Pediatric spine fractures are usually the result of high-speed and impact injuries such as a motor vehicle accident or a fall from great height. Spine fractures in children represent 1%–3% of all pediatric fractures.1,34 The incidence of pediatric spine injuries peaks in 2 age groups; children < 5 years old and children > 10 years old. There is a seasonal peak of pediatric spinal injuries from June to September, during summer break. There is another seasonal peak in the 2 weeks surrounding the Christmas holiday.

The mechanism of injury in the pediatric population varies with age. In young children ages 0–9 years, the predominant cause of injury is falls and automobile-versus-pedestrian accidents (> 75%). In children ages 10–14 years, motor vehicle accidents (40%) are the major cause of lumbar fractures, and falls and automobile-versus-pedestrian accidents are less prevalent. In children 15–17 years of age, motor vehicle and motorcycle accidents become the leading cause of spine injuries (> 70%), and there is also an increase in sports-related spine trauma.

The pediatric spinal column is different from the adult spine in many ways, and this can predispose infants and small children to flexion and extension injuries. They have proportionally larger heads compared with their bodies and have underdeveloped neck musculature.26,30 They also have inherent ligamentous laxity, elasticity, and incomplete ossification.23–25,30 Their facet joints are small and more horizontally oriented, resulting in greater mobility and less stability.23–25,32 Because of these biomechanical differences, younger children (0–8 years) tend to have fewer fractures and greater incidence of SCIWORA (spinal cord injury without radiographic abnormality). Hyperextension coupled with the hypermobility of the pediatric spine can result in momentary dislocation followed by spontaneous reduction, resulting in a damaged spinal cord but a radiographically normal–appearing vertebral column.20,24,26 Although SCIWORA has been reported to occur at rates as high as 20% in children, it falls dramatically to < 1% in adults. A more adult-like vertebral column (9–16 years) with sturdier osseoligamentous formation provides better protection of the spinal cord and therefore less severe spinal cord injury (SCI) in this age group compared with the younger age group. When subjected to high stress, the adult spine is more likely to suffer breakage of bones and frank rupture of ligaments in comparison with the pediatric spine, in which deformation and return to normal alignment is more common.

Lumbar Spine Radiographic Findings and Evaluation

Imaging studies are often used as an adjunct in evaluating and diagnosing injury in trauma. Findings can be misinterpreted as pathological in the setting of an imma-
Vertebral formation occurs in 3 stages: membranous proliferation, chondrification, and ossification. Although ossification begins in the womb, it is completed decades after birth. There are 3 ossification centers in the vertebra: the centrum of the vertebral body (VB), and right and left centers in the posterior arch (Fig. 1). At approximately 10 weeks of gestation, ossification of the centrum begins in the thoracolumbar region and proceeds in both directions. Evidence for ossification of the neural arches has been documented as early as 9 weeks of gestation in the cervical regions and progresses in the cranial-to-caudal direction. The neurocentral synchondrosis delineates the junction where the centrum and both arch centers fuse.

During the mid- to late teenage years, secondary ossification centers present in the transverse and spinous processes, and the ring apophyses fuse with the primary ossification centers. During the midteenage years endplates begin to fuse, and this is completed at approximately 21–25 years of age (Fig. 2).

Radiographic imaging of the pediatric spine is limited by the concern for radiation exposure to a maturing spine. Whereas an adult trauma evaluation may include a “pan scan” of the entire spine, evaluation of the pediatric patient relies heavily on a combination of the mechanism of injury and physical examination. Other factors such as “breath arrest” at the time of injury can be helpful in determining the likelihood of a VB fracture in the thoracic region.

When imaging studies are obtained, there can be findings that may be misconstrued as pathological that in fact are normal in children. The neurocentral synchondrosis can still be visible at 3–6 years of age. Radiographically, this can appear as a groove at the corner of each VB. Until the endplates fully fuse in the mid-20s, these areas may be misinterpreted as VB fractures.

“Wedge” of the VBs is sometimes read as a compression fracture. Gaca et al. performed a retrospective radiographic review looking at the occurrence and degree of wedging of the VB from T-10 to T-3 based on anterior/posterior VB height measurements. Although the previously reported ratio of 0.95 was used as the cutoff for concern about compression fracture, their study revealed that patients without spine injury can have an anterior/posterior ratio of as low as 0.893.

All imaging modalities have their advantages and limitations. Plain radiographic films are useful in evaluating for gross evidence of misalignment both in the anteroposterior (AP) and lateral views. Findings such as a trapezoidal shape to the VB, scoliosis, or offset spinous processes should raise the level of suspicion of acute injury. Following plain radiographs, CT scanning has repeatedly been shown to be superior in identifying acute bone injury. In the pediatric population, the concern for radiation exposure sometimes influences the practitioner to be judicious in obtaining a CT scan. Additionally, distraction and apophyseal injuries are difficult to determine on CT imaging alone. Magnetic resonance imaging studies are useful in determining spinal cord and soft-tissue injury (ligamentous, edema, and so on). Hemorrhage, edema, and acute bone injury represented by marrow changes in a series of T1-weighted, T2-weighted, and STIR images can aid in delineating true injury from false positives and acute versus chronic findings. However, the MRI modality can show false-negative findings in detecting neural arch fractures.

Although imaging studies have their usefulness in evaluating the pediatric trauma patient, knowledge of the natural progression in growth of the immature spine is critical in correctly interpreting results. If the mechanism of injury and physical examination are suspicious for spine trauma, then AP and lateral plain radiographs are warranted. From there, a CT scan is helpful if a fracture is detected on radiographs or if the results of physical examination do not match the imaging findings. An MRI scan is useful in the setting of neurological deficit.

Types of Lumbar Spine Injuries

Several classification systems exist to describe lumbar fractures systematically. The most comprehensive and accurate is probably the AO fracture classification. However, this system is cumbersome to apply in practice. Instead, most authors extrapolate from Denis’s 3-column model, originally described for fractures at the thoracolumbar junction. This model divides the spine into 3 columns: anterior (ventral half of the VB and intervertebral disc including the anterior longitudinal ligament [ALL]); middle (dorsal half of the VB and intervertebral disc including posterior longitudinal ligament [PLL]); and posterior (pedicles, lamina, facet joints, spinous processes, and interspinous and supraspinous ligaments). Depending on which combination of columns are injured, Denis labeled these fractures as compression, burst, seat belt, or fracture-dislocation. This classification system has thus been
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extrapolated to the thoracic spine, the lumbar spine, and the pediatric spine. Treatment approaches were then suggested by the type of fracture.

Compression Fractures

Compression fractures are the most frequently seen fractures in the lumbar spine and usually occur as a result of an axial compression load in flexion. This is a stable injury in which the posterior column is intact. Spinal cord injury has not been documented in this type of fracture, and spinal canal compromise does not occur. Kyphotic angulation can occur because there is more reduction in height of the VB anteriorly. A long-term increase in deformity can occur when there is an associated kyphosis of > 30%.

The patient in Case 1 was a 16-year-old girl who fell from a horse and was thrown over, landing on her buttocks. She presented to the emergency department with back pain and left wrist pain. She was found to have an L-2 compression fracture in addition to a left wrist fracture. She was neurologically intact. A CT scan of the lumbar spine showed an L-2 compression fracture with approximately 19° of kyphotic deformity. She was treated conservatively in a brace and did well with conservative management, with improved back pain (Fig. 3).

Burst Fractures

Burst fractures occur with axial load without flexion, and affect the anterior and middle columns. This type of fracture makes up 15%–20% of all major VB fractures. The VB is partially or completely comminuted and there is disruption of the posterior wall. There are often fragments that break into the spinal canal and there may be (SCI).

The patient in Case 2 was a 15-year-old male unrestrained passenger involved in a motor vehicle accident who presented with back pain and bilateral ankle pain. On CT imaging his lumbar spine demonstrated an L-1 burst fracture with approximately 19° of kyphotic deformity and disruption of the PLL with retropulsion of VB fragments posteriorly (Fig. 4A). An MRI study was performed, which demonstrated an associated contusion of the conus medullaris, disruption of the ALL and PLL, and no ongoing spinal cord compression (Fig. 4B). The patient was noted to have decreased strength in his bilateral lower extremities; his physical examination was limited due to pain but he was able to wiggle his toes bilaterally. The patient did have bowel and bladder dysfunction as well as some associated dysesthetic pain. Conservative treatment in a brace was attempted because there was no ongoing compression of the spinal cord on MRI or worsening of findings on his neurological examination; however, the patient had intractable back pain and increased kyphosis on upright lumbar spine radiographs (26° in brace; Fig. 4C). Therefore, the decision was made to perform posterior spinal stabilization and fusion from T-11 to L-3 (Fig. 4D). Postoperatively the patient did well, and after 2 weeks in the hospital was transferred to an inpatient rehabilitation center. He has been seen in a 3-month follow-up visit and at that time he was ambulatory, with a left orthotic foot brace and a walker.
Anterior and Posterior Element Injuries (3-Column Injuries)

This type of injury pattern is inherently unstable and is characterized by failure of all 3 columns. These account for approximately 20% of all spinal injuries and are associated with the highest likelihood of SCI. Approximately 75% of patients with fracture-dislocation injuries have some neurological deficit and 50% of these have complete SCIs.

There are different types of injury patterns in 3-column injuries: those with distraction and those with rotation. The first (with distraction) is a flexion-distraction type injury where the flexion force vector is acting around an anteriorly placed axis of rotation and the posterior elements are distracted. This is commonly seen in association with motor vehicle-associated seat belt injuries. Seat belt injuries are often associated with intraabdominal trauma, and neurological injury is infrequent. The second type of injury (with rotation) usually occurs with falls from great heights or with heavy objects falling onto a body with a bent torso. On CT scans, this is best appreciated on axial views where one can see rotation of the superior and inferior VBs. This type of injury has a high propensity for neurological sequelae. There may be disruption of the facets as well as narrowing of the spinal canal. It is the most unstable and severe of all the injury mechanisms.

The patient in Case 3 was a 9-year-old girl who was a restrained passenger in a motor vehicle accident in which she had no loss of consciousness. On presentation to the emergency department she complained of back, neck, and abdominal pain. She was neurologically intact with full strength and sensation in her bilateral lower extremities. A CT scan of her lumbar spine demonstrated an L-1 seat belt-type fracture with anterior VB wedging and a fracture through the bilateral facets and the T-12 spinous process (Fig. 5A). The patient had layering fluid in her abdomen and, due to concern for bowel injury, she was initially taken to the operating room by pediatric surgery for an exploratory laparotomy and small-bowel resection. She was kept on strict spinal precautions with no alteration in findings on her neurological examination. Lumbar spine MRI studies demonstrated mild compression of L-1 with STIR signal extending through both pedicle and pars with disruption of the interspinous ligaments and the ligamentum flavum (Fig. 5B). Because this injury was unstable, the patient was taken to the operating room for a T10–L3 posterior spinal fusion. Postoperatively she did well and was discharged home on postoperative Day 5. On 6-week follow-up the patient was doing well and thoracolumbar radiographs were obtained, which showed intact hardware and stable alignment (Fig. 5C).

Apophyseal Ring Fractures

The apophyseal ring is attached to the anulus fibrosus; it ossifies between 4 and 6 years of age and fuses at 18 years of age. There is an osteocartilaginous portion that exists between the VB and apophyseal ring that is relatively weak and susceptible to repeated stresses. Apophyseal ring fractures often result from lifting a heavy object, but may also occur from falls or twisting injuries. Many patients with apophyseal ring fractures describe a “pop” at the time of injury, which is then followed by radiculopathy. Diagnosis is confirmed with MRI and/or CT studies to pinpoint the exact location and configuration of the lesion. In the pediatric spine the growth zone in the VBs is found in the endplates. Disruption of this zone can easily occur with moderate shearing forces. This fracture is typically seen in the adolescent or young adult and presents just like a herniated disc with a radiculopathy. Yen et al. reported 4 adolescent cases and noted a strong association of adolescent apophyseal ring fractures with a slipped capital femoral epiphysis and overweight/obesity. The patient in Case 4 was a 13-year-old girl who fell on her tailbone while playing volleyball and developed acute onset of back pain with radicular pain down her left posterior extremity to the dorsum of her left foot. A CT scan was done, which demonstrated a posterior detached fragment at the superior S-1 endplate and a defect in the bone adjoining the fracture site (Fig. 6A and B). Lumbar spine MRI demonstrated a left eccentric disc herniation with impingement on the exiting left S-1 nerve root (Fig. 6C and D). Her clinical picture and radiographic imaging was consistent with an apophyseal ring fracture and associated L5–S1 disc herniation causing an S-1 radiculopa-
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Five months of conservative management, with rest, NSAIDs, steroids, and physical therapy, was attempted; however, she continued to have debilitating activity-limiting pain. Therefore, surgery was recommended and she underwent a minimally invasive left L5–S1 microdiscectomy. She did well postoperatively and on 3-month follow-up was pain free.

**Treatment Options**

Different classification schemes exist for thoracic and lumbar spine fractures. The Thoracolumbar Injury Classification and Severity Score has commonly been applied in the adult population with trauma to help determine nonoperative versus operative management of thoracolumbar...
fractures. It has subsequently been studied and applied to thoracic fractures and/or lumbar fractures alone. A score is calculated based on injury mechanism, neurological status, and integrity of the posterior ligamentous complex; a score of \( \leq 3 \) suggests nonoperative treatment, a score of 4 suggests nonoperative or operative treatment, and a score of \( \geq 5 \) suggests operative treatment. The Thoracolumbar Injury Classification and Severity Score has recently been studied retrospectively in the pediatric population, and Garber et al. report excellent validity of this scoring system in their pediatric cohort (unpublished data).

As a basic rule of thumb, many stable fractures can be treated conservatively, whereas unstable fractures require surgical stabilization. There are many different braces that can be used to obtain thoracic and lumbar immobilization for conservative management. The thoracolumbosacral orthosis (TLSO) or the Jewett brace (used if hyperextension is desired) both can be used to achieve this result. For upper thoracic spine fractures between T-1 and T-4, a SOMI (sterno-occipito-mandibular immobilizer) brace is used in conjunction with a TLSO brace for treatment. Duration of bracing therapy depends on the injury and neurosurgeon, but is typically at least 3 months.

Surgical stabilization for unstable lumbar fractures can often be managed via a posterior approach. Adolescents can often be stabilized with adult-type instrumentation; the pediatric spine reaches adult maturity at approximately 9 years of age. Younger children, however, have smaller pedicles, and thus pedicle screw placement may be challenging. They also have smaller spinal canals, so placement of sublaminar hooks is not safe. Stereotactic guidance has helped with placement of instrumentation in these cases. Also, rhBMP-2 has been used in young patients to promote bone fusion because they routinely have a very limited amount of bone autograft available. Although the FDA has only approved the use of rhBMP-2–soaked absorbable collagen sponges for use in adult anterior interbody lumbar fusion, “off-label” applications have been reported. We previously reported the early safety and efficacy of rhBMP-2 use for posterior spinal fusions in the pediatric population (mean follow-up of 11 months).

Lumbar compression fractures are treated with bed rest, with gradual resumption of activities as tolerated when the kyphotic wedge of the vertebra is \( < 10^\circ \). However, when the kyphotic deformity is \( > 10^\circ \) in the immature spine, immobilization in hyperextension is recommended for 2 months, followed by bracing for \( \geq 1 \) year. Surgery with posterior and/or anterior stabilization is recommended in adolescents who are near skeletal maturity with \( > 30^\circ \) of kyphosis, or if the patient has had a prior laminectomy. Stabilization and correction of the deformity can be accomplished with pedicle screw constructs, a universal segmental fixation system, or the Harrington rod distraction system.

Burst fractures may be treated conservatively when there is no neurological injury. Conservative treatment usually consists of hyperextension casting for 2–3 months and bracing for an additional 6–12 months. Surgical intervention is relatively indicated with \( > 50\% \) loss of body height, \( > 50\% \) canal compromise from retropulsed bone fragments, or \( > 30^\circ \) of kyphosis. Absolute indications for surgical decompression and/or fusion include neurological deficits or progressive kyphosis. In the presence of multiple nerve root palsies or SCI, anterior decompression must be considered.

Unstable injuries, such as the 3-column fractures mentioned above, are most often operative injuries. The only situation that can be treated conservatively is when there is fracture-dislocation with minimal displacement and the fracture line goes through the bone (a “bony chance fracture”). In this case, conservative management consists of case immobilization for 8–10 weeks followed by bracing thereafter. Surgical stabilization is indicated with progressive neurological deficit or displacement \( > 17^\circ \) of kyphosis or when the predominant injury is discoligamentous instead of bony. Three-column injury with
rotation is the most unstable and is uniformly treated with surgery. The procedure consists of posterior instrumentation and fusion 1 or 2 levels above and below the level of injury.11,19,21

Conservative management for apophyseal ring fractures consists of rest, analgesics, physical activity modification, and physical therapy; however, it is rarely successful and surgical excision of the limbus fragment is usually required. Surgery is done via a posterior approach to remove the offending fragments with or without an interlaminar laminectomy.13,35 Typically these are not unstable injuries, and thus fusion is not necessary and outcomes are usually favorable.

**Outcomes**

A majority of lumbar spine fractures in children and younger adolescents are minor, stable, and do not present with neurological deficit. One must approach pediatric spine fractures in a systematic way, taking into consideration immediate stability, the need for neurological decompression, and late stability and propensity for healing. Because children have more laxity of the spine, physicians must keep a high suspicion for SCIWORA and therefore order and proceed with more imaging (such as MRI) when clinically indicated. Previous reports estimate that anywhere between 7.5% and 30% of patients with thoracolumbar fractures require operative intervention.6,15,21,29

Erfani et al. have described the results of thoracic and lumbar instrumentation for pediatric traumatic spine fractures over a 10-year period. Of 102 individuals, L-1 was the most frequently injured vertebra (31 patients), followed by L-2 (19 patients), L-3 (18 patients), T-12 (16 patients), and L-4 (10 patients), and the remainder of vertebral levels had < 5 patients each. Twenty patients required surgical stabilization; however, only 15 patients participated in follow-up (mean 49 months). Eight (53.3%) of the 15 patients had lumbar spine fractures, and all underwent posterior spinal instrumentation and fusion alone. Three patients with lower thoracic or thoracolumbar fractures underwent an anterior followed by a posterior approach (those with delay in diagnosis). Four patients with SCI (2 with cauda equina and 2 with incomplete SCIs) had return of baseline neurological function. They reported no postoperative complications and all patients were functionally independent at follow-up.7

Dogan et al. also reviewed a series of 89 pediatric patients with traumatic thoracolumbar fractures, 23 of whom underwent surgery. Of these fractures, 19.2% were at the thoracolumbar junction and 29.8% were somewhere between L-2 and L-5. Of the 23 patients who underwent operation, 14 (60.9%) had lumbar spine fractures. The mean follow-up was 17.2 months, and all patients had a stable fixation, visible callus formation, and maintenance of alignment.8 Twenty-nine patients with mild lumbar or
sacral injuries were treated successfully with bed rest alone and gradual resumption of activities. There have been several previous studies that have reported successful fusion associated with normal thoracolumbar growth and good alignment after both anterior and posterior approaches for pediatric lumbar trauma.6,7,10,22,27

Many pediatric fractures are managed conservatively, and children have been noted to have a high propensity for healing. Karlsson et al. observed and reported on the ability of the pediatric spine to remodel after traumatic fracture in the thoracolumbar spine.24 The authors followed a 24-patient observational cohort of children with thoracic or lumbar fractures for up to 47 years (range 27–47 years, mean 33 years). Twenty-one patients had simple compression fractures, and all fractures were treated conservatively. There were 17 thoracic fractures and 7 lumbar fractures. The most notable result from this study is that they found a significant improvement in the ratio of the anterior height/posterior height (from 0.75 at time of injury to 0.87 at follow-up) in patients <13 years old. This improvement in wedging of the VB demonstrates the potential of VB remodeling during growth when a fracture is encountered in a younger patient. This is a stark contrast to adults, in whom we usually see increased posttraumatic kyphosis.

In terms of quality of life measures, Erfani et al. reported a 33.3% incidence of occasional back pain in the long term.7 They also reported near complete improvement in all 4 patients with neurological injury in their series. In another study by Moller et al.,5 (21.7%) of 23 patients had another study by Moller et al.,5 (21.7%) of 23 patients had no or minor neurological deficits.22 Dogan et al. noted that all neurologically intact patients remained so at follow-up and that 75% of the patients with incomplete SCIs recovered completely.5

Conclusions

Pediatric lumbar spine fractures constitute approximately 1%–3% of all pediatric fractures. Because of the differences in the pediatric spine, the incidence of SCI-WORA is much higher than in adults. Conservative versus surgical management of different types of fractures depends on the stability of the fracture, the neurological status of the patient, and his/her injury-healing ability. When surgical intervention is indicated it is safe and effective in the pediatric population, and outcomes in terms of fusion and neurological status are good.

Disclosure

Dr. Trost is a consultant for Medtronic.

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