Spine trauma is a devastating event with a high morbidity and mortality and many additional medical, psychological, social, and financial consequences for patients, their families, and society. It is estimated that the annual incidence of spinal cord injury, not including those who die at the scene of the accident, is approximately 40 cases per million population in the United States or approximately 12,000 new cases each year. The number of people in the United States who were alive in 2008 with a spinal cord injury has been estimated to be approximately 259,000 persons (range of 229,000–306,000). The average age of the typical patient with spinal cord injury has increased to 40.2 years as of 2005, and approximately 80.9% of all spinal cord injuries occur in males.1

Motor vehicle accidents account for 42.1% of reported spinal cord injury cases. The next most common cause is falls (26.7%), followed by acts of violence (15.1%), and sporting activities (7.6%). The proportion of injuries that are due to sports has decreased over time whereas the proportion of injuries due to falls has increased. Violence caused 13.3% of spinal cord injuries before 1980, and peaked between 1990 and 1999 at 24.8%, before declining to 15.1% since 2005.1,2

The most frequent neurologic category at discharge of patients with spinal cord injury is incomplete tetraplegia (30.1%), followed by complete paraplegia (25.6%), complete tetraplegia (20.4%), and incomplete paraplegia (18.5%). More than half (57.5%) of patients with spinal cord injury are employed at the time of their injury. By postinjury year 20, 35.4% are employed and a similar level of employment is observed 30 years after injury.3 Today 87.8% of all persons with spinal cord injury who are discharged alive from the system are sent to a private, noninstitutional residence (in most cases their homes before injury). Most patients with spinal cord injury (52.3%) are single when injured. The average hospital stay for a typical patient with spinal cord injury has declined from 24 days in 1973–1979 to 12 days in 2005–2008. The total cost of care for patients with spinal cord injury is dependent on the severity of injury; the first year cost of care for a tetraplegic patient costs an average of $801,161 and drops by an average of $143,507 a year thereafter.1,4,5

OVERVIEW OF SPINE TRAUMA

Spinal fractures represent 3% to 6% of all skeletal injuries.6 A systematic review by Sekhon and Fehlings7 found that 55% of all spinal injuries (including all types of spinal injuries) involve the cervical spine, 15% the thoracic spine, 15% the lumbar spine, and 15% the lumbosacral spine. The risk of damage to the spinal cord is greater in cervical spine injuries than in the thoracic and lumbar regions.8 Many epidemiologic studies have shown that fractures of the thoracic and the lumbosacral spine are much more common than fractures of the cervical spine.9,10

Cervical spine injuries, including fractures and ligamentous injuries, primarily occur secondary to traumatic injuries to the head and neck. An individual with an unstable cervical fracture is at risk for cervical spinal cord injury unless the fracture is stabilized. The majority of cervical spine fractures occur at the upper or lower ends of the cervical spine. C1 vertebral fractures represent approximately 10%,11 C2 vertebral fractures approximately 33%, fractures of the odontoid process of C2 approximately 15%, and C6 and C7 vertebral fractures approximately 50% of...
Fractures of the thoracic and lumbar spine are more common than fractures of the cervical spine. Major trauma is the most common cause of thoracolumbar fractures. In the United States, the incidence of spinal fractures from motor vehicle accidents is 5% to 6%. However, the majority of thoracolumbar fractures occur in elderly patients as a consequence of minor injury in a patient with osteoporosis. In the United States, the incidence of vertebral fractures from osteoporosis requiring hospitalization is 150,000 per year. The majority of thoracic spine fractures occur in the lower thoracic spine, with 60% to 70% of all thoracolumbar spine fractures occurring between T12 and L2. The majority of these fractures (75%–90%) occur without spinal cord injury. Injury to the cord or the cauda equina occurs in approximately 10% to 38% of adult thoracolumbar fractures and in 50% to 60% of adult fracture-dislocations.

CLEARING THE SPINE AND INDICATIONS FOR IMAGING

Cervical spine imaging is one of the most common imaging examinations performed in trauma centers in the United States and developed countries. The task of clearing the cervical spine for injury and the rationale for determining which patients require imaging can be challenging. There are additional challenges in special populations including the obtunded individual, the elderly individual, and children. Two large prospective multicenter trials have attempted to address the appropriate selection criteria for cervical spine imaging after blunt trauma.

In the multicenter National Emergency X-Radiography Use Study (NEXUS), investigators identified the key clinical risk factors that had significant predictive value in determining if a cervical fracture was absent. From the analysis of clinical data and radiography of 34,069 blunt trauma patients with 818 confirmed cervical spine fractures (2.4%), the investigators concluded that no imaging was required in the absence of the following clinical features: no midline cervical spine tenderness, no focal neurologic deficit, normal level of alertness, no intoxication, and no painful distracting injury. The NEXUS group found that their clinical prediction rule could adequately identify subjects at risk for fracture with a sensitivity of 99.6%.

A similar trial was conducted by the Canadian Cervical Spine Group, which identified the clinical criteria for which risk of cervical spine fracture is low after blunt trauma. The criteria included: (1) a fully alert patient with a Glasgow Coma Scale of 15; (2) absence of high-risk factors (e.g., age >65 years, dangerous mechanism of injury such as a fall from greater than 3 m/5 stairs, axial load to head, high-speed vehicular crash, bicycle crash, or a motorcycle crash, or the presence of paresthesias in the extremities); (3) presence of low-risk factors (simple vehicular crash, sitting position in emergency department, ambulatory at any time, delayed onset of neck pain, and the absence of midline cervical tenderness), and (4) ability to actively rotate the neck 45° to the left and to the right. The Canadian group found that their clinical criteria had 100% sensitivity and 42.5% specificity for predicting absence of cervical injury. Although the recommendations of the 2 groups differ, no clear advantage of one clinical rule over the other has emerged. One problematic feature of both studies is that in practice it is rare to encounter a patient who fulfills either set of criteria, therefore in many instances some imaging is still required.

The advent of newer technologies (e.g., CT, magnetic resonance [MR] imaging) has provided additional diagnostic imaging options for spinal clearance. For example, for cervical spine clearance, plain radiography consisting of the standard
Plain radiography can be used to evaluate the thoracic and lumbar spine after trauma. However, with the ever increasing use of CT in multitrauma patients, reconstructions of the thoracic and lumbar spine from the raw data of a CT abdomen and pelvis study are used, obviating the need for plain radiographs. However, the radiologist needs to be aware that the quality of the data is less than that acquired from a dedicated CT of the spine, and equivocal findings may require a dedicated CT of the thoracolumbar spine.

**STABILITY VERSUS INSTABILITY**

The concept of stable versus unstable spinal injuries is of critical importance in spinal imaging. Essentially, an unstable spinal injury is one in which the mechanically unstable spine moves and undergoes potentially deleterious deformation in response to physiologic loading and a normal range of movement. Many classification systems with regard to type and mechanism of injury have been proposed over the years. The most widely used of these systems is the 3-column theory of Denis, which helps predict stability associated with the different patterns of injury to the spine.

The 3-column theory of Denis divides the spinal column into anterior, middle, and posterior columns. The anterior column consists of the anterior vertebral body, the anterior longitudinal ligament, and the anterior annulus fibrosis. The middle column consists of the posterior vertebral body, the posterior longitudinal ligament, and the posterior annulus. The posterior column consists of the posterior bony elements including the pedicles, the laminae, the facets, and the spinous processes, the ligaments including the ligamentum flavum, the interspinous, and supraspinous ligaments, and the facet joint capsule. When only one column is disrupted, the injury is considered mechanically stable. When 2 columns are disrupted, the injury is considered unstable. In general, this requires failure of the middle column with either the anterior or the posterior column.

It is important for the radiologist to be descriptive in terms of the spinal injury/fracture and its morphology, so as to be able to communicate accurately to the physician the type of spinal injury/fracture and its stability or instability. The radiological features of mechanical instability include displacement/translation greater than 2 mm indicating ligamentous disruption, widening of the interspinous space, the facet joints, and/or the interpediculate distance, disruption of the posterior vertebral body line, widening of the intervertebral canal, vertebral body height loss of greater than 50%, and kyphosis of greater than 20°.

Awareness of the neurologic and mechanical stability allows the clinician to choose the appropriate treatment strategy, conservative or surgical.
CERVICAL SPINE INJURIES

Trauma to the cervical spine is frequently classified into injuries of the upper and lower cervical spine. The upper cervical spine injuries include injuries to the occipital condyles, the atlanto-occipital articulation, C1, C2, and the atlantoaxial joint. The lower cervical spine includes injuries to C3 to C7. However, more commonly cervical spine injuries are classified according to the underlying mechanism of injury. These mechanisms include hyperflexion, hyperflexion and rotation, hyperextension, hyperextension and rotation, vertical compression, lateral flexion, and indeterminate mechanisms that result in injuries.\(^1\)

**Upper Cervical Spine Injuries**

Occipital condyle fractures are rare and are rarely, if ever, diagnosed with conventional radiography. The classification system most commonly used to describe them is the Anderson-Montesano system. Using this system, a type I occipital condyle fracture is a comminuted fracture that occurs due to axial loading (Fig. 1). Type II is a skull base fracture that propagates into one or both occipital condyles. Type III is an inferomedial avulsion fracture with medial displacement of the fracture fragment into the foramen magnum, and is considered unstable because of an avulsed alar ligament. Type III occipital condyle fractures are the commonest of the 3. High-resolution CT of the skull base provides the best evaluation of this type of injury, and the base of the skull should therefore be included on all CT cervical spine examinations.\(^1\)

Atlanto-occipital dislocation results in disruption of the stabilizing ligaments between the occiput and C1, and this injury is more frequent in children due to the disproportionate size of the cranium. Atlanto-occipital dislocation has a high associated fatality rate because of stretching of the brainstem, which results in respiratory arrest. However, with improved on-scene and immediate management of patients with spinal cord injuries, this once uniformly fatal injury is now potentially survivable. No radiographic modality has 100% sensitivity for this injury, which is diagnosed on the basis of increased distance from the basion to the odontoid. Secondary radiographic signs include soft tissue swelling or subarachnoid/craniofacial junction/posterior cranial fossa hemorrhage. CT with coronal and sagittal reformats will demonstrate increased distance between the occipital condyles and the lateral masses of C1 (Fig. 2). MR imaging in the sagittal plain is the best modality for demonstrating ligamentous injury.\(^2\)

Acute atlantoaxial dissociation (AAD) is a rare injury in which there is partial or complete derangement of the lateral atlantoaxial articulations directly related to trauma. AAD is characterized by excessive motion between C1 and C2 caused by either a bony or a ligamentous injury. AAD is associated with certain congenital conditions such as Down syndrome, osteogenesis imperfecta, neurofibromatosis, Morquio syndrome, spondyloepiphysyeal dysplasia congenital, and chondrodysplasia punctata. The 3 mechanisms of AAD are flexion-extension, distraction, and rotation. Fieldings and Hawkins provided a classification system for AAD.\(^3\) Type I AAD is rotatory fixation without anterior displacement of the atlas. Type II AAD is rotatory fixation with less than 5 mm of anterior displacement of the atlas. Type III AAD is rotatory fixation with greater than 5 mm of anterior displacement of the atlas. Type IV AAD is rotatory fixation with posterior displacement of the atlas. All of these injuries can be associated with concurrent fractures, neurologic deficits, or vertebral artery injuries.

The classic "Jefferson fracture" is the result of a compressive force to C1, usually from a blow to the vertex of the head, resulting in fractures at the junctions of the anterior and posterior arches with the lateral masses. Although only one anterior and one posterior arch fracture is necessary to meet diagnostic criteria, any combination of anterior and posterior arch fractures can occur. On radiography, the key view is the open-mouth odontoid view, which may show displacement of the C1 lateral masses. However, CT provides a more comprehensive assessment to define the full extent of the fracture, document other fractures (eg, C2), and to identify bone fragments in the spinal canal (Fig. 3).\(^4\) Atypically, fractures limited to the lateral mass of C1 may occur because of a lateral tilt or eccentric axial loading. Isolated fractures of the anterior or posterior arch of C1 should be considered separate from the classic Jefferson fracture because they are stable. Isolated fractures can sometimes be difficult to distinguish from developmental clefts (Fig. 4).

Hangman’s fracture, or traumatic spondylolisthesis of the axis (C2), gained its name from the pattern of injury that used to occur with judicial hanging.\(^5\) Traumatic hangman’s fracture most commonly occurs in instances where there is rapid deceleration of the head such as when the head is forced against the dashboard in a motor vehicle accident. The transmitted force passes through the weakest part of C2, the interarticular segments of the pedicles, resulting in bilateral pars or isthmic fractures. Fortunately, spinal cord damage is uncommon because the spinal canal is wider at
Fig. 1. Type I occipital condyle fracture. (A) Coronal reformatted CT demonstrates bilateral fractures through the occipital condyles (white arrows). (B, C) Axial CT of the same patient shows the fractures extending through both occipital condyles with minimal displacement (white arrows).

Fig. 2. Atlanto-occipital dislocation. (A) Lateral radiograph of the cervical spine demonstrates increased separation of the basion (midpoint of the anterior margin of the foramen magnum on the occipital bone) and the superior tip of the dens in an intubated patient (white arrow). (B, C) Sagittal and coronal CT reformats again show increased basion to dens distance and superior dislocation of the occipital condyles with respect to the superior surfaces of C1 (white arrows).
this level and because the injury is decompressive. A classification system of the hangman’s fracture was devised by Effendi and colleagues and modified by Levins and Edwards. A type I hangman’s fracture is an isolated hairline fracture, with less than 3 mm fragment displacement, less than 15° angle at the fracture site, and a normal C2-C3 disc space. A type II hangman’s fracture consists of the type I changes and a C2-C3 articular facet dislocation. Radiography demonstrates anterior displacement of C2 on C3. CT better demonstrates the pattern and extent of injury. MR cervical spine may be necessary if neurologic symptoms develop, and MRA/CTA (MR angiography/CT angiography) of the neck and head may be necessary to look for a vertebral artery dissection if the fracture extends into the foramen transversarium (Figs. 5 and 6).

Fractures of the dens or the odontoid process occur through several mechanisms. The classic imaging appearance is of a lucent linear defect, usually through the base of the dens with posterior displacement of the dens arch of C1 relative to the C2 body and arch. The classification system proposed by Anderson and D’Alonso is used to describe dens fractures. A type I fracture is an avulsion of the tip, and needs to be distinguished from an os odontoideum, which is a well-corticated ossification center above a rudimentary dens. Controversy exists as to whether this type is a true consequence of trauma. A type II fracture, the most common, is a transverse fracture through the base of the dens (Figs. 7 and 8). This fracture is the most likely to go on to nonhealing, and a primary surgical fusion procedure may be necessary to prevent cervical myelopathy. A type III fracture extends into the body of C2 (Fig. 9). An isolated C2 lateral body fracture is a rare occurrence but may happen, and is distinguished from dens fractures.

### Lower Cervical Spine Injuries

#### Hyperflexion injuries

The clay shoveler fracture is an oblique avulsive fracture of a lower spinous process, most commonly C6-T1. This fracture gained its name from laborers who sustained this pattern of injury when performing activities involving lifting weights rapidly with the arms extended, for example, shoveling soil, rubble, or snow over the head backward. It is not a common fracture and is more likely to occur in the trauma setting nowadays. The clay shoveler fracture is a stable fracture (Fig. 10).

Anterior subluxation occurs in the cervical spine when the posterior ligament complex is disrupted but the anterior longitudinal ligament remains intact. There is no associated bone injury, and...
the facet joints may be subluxed. For this injury radiological diagnosis can be difficult, but detection is important because of a reported 20% to 50% incidence of failed ligamentous healing leading to instability (Figs. 11 and 12). A simple wedge compression fracture occurs from a flexion injury with loss of height of the anterior vertebral body and buckling of the anterior cortex.

Bilateral interfacetal dislocation (BID) is an extreme form of hyperflexion injury that occurs following a severe flexion force to the head and neck, causing significant anterior displacement of the spine and ligamentous disruption at the level of the facet joints.

Fig. 4. Atypical Jefferson fracture, isolated fracture through the right anterior arch of C1. (A) Lateral cervical spine radiograph demonstrates normal cervical spine alignment and no evidence of fracture. (B) Open-mouth view demonstrates asymmetry of the lateral masses with medial displacement on the right side (white arrow). (C) CT demonstrates a unilateral fracture through the right anterior arch of C1.

Fig. 5. Hangman's fracture. (A, B) Axial CT demonstrates bilateral pars interarticularis fractures of C2 (white arrows). (C) Sagittal CT reformat shows a minimally displaced fracture through the right pars interarticularis without significant fracture displacement (white arrow).
of the injury. Both inferior articular facets from one vertebral body can dislocate anterior to the superior facets of the subjacent vertebra, implying disruption of the major support ligaments of the anterior, middle, and posterior columns. The facets can be subluxed, perched, or locked. BIDs are often associated with compression fractures of the subjacent vertebra and/or disc herniation at the level of the injury, and these are highly unstable injuries. BIDs are more common in the lower cervical spine (Figs. 13 and 14).

The flexion teardrop fracture is the most severe cervical spine injury with a severe flexion force, resulting in a fracture dislocation of the cervical spine, most commonly at C5. This fracture is a devastating injury with complete disruption of all the soft tissues at the level of the injury, including the anterior longitudinal ligament, the intervertebral disc, and the posterior longitudinal ligament. There is a substantial axial force component, which causes the impacted vertebral body to literally “explode.” There is typically a large

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**Fig. 6.** Hangman’s fracture. (A) Lateral cervical spine radiograph demonstrates a fracture through the pars interarticularis of C2 with angulation and displacement at the fracture site (white arrow). (B, C) Axial CT shows bilateral pars interarticularis fractures with posterior displacement on the right side (white arrows). (D). Sagittal CT reformat confirms the posterior displacement (white arrow).
triangular fragment of the anteroinferior margin of the upper cervical vertebra, the teardrop fragment. The retropulsed posterior cortex affects the ventral dura and spinal cord, and patients classically present with the “acute anterior cord syndrome” with quadriplegia and loss of the anterior column senses but preservation of the posterior column senses (Fig. 15).\(^5\)

**Flexion rotation injuries**

A combination of flexion and rotation may result in dislocation of one facet, with the inferior articular process of the dislocated facet displaced in front of the superior articular process of the subjacent vertebra and tearing the posterior ligaments. MR imaging is warranted to assess for cord injury in patients who manifest neurologic symptoms (Fig. 16).\(^4\)

**Extension injuries**

Hyperextension injuries occur when there is forceful posterior displacement of the head or upper cervical spine, usually from trauma to the face or mandible and/or sudden deceleration, such as when the head is suddenly halted from forward motion by the steering wheel or dashboard in a motor vehicle accident. In general, extension injuries affect the lower cervical spine, although the extension teardrop fracture typically involves the C2 body. Extension mechanism injuries are more common in patients with ankylosing spondylitis, diffuse idiopathic skeletal hyperostosis

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*Fig. 7.* Type II fracture of the dens. (A, B) Sagittal and coronal reformats of the cervical spine in this intubated patient show a mildly displaced type II fracture of the dens (white arrows). (C) T2, (D) T1, and (E) short-tau inversion recovery (STIR) sagittal MR sequences show mild bowing but preservation of the posterior longitudinal ligament and no compression of the spinal cord at this level (white arrows).
Hyperextension sprain and hyperextension dislocation are injuries to the soft tissues from a hyperextension injury including the longus colli and capitis muscles, the anterior longitudinal ligament, the intervertebral disc, and the posterior longitudinal ligament. Hyperextension fracture dislocation more commonly occurs in elderly patients with disruption of the articular pillars, the posterior vertebral body, the laminae, the spinous processes, or the pedicles (Fig. 17).

Patients with ankylosing spondylitis or DISH are particularly prone to extension type fractures because of the loss of flexibility from ossification of the ligamentous complexes and disc spaces. These patients are therefore prone to fractures of the pathologic anterior calcification that extend obliquely through the disc into the subjacent vertebral body or posteriorly through the disc space (Fig. 18).

The extension teardrop fracture usually occurs when a hyperextension force produces an avulsion fracture of the anteroinferior corner of C2. The characteristic radiographic finding is that the vertical height of the avulsed fragment is greater than the horizontal width. These fractures only involve the anterior column, and therefore are stable in flexion and unstable in extension (Fig. 19).

Laminar fractures rarely occur in isolation, but when they do it is usually as a result of a hyperextension injury.

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**Fig. 8.** Type II fracture of the dens. (A, B) Axial CT with sagittal reformat shows a type II fracture through the dens (white arrows). The bones are osteopenic in this elderly patient. C2 fractures are more common in elderly patients because of osteopenia and degenerative changes.

**Fig. 9.** Type III fracture of the axis. (A) Lateral cervical spine radiograph demonstrates minimal subluxation of C2 on C3 but no definite fracture (white arrow). (B, C) Axial CT and sagittal reformat demonstrate a fracture through the body of C2 with extension into the base of the dens consistent with a type III fracture (yellow and white arrows).
Extension rotation injuries
An articular pillar fracture is a fracture through a lateral mass caused by impaction of the articular mass above during a hyperextension and rotational injury. This fracture usually extends into the transverse process or the lamina and is a stable fracture (Fig. 20).

The isolated articular pillar fracture can occur with a simultaneous fracture through the lamina and ipsilateral pedicle.

Burst fractures of the cervical spine
Burst fractures are much more common in the thoracolumbar spine, but can also occur in the cervical spine. They are characterized by a compression of the vertebral body with displacement of the posterior elements.

Fig. 10. Clay shoveler fracture. (A, B) Sagittal and (C) axial MR demonstrate an osseous defect through the spinous process of C7 consistent with a clay shoveler fracture (white arrows).

Fig. 11. Anterior subluxation. (A) Lateral cervical spine radiograph demonstrates mild anterior subluxation of C4 on C5 (white arrow). (B, C) Flexion and extension radiographs demonstrate no increased subluxation or kyphosis.
cervical spine. An axial compression force applied to the cervical intervertebral disc can result in the liquid nucleus pulposus imploding through the vertebral end plate into the center of the vertebral body with retropulsion of bony fragments into the spinal canal, which may cause neurologic compromise (Fig. 21). This situation typically results in combined sagittal and coronal splits in the vertebral body from dissipation of axial directed forces.59

THORACOLUMBAR SPINE INJURIES
Thoracolumbar spinal fractures are more common than cervical spinal fractures.2–4 Nearly 90% of all thoracolumbar fractures occur at the thoracolumbar junction, between T11 and L4. This region is vulnerable because of the change in the curvature of the spine from a kyphotic thoracic spinal curvature to a lordotic lumbar spinal curvature.21,22 The major types of thoracolumbar spine injury are described according to the mechanism of injury: compression or wedge, burst, flexion distraction or chance, and fracture dislocation.

Anterior Wedge Compression Fracture
Anterior wedge compression fractures account for nearly 50% of all thoracolumbar fractures. The classic imaging finding is of a wedge-shaped vertebral body compressing the anterior cortex and sparing the middle and posterior columns. These fractures may occur at multiple vertebral levels. Plain radiographs usually show a focal kyphotic deformity with cortical end plate buckling of the anterosuperior end plate, resulting in a wedge-shaped vertebral body. However, the exact amount of loss of vertebral body height and the fracture line may be difficult to see on plain film. Radiologic stability is best assessed by CT, which will better delineate the aforementioned features and prove the absence of posterior cortical displacement or middle column involvement. The injury may not be appreciated on axial CT images, as the plane of imaging is parallel to the fracture line, but they are well demonstrated on the sagittal reformatted images. MR imaging will demonstrate marrow edema as a secondary indicator of fracture in addition to any associated soft tissue injuries (Fig. 22). The mechanism of injury is an axial loading with or without a flexion component. The 2 population groups in whom this fracture occurs are young patients with a major trauma and osteoporotic patients with an insufficiency fracture. The superior vertebral end plate usually is affected in traumatic and benign insufficiency fractures whereas involvement of the inferior vertebral end plate raises suspicion for a pathologic fracture. Because 20% of vertebral compression fractures are multiple (Fig. 23), it is often recommended that the entire spinal axis be screened if a fracture is discovered.4,60

Lateral Compression Fracture
A lateral wedge compression fracture is characterized radiologically by a lateral wedge deformity of the vertebral body. This fracture occurs most commonly at the thoracolumbar junction followed by the midthoracic regions at T6-T7. Frontal radiographs may be suitable to establish the diagnosis showing the lateral extension of the fracture. CT confirms the diagnosis by showing an intact posterior vertebral body wall and no fragment retropulsion. The main risk factor is osteoporosis,
with many patients complaining of severe and prolonged pain (Fig. 24).\(^4\)

**Burst Fracture**

A burst fracture is typically produced by pure axial loading mechanism, and is distinguished from an anterior wedge compression fracture by the comminuted fracture of the vertebral body extending through both the superior and inferior vertebral end plates. The mechanism of injury is typically a vertical force such as jumping or falling from a height. Because of the mechanism of injury, burst fractures are often associated with bilateral calcaneal fracture, the so-called lovers’ leap fracture. A varying degree of rotation and comminution of the fracture fragments may occur. The requisite imaging feature of the burst injury is retropulsion of the posterior aspect of the vertebral body (ie, the middle column) into the spinal canal or posterior bowing of the posterior vertebral margin. Radiography usually shows a wedge-shaped vertebral body with widened pedicles. CT is superior in evaluating the burst fracture, demonstrating a comminuted vertebral body best seen on axial views. CT shows the degree of posterior retropulsion and

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**Fig. 13.** Anterior subluxation of C6 on C7 with spinous process fracture of C6 and anterior wedge compression fracture of C7. (A, B) Sagittal reformatted CT demonstrates approximately 25% anterolisthesis of C6 on C7 with subluxation of the facet joints at C6-C7 (white arrows). There is an oblique fracture through the spinous process of C6 and there is loss of stature of the anterior body of C7 secondary to a compression fracture. (C) Axial CT confirms the bilateral facet subluxation (white arrows).
any posterior displacement of bone fragments into the spinal canal. Burst fractures most commonly occur at the thoracolumbar junction, especially T12 and L1. In these regions, retropulsion of bony fragments can cause significant neurologic compromise. In patients with burst fractures with minimal trauma, an underlying cause such as osteoporosis or malignancy should be considered. There is also an increased incidence of sacral and pelvic fractures. Neurologic stability has been defined as spinal canal stenosis of greater than 50%. Surgical versus nonsurgical treatment of burst fractures without neurologic sequelae has been debated recently. There is a body of literature advocating a conservative, nonsurgical approach, with surgical intervention reserved for cases of delayed instability or pain. These options include bed rest or immobilization with or without casting/bracing. There are few good long-term follow up data for simple burst fractures, likely because of the variable management approach. At present, the choice between conservative management and surgery for burst fractures depends on the practice patterns of the surgeon and clinical status of the patient (Figs. 25–27).4,61–64

**Chance Fracture**

A Chance fracture involves compression of the anterior column with distraction of the middle and posterior columns. The term “distraction” refers to a complete separation of bone fragments in a craniocaudal direction. The classic Chance or lap-belt injury has decreased in incidence in recent...
Fig. 15. Flexion teardrop fracture. (A, B) Lateral radiographs and (C, D) sagittal CT reformats of the cervical spine demonstrate a typical flexion teardrop injury with an anterior triangular fracture fragment (the teardrop) of the anteroinferior aspect of the vertebral body of C5 (white arrows) and retropulsion of its posterior vertebral body fragment into the spinal canal with localized kyphotic angulation at C5-C6 (red arrows). (E, F) Axial CT images demonstrate a sagittal fracture of the vertebral body (white arrow).

Fig. 16. Unilateral facet dislocation. (A) Sagittal T2-weighted MR shows mild anterolisthesis of C6 on C7 (white arrow). (B) There is unilateral right-sided facet joint dislocation (yellow arrow).
times with the routine use of conventional 3-point restraint. A classic Chance fracture is a horizontal fracture through the spinous process, the lamina, the pedicles, the intervertebral disc space, and the posterior longitudinal, supraspinous, and intraspinous ligaments. The anterior longitudinal ligament is generally intact but may be disrupted in severe injuries. Chance fracture most commonly occurs at L1-L3. It is an acutely unstable injury and is associated with a high rate of abdominal visceral injury. On radiography the findings may be subtle, and include wedging of the anterior vertebral body and increased interspinous distance, that is, posterior element distraction, disc widening, and/or a horizontal fracture through the vertebra. CT is more sensitive, with the sagittal reformatted image showing a horizontally oriented fracture extending across the posterior elements and continuing into the vertebral body with more separation of the fragments posteriorly. The management of these patients depends on the neurologic damage and/or the degree of extraspinous injuries. Due to the extensive degree of soft tissue disruption, the majority of patients do

Fig. 17. Hyperextension dislocation. (A) Sagittal reformat CT demonstrates mild posterior displacement of C4 on C5 with distraction of the anterior and middle columns (white arrow). (B, C) T2-weighted sagittal and axial MR confirm these findings and demonstrate widening of the C4-C5 disc space (white arrow).

Fig. 18. Hyperextension fracture dislocation in a patient with ankylosing spondylitis. (A, B) Sagittal CT reformats demonstrate squaring of the vertebral bodies, syndesmophytes, and calcification of the anterior and posterior longitudinal ligaments, producing a “bamboo spine” appearance. There is a fracture through the calcified anterior longitudinal ligament at C5-C6 extending through and widening the C5-C6 disc space, consistent with a hyperextension fracture dislocation (white arrows).
require surgery with correction of the deformity (Figs. 28 and 29).67

Fracture Dislocation

A variety of fracture dislocations of the thoraco-lumbar spine can occur as a result of combined shearing and flexion forces. With severe hyperflexion injuries, dislocation occurs anteriorly. With flexion rotation injuries, dislocation of the facet joints may occur, with traumatic spondylolisthesis. With severe hyperextension injuries, usually from a blow to the back, there is classically posterior element impaction with fractures of the spinous process, lamina, or facet. Instability results from anterior ligament injuries, with hyperflexion injuries, dislocation occurs anteriorly. With flexion rotation injuries, dislocation of the facet joints may occur, with traumatic spondylolisthesis. With severe hyperextension injuries, usually from a blow to the back, there is classically posterior element impaction with fractures of the spinous process, lamina, or facet. Instability results from anterior ligament injuries, with hyperflexion injuries, dislocation occurs anteriorly. With flexion rotation injuries, dislocation of the facet joints may occur, with traumatic spondylolisthesis. With severe hyperextension injuries, usually from a blow to the back, there is classically posterior element impaction with fractures of the spinous process, lamina, or facet. Instability results from anterior ligament injuries, with hyperflexion injuries, dislocation occurs anteriorly. With flexion rotation injuries, dislocation of the facet joints may occur, with traumatic spondylolisthesis. With severe hyperextension injuries, usually from a blow to the back, there is classically posterior element impaction with fractures of the spinous process, lamina, or facet. Instability results from anterior ligament injuries, with hyperflexion injuries, dislocation occurs anteriorly. With flexion rotation injuries, dislocation of the facet joints may occur, with traumatic spondylolisthesis. With severe hyperextension injuries, usually from a blow to the back, there is classically posterior element impaction with fractures of the spinous process, lamina, or facet. Instability results from anterior ligament injuries, with hyperflexion injuries, dislocation occurs anteriorly. With flexion rotation injuries, dislocation of the facet joints may occur, with traumatic spondylolisthesis. With severe hyperextension injuries, usually from a blow to the back, there is classically posterior element impaction with fractures of the spinous process, lamina, or facet. Instability results from anterior ligament injuries, with hyperflexion injuries, dislocation occurs anteriorly. With flexion rotation injuries, dislocation of the facet joints may occur, with traumatic spondylolisthesis. With severe hyperextension injuries, usually from a blow to the back, there is classically posterior element impaction with fractures of the spinous process, lamina, or facet. Instability results from anterior ligament injuries, with hyperflexion injuries, dislocation occurs anteriorly. With flexion rotation injuries, dislocation of the facet joints may occur, with traumatic spondylolisthesis. With severe hyperextension injuries, usually from a blow to the back, there is classically posterior element impaction with fractures of the spinous process, lamina, or facet. Instability results from anterior ligament injuries, with hyperflexion injuries, dislocation occurs anteriorly. With flexion rotation injuries, dislocation of the facet joints may occur, with traumatic spondylolisthesis. With severe hyperextension injuries, usually from a blow to the back, there is classically posterior element impaction with fractures of the spinous process, lamina, or facet. Instability results from anterior ligament injuries, with hyperflexion injuries, dislocation occurs anteriorly. With flexion rotation injuries, dislocation of the facet joints may occur, with traumatic spondylolisthesis. With severe hyperextension injuries, usually from a blow to the back, there is classically posterior element impaction with fractures of the spinous process, lamina, or facet. Instability results from anterior ligament injuries, with
Fig. 21. Cervical burst fracture. (A) Axial CT demonstrates a comminuted fracture of a cervical vertebral body with mild retropulsion posteriorly (white arrow). (B) Sagittal reformat CT demonstrates a burst type fracture of C6 (white arrow). (C) Coronal reformat CT demonstrates the vertical course of the fracture (white arrow).

Fig. 22. Acute compression fracture of L4. (A) T1 and (B) T2 sagittal MR demonstrate a wedge-type fracture deformity of the anterior body of L4 (white arrows). (C) STIR sagittal MR demonstrates bone marrow edema changes in the inferior vertebral end plate of L3 and throughout the body of L4, indicating that this is an acute fracture (white arrows).
widening of the anterior intervertebral disc space and retrolisthesis. There is frequently spinal cord injury (Fig. 30).⁶⁸

**Other Fractures of the Thoracolumbar Spine**

Fractures of the transverse processes of the thoracolumbar spine can and do occur. These fractures can be missed on plain radiography, with CT being more sensitive for detection. The presence of a transverse process fracture increases the likelihood of other injuries including additional transverse process fractures, additional vertebral fractures, and/or abdominal viscera injury (Fig. 31).⁶⁹ Other fractures that can occur include spinous process fractures or pars interarticularis fractures.

![Fig. 23. Multiple thoracolumbar compression fractures. (A) T1 and (B) STIR sagittal sequences demonstrate multiple insufficiency type vertebral body fractures of varying ages (white arrows). There is hyperintense signal within several the vertebral bodies on the STIR sequence, indicating bone marrow edema consistent with more recent or acute fractures (red arrows).](image)

![Fig. 24. Lateral T8 cortex fracture. (A, B) Coronal reformat CT demonstrates a linear nondisplaced fracture through the left lateral cortex of T8 (yellow and white arrows).](image)
Fig. 25. Burst fracture of T12. (A, B) Coronal and sagittal CT reformats of the thoracolumbar spine demonstrate a burst type fracture of T12 with near complete loss of height of the T12 vertebral body, buckling of the posterior cortex of the T12 vertebral body, and posterior bony retropulsion, causing bony canal narrowing (white arrows). (C, D) Axial CT demonstrates the comminuted nature of the fracture. (E, F) Sagittal and axial T2-weighted MR demonstrate the spinal canal narrowing caused by the fracture (yellow arrows).

Fig. 26. Burst fracture of L1. (A) Sagittal reformat CT demonstrates anterior wedging of the L1 vertebral body with posterior bony retropulsion into the bony canal (yellow arrow). (B) Axial CT demonstrates the comminuted pattern of the fracture and the degree of retropulsion (yellow arrow).
SACRAL FRACTURES

High-velocity injuries of the pelvis can result in traumatic sacral fractures. The best radiographic clue is disruption of the sacral arcuate lines. Approximately 95% of these fractures are vertical or oblique and 5% are horizontal. Approximately 95% occur in association with other pelvic fractures, and the symptoms can be masked by concurrent injuries at higher levels. There are 3 classic appearances: the first is the "open book," which is a vertically oriented fracture; the second is a "T-bone injury," which is an impacted vertically oriented fracture producing a sclerotic line; and the third is a "vertical shear," which is a vertically oriented fracture with vertical displacement and/or fractures of the L5 transverse processes. Lumbar spine fractures will be present in up to 30% of patients with sacral fractures. The Denis system is used to classify sacral fractures; zone 1 is lateral to the neural foramina, zone 2 is through the neural foramina, and zone 3 is through the spinal canal. A fracture confined to the sacrum only is considered a stable fracture, but fracture involving the sacrum and another component of the bony pelvis (ie, 2 fractures) is considered an unstable fracture (Fig. 32).

A sacral insufficiency fracture is a stress fracture from normal physiologic force on demineralized bone, most commonly occurring in patients with osteoporosis. This fracture can sometimes be overlooked on an MR image of the lumbar spine. The MR signs are of unilateral or bilateral T1 hypointensity and T2/short-tau inversion recovery hyperintensity in the sacrum. The classic "Honda sign" on bone scan is produced by a characteristic H-shaped pattern of radiotracer uptake in the sacrum (Fig. 33).

MR IMAGING OF SPINAL TRAUMA

MR imaging has revolutionized the diagnosis of spinal cord injury and provides the best imaging evaluation of the intervertebral discs, the ligaments, and the spinal cord. Plain radiography and CT are the most appropriate, quickest, and cost-effective methods of assessing for spinal injury, particularly fractures, in the initial acute diagnostic stage. MR imaging, however, has replaced myelography and CT myelography as the primary imaging modality in assessing for epidural hematoma, ligamentous injury, traumatic disc herniation, and spinal cord compression. However, these modalities are reserved only for patients in whom MR imaging is contraindicated.

At a minimum, T1 and T2 sagittal imaging of the spine should be obtained. The T1 sequences provide information on basic anatomy. The T2 sequences are the best for visualizing spinal cord injury, ligamentous edema/disruption, marrow edema, and traumatic disc herniation. A sagittal proton density sequence is useful for confirming ligamentous disruption and/or identifying epidural

Fig. 27. Failure of conservative management of a T12 burst fracture. (A–C) T1, T2, and STIR sagittal MR demonstrate a burst fracture of T12 with approximately 30% to 40% loss of height anteriorly (white arrows). (D–F) T1, T2, and STIR sagittal MR performed 3 months later following conservative treatment with a back brace demonstrate progressive wedging of the T12 vertebral body with approximately 50% loss of height anteriorly (white arrows). Plain films at diagnosis (G) and 3 months later (H) demonstrate the interval change (white and yellow arrows).
blood/fluid collections. A sagittal gradient echo sequence is useful for detection of spinal cord hemorrhage. Axial T2 sequences are useful to confirm spinal cord signal abnormality identified on the sagittal sequence. An axial T1 with fat saturation is useful to identify vascular dissection. The area of interest, the cervical, thoracic, or lumbar spine, should be imaged first and, depending on the patient’s clinical status, the MR findings, and patient cooperation, MR of the additional spinal levels can be obtained. Limited surveys can be obtained if the examination needs to be rapidly terminated.72

At present, MR imaging does not offer any advantage over CT in spinal osseous injuries. CT, or at least plain radiography when CT is not available, should first be obtained to assess for osseous fractures. MR imaging is less sensitive than CT in fracture detection but can demonstrate bone marrow edema related to compressive injuries (Fig. 34).

MR imaging directly visualizes changes to the anterior longitudinal ligament, the posterior longitudinal ligament, the ligamentum flavum, and the interspinous ligaments. Ligamentous rupture is visualized as focal discontinuity with or without associated hematoma. Widening of the facet joints with increased fluid signal can be demonstrated, suggesting a distraction injury (Fig. 35).

Posttraumatic disc herniation is more common in the cervical and thoracic regions, unlike degenerative disc herniations. Posttraumatic disc injuries on MR imaging can be classified as either disc injury or disc herniation. Traumatic disc injury manifests as narrowing or widening of the disc space with T2 hyperintense signal abnormality, usually reflecting tearing of the disc substance. Traumatic disc herniation has a similar MR appearance to nontraumatic disc herniation (Fig. 36).

Epidural hematoma is frequently seen in spinal cord injury. Fortunately, it is generally asymptomatic. The imaging characteristics vary with the oxidative state of the hemorrhage and the clot retraction. The incidence of posttraumatic epidural hematoma is greater in patients with ankylosing spondylitis (Fig. 37).73

Dissection of the vertebral artery is more common than dissection of the carotid artery because the vertebral arteries are fixed in location by the foramina transversaria. Prior data suggest the incidence of vertebral artery dissection in cervical spinal trauma to be as high as 40%, with a large subclinical cohort. Early recognition of this injury is crucial because of its associated morbidity. Neck MRA with 2-dimensional time-of-flight and T1 fat saturation axial sequences are used to screen for this potential complication (Fig. 38).

Spinal cord injury without radiographic abnormality (SCIWORA) is defined as spinal cord injury with normal plain radiographs. SCIWORA occurs in children and adults. It usually occurs in the cervical spine following a rear-end motor vehicle accident or direct facial trauma, resulting in a hyperextension sprain or dislocation, sometimes on superimposed cervical spondylosis. Plain radiographs are frequently normal. MR imaging is of particular diagnostic value because it depicts many abnormalities that cannot be seen on plain

Fig. 28. Chance fracture. (A) Coronal, (B) sagittal, and (C) axial CT images of the thoracolumbar spine demonstrate a comminuted fracture of the posterior vertebral body with a horizontal or split component extending into the pedicles, the bases of the transverse processes, the laminae, and into the spinous process (white arrows).
radiography, including separation of the intervertebral disc, rupture of the anterior longitudinal ligament, prevertebral hemorrhage, and/or parenchymal spinal cord injury.\textsuperscript{74}

**MR IMAGING FINDINGS IN SPINAL CORD INJURY**

MR imaging is the best imaging modality in evaluation of the spinal cord injury, providing information that helps determine prognosis and potential for patient recovery. MR is the best imaging modality for depicting the internal architecture of the spinal cord. However, it can be difficult to distinguish spinal gray matter from white matter, particularly on the sagittal sequences. The central gray matter is uniformly hyperintense to white matter on all pulse sequences, which is attributed to the higher spin density of gray matter. These image characteristics are usually lost after

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**Fig. 29.** Chance distraction type fracture. (A, B) Sagittal reformat CT demonstrates a horizontal fracture through the inferior vertebral end plate of T8 extending into the posterior elements (white arrows). The patient underwent posterior thoracolumbar fusion but his symptoms progressed. (C) Sagittal reformat CT myelographic images demonstrate a fracture through the inferior vertebral end plate of T8 with widening of the fracture in the cranio-caudal direction (distraction) (white arrow). (D) Sagittal reformat CT myelographic images demonstrate contrast opacification from the sacrum to T9, where there is a myelographic block (white arrow).
spinal cord injury because of accumulation of edema and hemorrhage with swelling of the cord parenchyma.75

Spinal cord hemorrhage, as a manifestation of spinal cord injury, usually occurs in the central gray matter of the cord at the point of maximal mechanical impact. Pathologic studies have shown that the underlying lesion is usually hemorrhagic necrosis. In the acute phase following injury the blood products are in the deoxyhemoglobin state, manifesting as hypointensity on T2 and gradient echo images. Deoxyhemoglobin evolves into methemoglobin (animal studies have suggested a time period of up to 8 days), which manifests as hyperintensity on T2 images. Many studies have shown that parenchymal hemorrhage develops rapidly in the cord following trauma. MR imaging can detect the anatomic location and the extent of the hemorrhage. The presence of frank hemorrhage carries a poorer prognosis.76

Spinal cord edema, as a manifestation of spinal cord injury, is best demonstrated on T2-weighted sequences as abnormal T2 hyperintense signal within the affected cord segment (Fig. 39). Spinal cord edema reflects a focal accumulation of intracellular and interstitial fluid in response to injury, involves a variable length of the cord above and below the level of the injury, and is invariably associated with a degree of swelling. It usually occurs in association with spinal cord hemorrhage, but not always; spinal cord edema without hemorrhage carries a more favorable prognosis.77

Spinal cord swelling, as a manifestation of spinal cord injury, is a focal increase in the caliber of the spinal cord centered at the level of the injury. The cord is normally uniform in caliber with minimal changes at the lower cervical and lower thoracic levels. Abnormal cord swelling is best demonstrated on T1-weighted sequences. The swelling can occur in association with spinal cord hemorrhage and/or edema, and is by itself an indicator of spinal cord injury but not a predictor of the degree of underlying spinal cord dysfunction.78

INITIAL ASSESSMENT OF SPINAL CORD TRAUMA

The initial management of a patient with suspected spinal cord injury consists of resuscitating and stabilizing the patient. In the immediate management of any patient with a suspected cervical spine injury, complete cervical spine immobilization is mandatory.79 Further assessment with a neurologic examination is used to make diagnoses and treatment decisions for the patient. However, it is often difficult to perform an accurate and/or complete neurologic examination of the patient because of a variety of factors including the urgency for medical stabilization, surgical interventions, and factors limiting patient
cooperation such as pain, analgesics, alcohol, and drugs. Often, a repeat neurologic examination performed 3 to 7 days after the injury is a better indicator of prognosis than the initial examination.\textsuperscript{80,81}

The most frequently used scale to classify spinal cord injury is the American Spinal Injury Association (ASIA) impairment scale (AIS), a 5-point scale from A to E; where AIS A is complete loss of motor and sensory function below the neurologic level including the sacral dermatomes (S4-S5), AIS B is complete loss of motor power with sparing of sensation in the sacral dermatomes (eg, S4-S5), AIS C and AIS D represent motor incomplete injuries differentiated by motor strength, and E is normal.\textsuperscript{82,83}

Another clinical parameter that has a significant impact on patient diagnosis, neurologic function, and potential to recover neurologic function is the neurologic level of injury (NLI). The NLI is determined from assessing the motor power and sensory function for myotomes and dermatomes that are innervated by adjacent spinal cord segments. The most caudally intact myotome or dermatome is determined in order to determine the NLI. By inference, the NLI obtained from clinical examination determines the location of the lesion in the spinal cord. Many studies have shown high concurrence rates between the NLI and MR imaging signal changes.\textsuperscript{84}

**MEDICAL MANAGEMENT OF SPINAL CORD INJURY INCLUDING MEDICAL COMPLICATIONS**

Many patients with spinal cord injuries are trauma patients. The initial management of these patients

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**Fig. 31.** Transverse process fractures. Axial CT demonstrates acute fractures through the left transverse processes of L1 (A), L2 (B), L3 (C), L4 (D), and L5 (E) (white arrows). Axial postcontrast CT (F) demonstrates a small hematoma in the splenic hilum (white arrow).
consists of basic life support, with full attention to airway management and breathing and circulation parameters. A full primary and secondary survey is necessary, as these patients may have distracting injuries.

Following medical stabilization, determination of approximate level and extent of spinal cord injury, and surgical assessment, pharmacotherapy with methylprednisolone is considered. The use of methylprednisolone in the treatment of acute spinal cord injury is controversial with regard to indication, dosage, and timing. However, most trauma centers will use it at up to 8 hours after injury.85

The initial and subsequent medical management of spinal cord injury patients is directed toward prevention of the many medical complications that patients with spinal cord injury are prone

Fig. 32. Acute traumatic sacral fractures. Sagittal (A) and coronal (B) CT reformats and axial CT (C) demonstrate bilateral comminuted fractures of the sacral ala with anterior displacement of the fractured proximal sacral segment (white arrows).
to develop. These complications include urinary tract infections, pressure ulcers, pain, depression, spasticity, pneumonia, autonomic dysreflexia, deep venous thrombosis with occasional subsequent pulmonary emboli, renal and bladder stones, renal failure, and heterotopic ossification.\textsuperscript{1,86} Deep venous thrombosis with or without subsequent pulmonary emboli occur in 47\% to 100\% of patients with spinal cord injury, and is a life threatening complication.\textsuperscript{87} The use of antithrombotic compression stockings is standard.

Several clinical guidelines support the use of low-dose subcutaneous or low molecular weight heparin as prophylaxis.\textsuperscript{88} This prophylactic treatment should last for 2 to 3 months. Despite several case series in the literature, at present the literature does not support the use of prophylactic inferior vena cava filters.\textsuperscript{89} If contraindications to anticoagulation exist in a patient with a proven deep venous thrombosis or pulmonary embolism, then an inferior vena cava filter is indicated.\textsuperscript{90} The aim of management is to prevent recurrent

![Fig. 33. The Honda sign with a sacral insufficiency fracture. (A) A nuclear medicine bone scan demonstrates diffuse uptake of radiotracer throughout the sacrum in an H shape, the Honda sign (white arrow). (B) Axial CT demonstrates bilateral sacral fractures and osteopenia (white arrows).](image)

Fig. 33. The Honda sign with a sacral insufficiency fracture. (A) A nuclear medicine bone scan demonstrates diffuse uptake of radiotracer throughout the sacrum in an H shape, the Honda sign (white arrow). (B) Axial CT demonstrates bilateral sacral fractures and osteopenia (white arrows).

![Fig. 34. MR imaging of a flexion teardrop fracture. (A) T2, (B) T1, and (C) STIR sagittal MR demonstrate a hypo-intense band through the anteroinferior body of C6 with STIR hyperintensity throughout C6 consistent with a fracture. MR is less sensitive than CT in fracture detection but can be diagnosed, as in this case. Additional findings include posterior subluxation of C6 compressing the spinal cord with T2 hyperintense signal from C5 to C7, consistent with spinal cord edema.](image)

Fig. 34. MR imaging of a flexion teardrop fracture. (A) T2, (B) T1, and (C) STIR sagittal MR demonstrate a hypo-intense band through the anteroinferior body of C6 with STIR hyperintensity throughout C6 consistent with a fracture. MR is less sensitive than CT in fracture detection but can be diagnosed, as in this case. Additional findings include posterior subluxation of C6 compressing the spinal cord with T2 hyperintense signal from C5 to C7, consistent with spinal cord edema.
Pulmonary emboli. Patients with a neurologic level above T6 are at risk for a life-threatening condition called autonomic dysreflexia, in which noxious stimuli can cause malignant hypertension leading to cardiovascular compromise. There are clinical guidelines regarding autonomic dysreflexia, and it is prudent to be aware of this potential complication when managing a patient with a spinal cord injury. Pulmonary complications are the leading cause of mortality in the first year of recovery from a spinal cord injury as well as in long-term survivors. As such, attention must be given to reducing all risk factors for respiratory complications in patients. Depending on the level of the spinal cord injury, patients may require temporary or permanent ventilator support. Because of immobility and absence of sensation, pressure ulcers or decubiti can form, which can lead to more severe sequelae such as sepsis and osteomyelitis. Prevention of decubiti requires vigilance regarding regular patient turning/repositioning, adequate nutrition, regular assessment of parameters such as albumin, and prompt consultation with a wound care specialist when a pressure ulcer develops. Neurogenic bowel and bladder dysfunction are also common in patients.

**Fig. 35.** MR of acute cervical ligamentous injury. (A) Sagittal reformat CT demonstrates normal alignment with no fracture. (B) T2 and (C) STIR sagittal MR demonstrates anterior subluxation of C5 on C6 (white arrows) with signal abnormality in the posterior longitudinal ligament and spinous ligaments at C5-C6 (red arrows). (D) The patient was surgically stabilized with a C5-C6 anterior and posterior fusion (white arrows).
with spinal cord injury. Without proper care, this can lead to recurrent urinary tract infections and sepsis. Close attention needs to be maintained to prevent these complications with regard to diet, stool softeners, and urinary catheterization.96

SURGICAL TREATMENT OF SPINAL CORD INJURY

Surgical management of spinal cord injuries can vary from simple external bracing with limitation of activity to complex instrumentation of the spine. The approach to management can vary from center to center, but the overall aim is to use the least invasive technique to stabilize the injured segment and prevent long-term complications.

Numerous spinal braces are available for the treatment of spinal injuries. The principle of bracing is to reduce motion at the injured spinal area in order to improve the likelihood of healing and reduce the potential for spinal cord injury from an unstable injury. For cervical spine injury, bracing ranges from soft and hard collars (eg, the Miami J collar; Ossur, Foothill Ranch, CA, USA)

Fig. 36. Traumatic disc herniation. (A, B) T2 sagittal MR of the cervical spine demonstrates an extrusion type disc herniation at C3-C4 (white arrows) displacing the posterior longitudinal ligament and compressing the spinal cord with diffuse T2 hyperintense cord signal from C2 to C5 (red arrows). T2 axial MR above the level of the extrusion (C) demonstrates normal subarachnoid space anterior to the cord (yellow arrow). T2 axial MR at the level of the extrusion (D) demonstrates an extruded disc that compresses the cord and causes diffuse T2 hyperintense signal, consistent with cord edema (white arrow).
to bracing (eg, the Minerva brace) to halo vest immobilization. A simple cervical collar is the least cumbersome but comes at a cost in that it does allow a very limited range of motion. A brace is more cumbersome but allows less movement. Halo vest immobilization provides the most rigid immobilization by fixing a halo ring around the head and securing the halo ring to a thoracic vest with rods.

The upper thoracic spine is a difficult region to immobilize with external orthosis, and requires a long thoracic vest. Spinal fractures from T6-L2 are easier to immobilize with bracing. Casting is another option for lumbar and lumbosacral immobilization.

Surgical intervention in spinal trauma is required to decompress the neural elements in cases of neurologic deficit, to prevent spinal cord injury from potentially unstable injuries, to correct and prevent deformity that could cause long-term adverse neurologic sequelae, and to provide for early mobilization. Anterior, posterior, and combined approaches can be taken operatively. All approaches require a form of spinal instrumentation, defined as a means of straightening and stabilizing the spine using hooks, rods, or wires. An anterior approach is favored when a herniated disc or bone fragment compresses the spinal cord. A posterior approach with instrumentation is favored when deformities are present. A combined anterior and posterior approach is favored for fracture-dislocation injuries when anterior-posterior instrumentation increases the success rate for a surgical stabilization procedure.4

Fig. 37. Epidural hematoma. Sagittal MR of the lumbar spine demonstrates a burst fracture of L1 (white arrows) with (A) T1 hyperintense, (B) T2 isointense, and (C) STIR hyperintense, extra-axial material posterior to T12-L2, consistent with blood products (red arrows). (D, E) T2 axials confirm the epidural location of the blood products, confirming that this is an epidural hematoma (white arrows).
Fig. 38. Traumatic induced right vertebral artery dissection. (A, B) Axial CT images in this intubated patient demonstrate a fracture through the right lamina of C4 extending into the right pedicle and through the posterior wall of the right foramen transversarium (white arrows). (C) CT angiogram through the neck demonstrates no flow in the right vertebral artery at C4 (white arrow). (D) Coronal CT angiogram reformat through the neck demonstrates no flow in the right vertebral artery at C3-C4 with marked attenuation of the C2-C3 segment of the vessel, reflecting acute dissection (white arrow).

Fig. 39. Spinal cord edema. (A) Sagittal and (B) axial T2-weighted MR through the cervical cord demonstrate diffuse T2 hyperintense signal at C6, reflecting spinal cord edema (white arrows).
SUMMARY

Spine trauma is a complex diagnostic area in which the radiological assessment is crucial. Plain radiography is often used as the initial diagnostic modality. However, stabilization of the acutely injured spine is a primary concern. In this respect, CT is vastly superior to plain film in terms of speed and accuracy. CT requires much less patient mobilization than plain film. In many trauma centers, CT has replaced plain film as the primary modality for evaluation of spinal trauma. MR imaging is not indicated for all cases of spinal trauma but provides detailed information about soft tissue structures including the intervertebral disc, the ligaments, the epidural space, the blood vessels, and the spinal cord. MR imaging provides information on these structures not obtained from other modalities. Patients with spinal cord injury may suffer devastating long-term neurologic deficits, so prompt and efficient spinal imaging guidelines are necessary in all trauma centers. Both the radiologist and the physician need to be aware of the patterns of injury and the implications of these injuries.

REFERENCES


