesias (tingling or burning), weakness, priapism and incontinence. Vertebral and ligament injuries are typically extremely painful and tender to the touch, and are associated with swelling.

While pediatric patient spine clearance has not specifically been researched, it has been discussed in published literature. In 2006, the Journal of Trauma published "A Statewide Prehospital Emergency Medical Service Selective Patient Spine Immobilization Protocol," by a team led by physician John Burton. This paper presented research on
spine assessment protocols in Maine. During this study, EMS providers used an approved spine assessment to determine the need for immobilization, and the study proved 87% sensitive for identifying spine injury. During this study all patients deemed reliable were candidates for the spine assessment, regardless of age. Patients ranged from 0–109 years, and of the 20 not immobilized and later found to have spine injury, none were pediatric. This supported a 1999 paper from authors led by Marc Muhr, EMT-P, that demonstrated paramedics could safely rule out the need for spine immobilization. Muhr’s study included 118 patients under 18 and had no minimum age for inclusion. Thus, for those regions with spine assessment protocols in place, it is reasonable to discuss with local medical directors if inclusion criteria should be based on patient reliability, mentation and ability to follow commands rather than age.

During a physical exam providers may observe motor deficit. While the degree of motor deficit has not traditionally been documented during prehospital care, doing so can allow neurosurgeons to compare how patient motor strength changes over time. Additionally, prehospital providers with extended transport times may be able to document measurable improvements or declines in motor function depending on the type of injury sustained. Table 1 identifies the motor strength assessment scale from the American Spinal Injury Association.

<table>
<thead>
<tr>
<th>Degree of Motor Deficit</th>
<th>Motor Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>None detectable</td>
</tr>
<tr>
<td>1</td>
<td>Bilateral Pt.</td>
</tr>
<tr>
<td>2</td>
<td>Incomplete abduction</td>
</tr>
<tr>
<td>3</td>
<td>Complete abduction</td>
</tr>
<tr>
<td>4</td>
<td>Complete abduction with force</td>
</tr>
</tbody>
</table>

It is important to note that motor deficit does not include a patient’s ability to make a fist and squeeze, as is typically performed during a CSM (circulation, sensation and motion) evaluation. Our ability to squeeze the hand into a fist comes through motor nerves buried deep in the central spinal cord and may be intact even with other motor deficits in the extremity. Though people are able to squeeze hands voluntarily, our abilities to abduct our fingers apart and extend our wrists backward are motor functions that will be lost prior to the squeezing motor nerves becoming impaired. A better motor test may be evaluating for equal strength between the hands, where a patient’s ability to keep their fingers spread apart against your light pressure. While a CSM test is a great evaluation of the integrity of the neurovascular bundle in an extremity, particularly in an extremity injury, it is an incomplete evaluation during a spine assessment.

Instead, sensory deficit during a spine assessment may be noted by a patient’s inability to distinguish light touch from pain—for instance, the difference between a gauze pad and a needle pressing against their skin. Normally, distinguishing these is possible because there are two major sensory tracts within the spinal cord. Light touch is sensed through nerves originating in the dorsal column/medial lemniscus, which also senses vibration and proprioception. Pain, temperature and crude touch are sensed through nerves innervating the skin that originate from the spinothalamic tract in the spinal cord. A complete spine assessment evaluates both of these tracts, which is accomplished by having a patient distinguish light touch and pain. Motor deficit may also result in loss of the ability to notice differences in temperature and feel hot/cold. Motor deficits are best noted by having the patient lift the arms/legs against light resistance and then keep the extremity elevated as the evaluator pushes downward.

A patient who is reliable can understand and follow commands. Typically this means patients with normal mentation, who are free of distracting injuries and have physical exams absent of motor and sensory deficit, as well as spine tenderness, and have no complaints of spine pain, are unlikely to have spine injuries. The same tests performed on adults can theoretically be performed with a high degree of accuracy on any child with the ability to understand and follow commands. Theoretically is used intentionally because there is limited direct data available on clearing pediatric spines; most studies are very small, and most protocols are based on adult research. A 2009 Journal of Trauma article reviewed available data on pediatric c-spine clearance and concluded it’s possible to rule out the need for radiologic testing for injured children with mechanisms carrying a low risk of injury. Guidelines produced from the study provide the most reliable assessment for the pediatric patient’s spine and were able to rule out injury with 100% accuracy in the small population studied. The authors stress that the data must be taken into context of the patient’s reliability and mechanism of injury, as the research is still limited and there is no one standardized best-practice protocol for pediatric spine clearance.

**Injury Types**

Different references report varying degrees of frequency between column injury and associated spinal cord injury in pediatric patients. One study reported 64% of patients only had spinal column injury upon ED presentation, while another found neurological deficit in 66% of pediatric patients with cervical column injury. However, what is understood is that pediatric spine injuries nearly always occur in the cervical spine due to inherent weaknesses in the pediatric patient’s cervical spinal column. Further, these patients present with symptoms of incomplete cord injury in nearly 75% of cases.

When spinal column injury occurs, it may result in injury to the vertebrae themselves or to the ligaments surrounding the column. Whether bony or ligamentous, these injuries present with significant pain as well as tenderness. Additionally irritation and swelling are common and may develop rapidly.
Spinal cord injuries are defined as primary or secondary. Primary cord injuries occur at the moment of trauma or impact and may include tearing, lacerations, punctures and compressions. Secondary injuries develop over time and often result from bleeding, ischemia and swelling. Additionally, spinal cord injuries are considered either complete or incomplete. Complete injuries result in the total loss of both motor and sensory function below the injury site, while incomplete injuries result in some degree of cord impairment. Pediatric patients may have one of several types of incomplete spinal cord injuries, including injuries without radiological abnormalities; central cord syndrome; cord contusion; and Brown-Séquard syndrome.4

When a patient presents with the symptoms and signs of spinal cord injury but boney injury cannot be found, the patient is said to have a spinal cord injury without radiological abnormalities (SCIWORA). SCIWORA injuries occur nearly exclusively in children because pediatric patients have elastic spinal columns with immature ligaments and muscles that permit cord injury without obvious column injury from hyperextension and hyperflexion. While prehospital providers will be able to detect motor/sensory deficit suggesting spinal cord injury, do not plan on being able to differentiate patients with boney injury from those with SCIWORA. However, providers who perform interfacility transports may be asked to transport these patients to trauma centers. Management of these patients is identical to any other spinal cord-injured patient.

SCIWORA is most common in children under 8; in fact, one study found it only occurred in patients younger than 8.9 The authors of this study, led by physician Patrick Platzer, do believe SCIWORA is possible in older children. Mechanisms associated with SCIWORA are typically high-energy impacts with hinging forces that produce extreme stretching and whipping of the child’s head and neck. There are no defining symptoms for SCIWORA other than that the patient will have some type of motor or sensory deficit but x-rays and CT scans will fail to show spinal column injury.

Central cord syndrome is an incomplete spinal cord injury that occurs from hyperextension of the cervical spine. When cervical spinal cord hyperextension occurs, one of two injuries may result; both of which present as central cord syndrome. The more common comes from tearing and/or stretching of the central portion of the cervical spinal cord. Alternatively, central cord syndrome can result if the spinal artery is injured and inadequate blood flow to the central portion of the spinal cord leads to ischemia and then central cord necrosis. Distinguishing these two injuries in the field is impossible.

The symptoms of central cord syndrome are hallmarked by a disproportionately greater loss of motor strength in the upper extremities compared to the lower extremities. Additionally some degree of sensory loss is common. The upper extremities experience greater symptoms because the nerves that affect them are concentrated in the central column of the cervical cord.

Brown-Séquard syndrome is observed following hemisection of the spinal cord by penetrating trauma. It is fortunately quite rare.5 This syndrome manifests with ipsilateral (same side as the injury) motor loss, the generalized loss of sense of position, and contralateral (opposite side from the injury) sensation loss for pain and temperature.

Spinal cord contusions are bruises to the spinal cord, and their presentation is determined on the location of the contusion. Typically cord contusions present with some varying degree of sensory or motor deficit in the extremities. Completely flaccid extremities are not consistent with spinal cord contusions.

### Immobilization Techniques

When a patient has a mechanism suggesting a potential spine injury and is not reliable for a spine assessment, immobilization is indicated. The threshold for identifying a mechanism as able to cause a spine injury needs to be lower in children than in adults, particularly since no studies have focused on prehospital pediatric spine clearance.10

There are two goals during immobilization: Limit current damage and prevent secondary injury. Immobilization with a cervical collar does not effectively stabilize the entire spine. Spine stabilization is achieved with the patient’s spine and the weight centers (head, shoulders, pelvis) and legs all in an inline neutral position.10

Pediatric cervical collars are designed for children, and their use is essential as a part of proper immobilization. Be sure to apply the properly sized cervical collar, as using one that’s too small will provide no stabilization and may obstruct the airway, while one that’s too large may allow the cervical spine to flex.

The principles of immobilizing children are simple:

1. Maintain the spine in a neutral and inline position;
2. Control the weight centers: head, shoulders and pelvis;
3. Controlled spine movement toward
adult longboard provides inadequate immobilization and is likely to cause neck flexion unless significant padding is provided. If this is the only option on a scene, then place 2–4 cm of padding beneath the shoulders and back level with the occipital region of the head. Without padding the child’s neck will flex forward. The padding beneath the shoulders needs to extend continuously from the shoulders through the thoracic and lumbar spine to the pelvis (Figure 3). Simply padding beneath the shoulders flexes the thoracic and lumbar spine. Additionally pad between the patient and the edges of the board. Imagine a small child in the center of a longboard and bringing the board’s straps across from the edge and over the patient. A large triangular void forms between the strap, the board and the patient and allows the patient to slide laterally. Adequate padding on both sides fills these voids and prevents lateral shifting.

For younger children the Kendrick Extrication Device (KED) has been demonstrated as a safe and effective immobilization tool. This technique places the child supine on the KED with their head in the same location an adult’s would occupy and the rest of the body lying in the torso section. For proper immobilization, however, it is essential to pad the KED with a blanket or towels to maintain and the patient and allows the patient to slide laterally. Adequate padding on both sides fills these voids and prevents lateral shifting. Proper pediatric immobilization requires careful control of the spine’s weight and proper padding to ensure the spine remains in a neutral position.

**REFERENCES**


Kevin T. Collopy, BA, FP-C, CCEMT-P, NREMT-P. WEMT, is performance improvement coordinator for Vitalink/Arinik in Wilmington, NC, and a lead instructor for Wilderness Medical Associates. E-mail kcollopy@collegiatealumni.org.

Sean M. Kivlehan, MD, MPH, NREMT-P: an emergency medicine resident at UC San Francisco. E-mail sean.kivlehan@gmail.com.

Scott R. Snyder, BS, NREMT-P: is EMT program director for the San Francisco Paramedic Association in San Francisco, CA. E-mail scottrnsnyder@me.com.