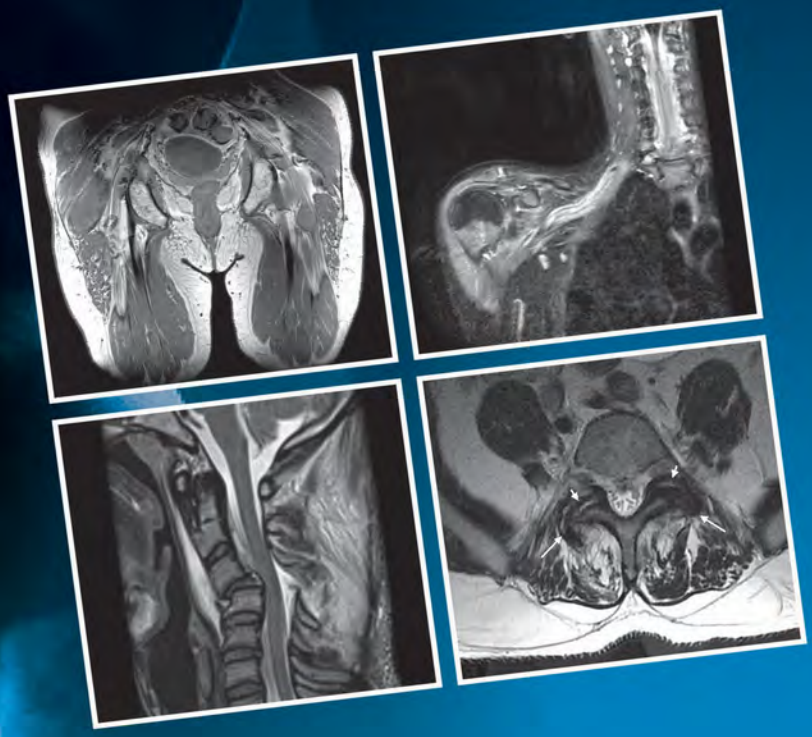
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Spinal Imaging

Critical Topics for Clinical Practice



2nd Edition

Mauricio Castillo

JAYPEE

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CHAPTER 4

Imaging of Acute Spinal Trauma

Daniel Varon, J Keith Smith, Mauricio Castillo

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Nowadays, multidetector computed tomography (CT) is the method of choice when evaluating the spine after blunt trauma. The development of multidetector CT has allowed faster volumetric acquisition with thin collimation and isotropic and multiplanar display, which obviates the need for plain radiographs that are difficult to obtain in such patients and in many cases are nondiagnostic. Multidetector CT is a faster technique than conventional CT, and has shown a much higher, sensitivity than radiography for bone injury detection. In the trauma setting, multidetector CT is used concurrently to assess other body regions, and the spine can easily be included as part of multisegment scan. Magnetic resonance imaging (MRI) is considered indispensable in many situations and is considered the modality of choice for assessing soft tissue injuries, spinal cord injury, intervertebral discs and ligament injury.[1-14]

Plain radiography and CT continue to be of great importance in the evaluation of the spine after acute trauma. Magnetic resonance imaging is gaining acceptance and is considered indispensable in many situations.[1-15] At our institution, all patients who have significant spine trauma with nondiagnostic plain radiographs or who cannot have complete physical examination are studied with CT. There is a tendency to obtain a spiral CT scan of the cervical spine in all patients who arrive to the emergency department with their head immobilized. This obviates the need for plain radiographs that are difficult to obtain in such patients and in many cases are nondiagnostic.

If the CT is normal and there are no neurologic symptoms, the diagnostic evaluation of the patient is terminated. If the CT is normal but neurologic symptoms are present, MRI is obtained. If the CT scan is abnormal in absence of neurologic symptoms, MRI is usually not performed. Many patients with spine fractures or dislocations receive CT and MRI, because they provide complementary information. In many cases, MRI can reveal an underlying lesion that may change the treatment, prognosis, or surgical approach.

In the cervical spine, our CT imaging protocol includes 3-mm thick spiral sections (pitch = 1) extending from the base of the skull to the first thoracic vertebra. Sagittal and coronal reformations are performed in all patients. If abnormalities are suspected but inadequately revealed by this study, or if abnormalities of the craniocervical junction are present, a focused study with spiral 1-mm axial images is obtained.

Our MRI protocol for the acutely injured spine includes sagittal T1-weighted, fast spin echo (FSE) T2-weighted images, FSE T2-weighted with fat saturation, and axial T1- and gradient echo (GE) T2-weighted images. No contrast is necessary in these patients. The sagittal FSE T2-weighted images provide high resolution at the expense of less susceptibility effects, thereby underestimating the presence and degree of hematomas. For this reason, the axial T2-weighted images are obtained using a low flip angle gradient technique that increases the visualization of susceptibility effects, making acute hemorrhage more visually obvious. The use of fat saturation with FSE T2-weighted images enhances the visibility of ligament and soft tissue injuries and reduces the relatively bright signal of fat seen with this sequence.

This chapter reviews the utility of the multidetector CT and MRI for evaluation of the spine, spinal cord (and nerves), and vascular structures in the setting of acute trauma.

BONES

The evaluation of bony injury is best performed with CT and plain radiographs. If there is a question as to the etiology underlying an acute spinal fracture (i.e. pathologic vs.

traumatic), MRI is essential. Distinction of benign from malignant fractures is discussed later. Magnetic resonance imaging also may discover unsuspected fractures, particularly involving the sacrum or vertebral end plates. Evaluation of the facet joints is also aided by the sagittal orientation of reformatted CT images.

LIGAMENTS

Magnetic resonance imaging is the only technique that permits visualization of the ligaments. In many cases, torn ligaments create instability and indicate the need for internal fixation.[16-18] In the past, ligamentous injury could only be inferred from bony malalignment or abnormal mobility on flexion or extension radiographs. These techniques are insensitive because malalignment may be reduced by the time imaging is performed, and muscle spasm may limit abnormal mobility acutely. Important spinal ligaments that can be routinely assessed by MR include the anterior longitudinal ligament (ALL), the posterior longitudinal ligament (PLL), and the posterior ligament complex (PLC), composed of the supraspinous and intraspinous ligaments, the capsules of the facet joints, and the ligamentum flavum.[16] The ALL is best visualized on T1-weighted sagittal images, where its homogenous low signal contrasts with the high signal from fat in the marrow spaces and adjacent soft tissue. The PLL is best visualized on T2-weighted images where the high signal from the adjacent spinal fluid provides contrast to the low signal ligament. Depiction of the PLC is aided by T2-weighted images with a fat saturation technique.[18] This is because the ligaments are less well defined, and interspersed fat yields high signal intensity that is made more pronounced by the proximity to the MR spinal surface coil. The reader should note that in many situations, it is not possible to separate the dark signal intensity of a ligament from the adjacent cortical bone. The ligaments are, however, seen independently at the disc spaces. The transverse atlantal ligament of Cl is another important structure that can be imaged with MR. More detailed discussion of ligament injuries is provided below in the sections on individual types of injury. Most ligamentous injuries are accompanied by edema in the perivertebral tissues that can be seen as areas of increased T2 signal intensity.

DISC

Magnetic resonance imaging allows for identification of disc abnormalities in acute spinal trauma.[19-24] In severe trauma, disc herniations are present in 20–50% of cervical injuries. Most post-traumatic disc herniations occur in the cervical region and at similar levels as degenerative disc herniations (C4-C7) due to the change in curvature that results in differences in spinal biomechanics and axial loading.[20]

Patients with acute anterior spinal cord syndrome have a nearly 100% incidence of disc herniations. Brown-Séquard syndrome and central cord syndrome also are associated with a high incidence of herniated discs. These neurologic deficits usually correspond to the level of the disc herniation that can be clearly identified with MRI. With spine dislocations or fracture dislocations, herniated disc fragments may become displaced into the spinal canal during reduction of the dislocation, leading to neurologic deterioration. For this reason, it has been recommended that patients with significant dislocations or fracture dislocations be studied with MRI prior to reduction.[19] In many institutions, the presence of a significant disc herniation leads to consideration of an anterior approach with discectomy.

Most acute post-traumatic disc herniations are bright on T2-weighted images and may be associated with ventrally located and adjacent epidural hematomas. Acute intravertebral disc herniations (Schmorl's nodes) may be painful and show contrast enhancement (particularly in the vertebral end plates), but need no treatment. They are more common in the lumbar region. Magnetic resonance permits definite diagnosis in these patients.

Epidural and Subdural Spaces

Most spinal epidural hematomas are spontaneous, with 15% occurring as a consequence of trauma.[25-29] Trauma-related extradural hematomas usually are found in the presence of severe trauma, but some are secondary to minor trauma (particularly in patients with a coagulopathy) or may be associated with acute disc herniations. Epidural hematomas also may follow lumbar puncture or spinal surgery and most of these are located in the dorsal extradural compartment.

While most spontaneous epidural hematomas are venous in nature, those following trauma are thought to be arterial in origin. Unlike the spontaneous epidural hematomas, post-traumatic ones are ventral in location and intimately related to the site of injury (Figs. 4.1 and 4.2). Most post-traumatic epidural hematomas are found in the thoracic, lumbar, and sacral regions and are uncommon in the cervical spine. In general, epidural hematomas have a biconvex shape, while subdural hematomas conform to the shape of the spinal canal.

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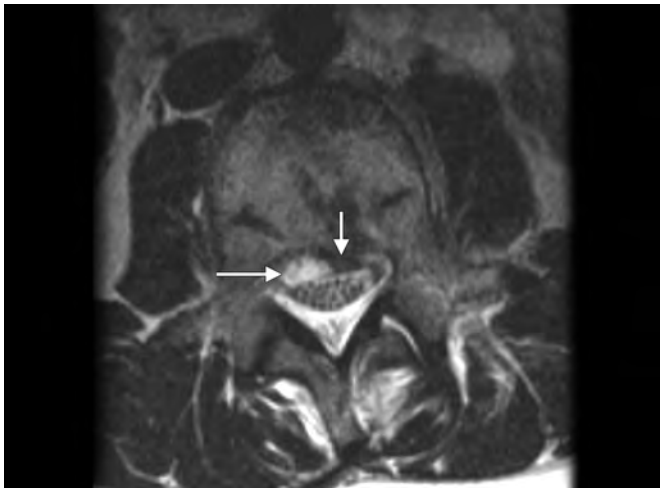


Fig. 4.1: Epidural hematoma. Axial T2-weighted image of the lumbar spine shows a heterogeneous anterior epidural collection (arrows), with areas of high and low signal intensity consistent with subacute epidural hematoma.

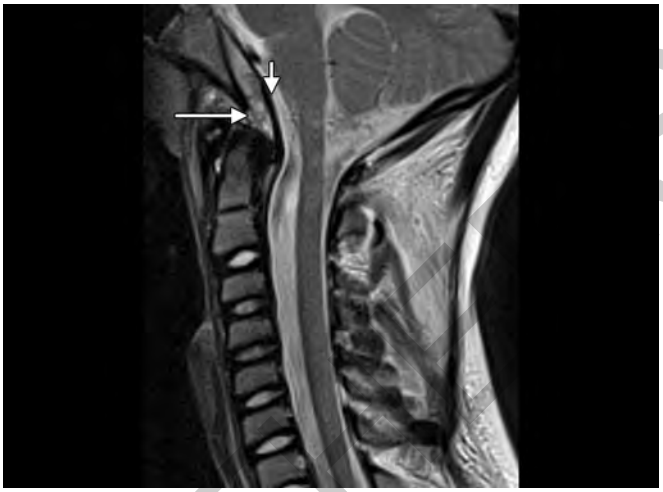


Fig. 4.2: Sagittal fast spin echo T2 image shows elevation of tectorial ligament off clivus, with underlying epidural hemorrhage (long arrow), but the tectorial membrane appears intact (arrow).

Table 4.1: Magnetic resonance imaging classification of spinal cord injuries according to Kulkarni.[30]

Type of injury	*T1 signal*	*T2 signal (particularly on gradient echoes)*	*Prognosis*
Type 1 (hematoma)	Isointense	Low (blood) with rim of high signal (edema)	Poor
Type 2 (edema)	Low or isointense	High	Relatively good
Type 3 (edema and hematoma)	Low or isointense	Mottled	Poor to fair

Traditionally, spinal epidural hematomas have been considered surgical emergencies; nevertheless, several cases with improving or minimal neurologic deficit have been successfully managed conservatively.[26] Subdural hematomas are very rare in the spine. Presence of a subdural hematoma indicates the need for the surgeon to open the dura for adequate evacuation; this is not necessary for epidural hematomas. Most epidural and subdural hematomas are slightly bright on T1- and T2-weighted images but dark on GE T2 images.

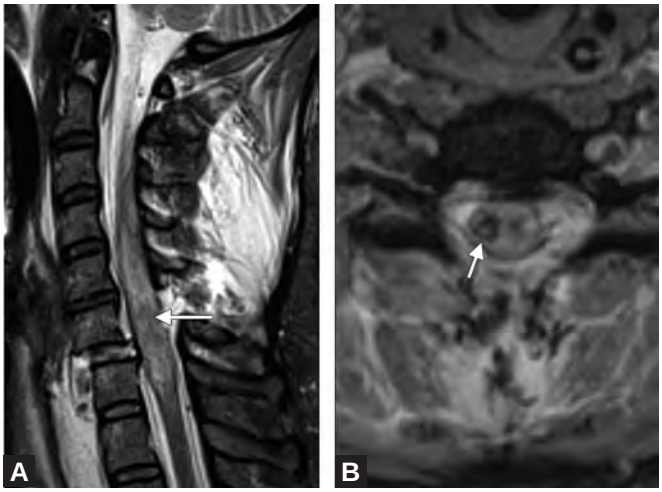
An unusual complication of acute trauma is the formation of extramedullary cerebrospinal fluid-filled cysts in either the epidural or subdural spaces. These are probably equivalent to subdural hygromas occurring intracranially and occur in the presence of severe spinal trauma. These cysts may compress the spinal cord, resulting in neurologic deficits.[27,28] They are readily identified by MRI.

SPINAL CORD

Acute injuries to the spinal cord may be categorized as contusions (hemorrhagic and nonhemorrhagic), transection, and vascular injuries.[30,31] Spinal cord contusions can be classified by their MR appearance to assist in establishing prognosis (Table 4.1). Type 1 injuries show swollen spinal cord with inhomogenous T1 signal, central dark T2 signal, and surrounding edema. They represent intramedullary hematoma within a swollen spinal cord and these patients have a poor prognosis for any recovery of function (Fig. 4.3). In type 2 injuries, there is homogenous high signal on T2-weighted images, reflecting only edema in the spinal cord (Fig. 4.4). These patients have a more favorable prognosis. Type 3 injuries show mottled signal abnormalities on all MRI sequences, which is related to edema and minute hemorrhagic foci. These patients have an intermediate prognosis.

Spinal cord injury may occur in the absence of bone/ligamentous injury.[30-34] This has been referred to as spinal cord injury without radiographic abnormality. This type of injury is more commonly seen in children than in adults, and almost always occurs in the cervical spine, although case reports of thoracic injuries exist.[35] In adults, degenerative disc disease, congenitally narrow spinal canal, and ossification of the PLL predispose to acute spinal cord

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Figs. 4.3A and B: Spinal cord injury. Kulkarni type 1 pattern (hematoma): sagittal T2-weighted (A) and gradient echo T2 (B) images of the cervical spine of a patient imaged after sustaining severe hyperflexion injury with anterior dislocation of C6 on C7 and ligamentous disruption. There is a central area of low signal intensity (from blood products; arrows) with surrounding high signal intensity (from edema).



Fig. 4.4: Spinal cord injury. Kulkarni type 2 pattern (edema): sagittal T2-weighted magnetic resonance imaging of the cervical spine of a patient with a hyperflexion. There is a homogenous area of high signal intensity (from edema) (arrow).

injury without bone abnormalities. Patients with neurologic deficits after trauma should be evaluated with MRI even in the face of normal radiographs and/or CT.[36]

Spinal cord transection is more common in children. In adults, there is generally severe accompanying bone trauma.[37] Magnetic resonance imaging reveals that the injured spinal cord may appear nearly transected (which has the same implications as complete transection) or in shreds.[38] Magnetic resonance imaging allows for identification of the level of the proximal spinal cord stump, which helps to establish the level of permanent clinical disability. Hemorrhage involving the entire transverse diameter of the spinal cord behaves clinically as a complete transection. Transection of the spinal cord may also occur in newborns subjected to a difficult delivery. This is more common following difficult breech deliveries, but may occur in head presentations complicated by pelvic disproportion. In these infants, the spinal cord may be directly injured or may be infarcted due to stretching of the cord and compromise of its vascular supply. These infarctions are more common at the cervicothoracic junction because it is a watershed zone between vascular territories. This region of the spinal cord will undergo significant atrophy with time.

Vascular injury to the spinal cord is rare following trauma or surgery. Initially, most spinal cord infarctions result in swelling of the gray matter, giving origin to the so-called owl-eye appearance on axial T2-weighted images. The edema then progresses to involve the white matter and, if the entire transverse diameter of the spinal cord is affected, the prognosis is poor. Most infarctions are secondary to involvement of the anterior spinal artery, but they are also known to occur after occlusion of the paired posterior spinal arteries. Most distal thoracic and conus infarcts occur during repair of abdominal aortic aneurysms. Spinal cord infarcts may also occur secondary to rib fractures (with occlusion of the intercostal arteries that supply the spinal cord).

Vertebral Arteries

About 20% of all patients with cervical spine fractures have either symptomatic or asymptomatic injuries to one of both vertebral arteries.[39-44] In patients with fractures involving the foramen transversarium with facet dislocations, the incidence of vertebral artery injury is as high as 50–75%.[39] Occlusion of a vertebral artery in presence of a normal contralateral artery is usually asymptomatic. Dissection of one vertebral artery (even if the contralateral one is normal) or bilateral occlusion may cause stroke or death, and may indicate the need for anticoagulation.[39-43] Many of these patients will have other injuries that prevent anticoagulation such as intracranial hemorrhage, spinal epidural and subdural hematomas, or recent surgery.

The vertebral arteries may be occluded, dissected, or show pseudoaneurysms. Occluded and dissected vertebral arteries are well depicted by MRI and MR angiography, but suspected pseudoaneurysms need confirmation

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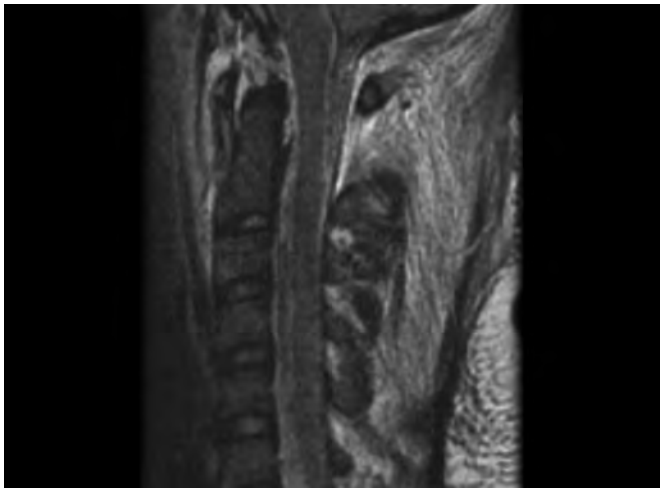


Fig. 4.5: Atlanto-occipital and atlantoaxial dislocation. Sagittal T2-weighted magnetic resonance imaging demonstrates abnormal basion-dental interval (>12 mm) and inferior dislocation of the axis with abnormal atlantodental interval. There is disruption of the anterior atlanto-occipital membrane and tectorial membrane. Prevertebral soft tissue edema is also noted.

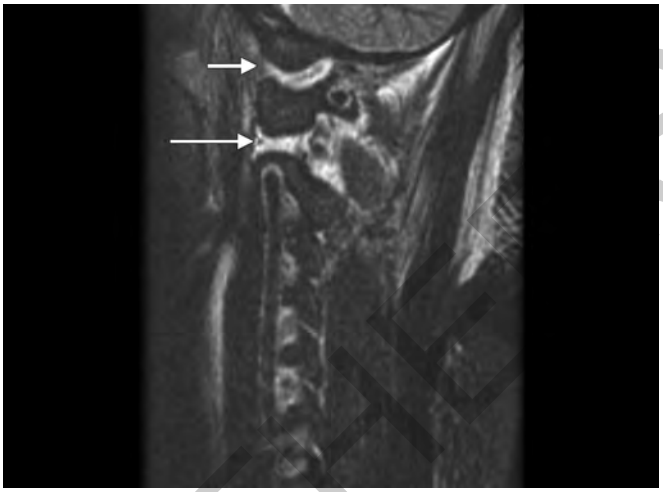


Fig. 4.6: Atlanto-occipital and atlantoaxial dislocation (same patient as in Fig. 4.5). Off-midline sagittal short tau inversion recovery (STIR) demonstrates abnormal signal within the atlanto-occipital joint and C1-C2 facet joint, which are also widened (arrows).

with conventional catheter angiography. Evaluation of possible dissection needs careful review of the source MR angiography because the arteries may only appear diffusely narrowed on the projection images. Since the intramural clot tends to be bright acutely, it may be difficult to separate it from the normal fat in the foramen transversarium without fat suppression techniques.

SPECIFIC TYPES OF SPINAL INJURY

Cervical Spine

Biomechanically, the cervical spine may be divided into two segments: base of skull to C2 (upper) and C3-C7 (lower). The C3 vertebra represents a transitional segment and may behave as part of the upper or lower regions. The upper segment has considerable rotational and lateral motion, while the lower has mostly rotational and flexion motion. Each of these segments responds differently to trauma, and the mechanisms leading to fractures are also distinct for each region.

Upper Cervical Spine Fractures

The craniovertebral junction is well adapted to provide a remarkable range of motion, with approximately half of the neck rotation occurring at the C1–C2 articulation. This specialized structure also results in patterns of injury that are specific to the vertebrae in this region. Because of the relatively large spinal canal diameter at this level (approximately twice the spinal cord diameter), neurologic deficits may be mild or absent.

Occipitoatlantal dissociation may be a subluxation or a dislocation injury. The latter is frequently fatal, but an increasing number of these patients arrive alive at the emergency room. The displacement may be anterior, posterior, or longitudinal (distraction). Distraction is more commonly encountered in children than in adults. The powers ratio is probably the most commonly used measurement to establish the diagnosis of anterior occipitoatlantal dislocation. This ratio is obtained by dividing the distance between the basion and the posterior lamina of C1 by the distance between the posterior cortex of the anterior tubercle of C1 and opisthion. If the ratio is >1, an anterior dislocation is present. This measurement is not useful for posterior or distraction dislocations. Distractions may be diagnosed by a distance between the basion and tip of the dens >12 mm on plain radiograph or sagittal CT-reformatted and MR images (Fig. 4.5). The initial diagnosis of this injury may be difficult, because the numerical measurements are not perfect, and the dislocation might be reduced at the time of imaging. For this reason, MRI can confirm the diagnosis by depicting disruption of the tectorial membrane, the superior band of the cruciate ligament, the apical ligament, and the anterior and posterior atlanto-occipital ligaments (Figs. 4.6 and 4.7).[45,47,48] Less severe ligamentous and muscular injury can also be documented. A case series analysis by Sun et al.[46] emphasizes the importance of disruption of the tectorial membrane in predicting instability;

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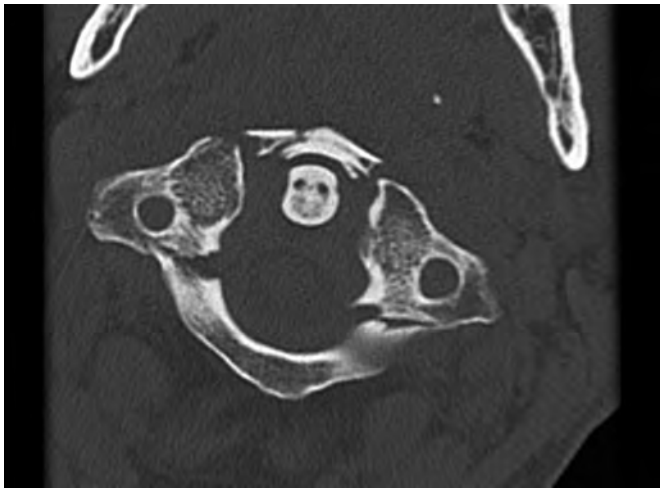
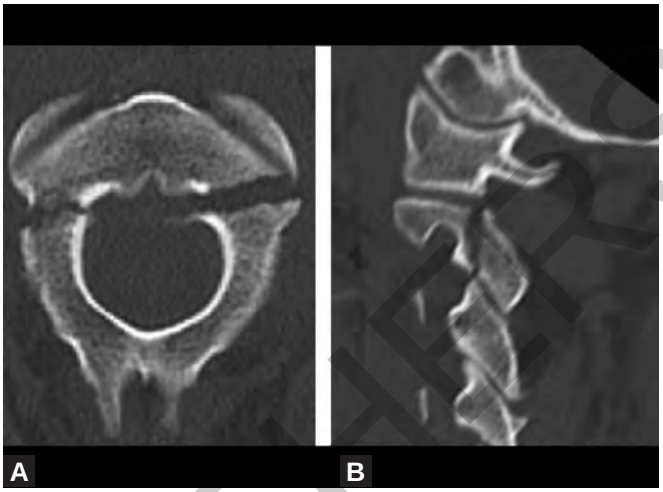


Fig. 4.7: Jefferson burst fracture. Axial computed tomography image demonstrates dispersed fracture fragments from multiple fractures of the anterior and posterior arches.



Figs. 4.8A and B: Hangman's fracture. (A) Axial computed tomography (CT) shows bilateral pars interarticularis fractures with mild posterior displacement. (B) Sagittal CT reformat confirms the posterior displacement.

they found that the ratio of the distance between the posterior elements of C1 and C2 over the distance between C2 and C3 (C1-C2:C2-C3 ratio) correlates with tectorial disruption.[49] They identified seven of eight patients with tectorial membrane disruption as having a C1-C2:C2-C3 ratio ≥2.5, with no false positives.

Jefferson fracture or burst fracture of C1 is a result of axial loading with bilateral outward displacement of the lateral masses of C1. This injury can be diagnosed by recognizing the resultant fractures in both the anterior and posterior arches of C1 (Fig. 4.7). Generally, there is no spinal cord injury because the canal becomes widened with these fractures. Some patients, however, may be symptomatic due to the presence of hematoma in the epidural space. Isolated fracture of the posterior arch of C1 may result from hyperextension, with impaction of the posterior arch of C1 between the occiput and C2. This injury may be distinguished from the burst fracture of C1 by the involvement of only the posterior arch of C1.

Isolated fracture of the anterior arch of C1 occurs less commonly and also results from hyperextension, with avulsion of the attachment of the anterior spinal ligament. The small avulsed bone fragment is visible ventral to the anterior arch of C1. The posterior arch of C1 remains intact. Magnetic resonance imaging is helpful in the evaluation of the Jefferson-type injuries, because it can identify a ruptured transverse ligament dictating the need for open fixation.

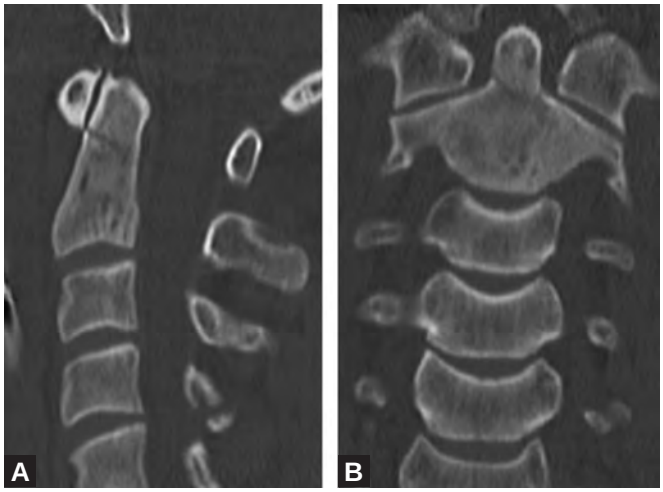
A transverse ligament avulsed at the level of the tubercle may be treated conservatively, and fusion occurs in up to 70% of patients.

Hangman's fracture or traumatic spondylolysis of C2 is the most common fracture of the C2 vertebra. This injury is usually caused by hyperextension. There are resultant bilateral fractures of the pars interarticularis, the part of the vertebra between the superior and inferior facets (Figs. 4.8A and B).These fractures are graded from 1 to 3 depending on their severity. Type 1 has minimal displacement. In the type 3 fracture, there is a wide gap between the pars interarticularis, anteroinferior rotation of the body of C2, bilateral interfacetal dislocation of C2-C3, and injury to the second intervertebral disc. Spinal cord injury is common with type 3 fractures but less common in the types 1 and 2 fractures. There is no need to obtain MRI in patients with a type 1 injury. Patients with type 2 and 3 fractures need MRI to exclude herniated discs, extradural hematomas, intramedullary edema, and/or hematomas, and to assess the ligaments.

Dens fractures occur through a mechanism that is poorly understood, but hyperextension is believed to play a major role.[50-52] Fractures of the dens are commonly classified according to a scheme proposed by Anderson and D'Alonzo into types I, II, and III fractures.[50] Type II fractures are the most common, and consist of a fracture through the base of the dens, at its junction with the C2 body (Figs. 4.9A and B).

Type II fractures have a high incidence of nonunion if not surgically fused. If the fracture extends through the upper body of C2, it is classified as type III (Fig. 4.10). Type III fractures usually heal completely with external immobilization. The type I fracture is an avulsion fracture of the tip of the dens. This is a rare injury. Vertical fracture of the

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Figs. 4.9A and B: Type II dens fracture. Sagittal (A) and coronal (B) computed tomography images demonstrate an incomplete fracture involving the base of the dens.

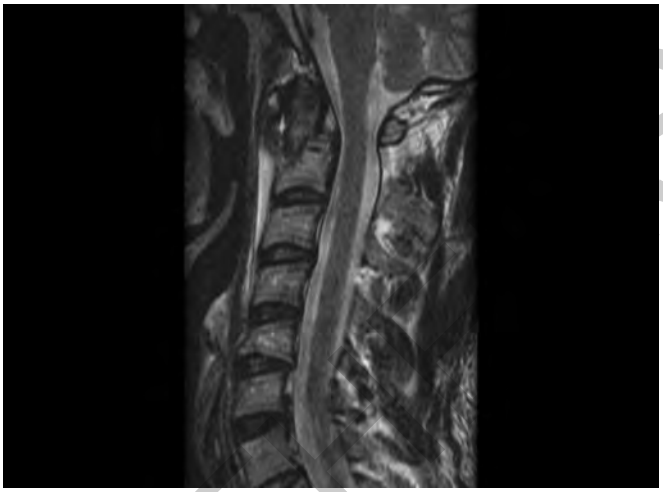


Fig. 4.10: Type III dens fracture. Sagittal T2-weighted image demonstrates an oblique fracture of the dens with anterior displacement of the superior portion of the dens.

dens is a fourth and less common injury.[52] There is no need to obtain MR studies in patients with uncomplicated dens fractures. Thin-section CT with sagittal and coronal reformatted images is the imaging modality of choice in these patients.

The transverse atlantal ligament extends between the medial portions of the lateral masses of C1, behind the odontoid process of C2. This ligament provides the major support for the C1-C2 articulation, allowing rotation of C1 about the dens, while maintaining their proximity.

Injury to this ligament is common. This injury may occur in isolation or may accompany dens fractures or burst fractures of C1. Transverse atlantal ligament injury can be inferred from widening of the atlantodental interval beyond 3 mm or lateral displacement of the lateral masses of C1 by >7.0 mm. These measurements, however, may miss a significant number of injuries. For this reason, MRI with thin-section (3 mm) GE T2-weighted images is recommended for evaluation of patients with C1-C2 instability, dens fractures, or C1 burst fractures.[53] Patients with disruption of the substance of the ligament have a very low likelihood of healing with nonsurgical treatment. In contrast, patients with C1-C2 instability related to fracture of the lateral mass of C1 or avulsion of the bony tubercle for insertion of the ligament heal with conservative treatment in 75% of cases.[53] Magnetic resonance imaging allows identification of ligament substance disruption, which can prompt immediate surgery and avoid unsuccessful prolonged immobilization.

Lower Cervical Spine Fractures

The majority of fractures in adults occur in the lower cervical spine, predominantly at the C6 and C7 levels.[55] The classification of these fractures is conventionally based on the presumed mechanism of injury, i.e. hyperextension, hyperflexion, vertical compression, or mixed.

Hyperextension injuries occur with impact to the face or forehead. Injuries to the lower cervical spine caused by hyperextension include hyperextension dislocation and hyperextension teardrop fracture.[56] Fifty percent or more of hyperextension injuries may be associated with herniated fragments of intervertebral disc that may cause or worsen the associated spinal cord injury.[17,20] Ligamentous disruption is the major pathology in these lesions, and MRI provides excellent depiction of ligament injury. Hyperextension dislocation is a disruption of the ligaments between adjacent vertebrae, including the ALL and annulus fibrosis. Severe cases may also show disruption of the PLL and facet capsular ligaments. Because the dislocation may be reduced at the time of imaging, and there may be no fracture, the plain radiograph may be near normal, except for diffuse thickening of the prevertebral soft tissues. Magnetic resonance imaging identifies the prevertebral hematoma and discontinuity of ligaments. Disruption of the ALL and separation of the disc from the vertebral body end plate may be associated with prolonged pain and delayed instability, which may require anterior fusion. This injury is frequently associated with severe spinal cord contusion, especially in patients with pre-existing

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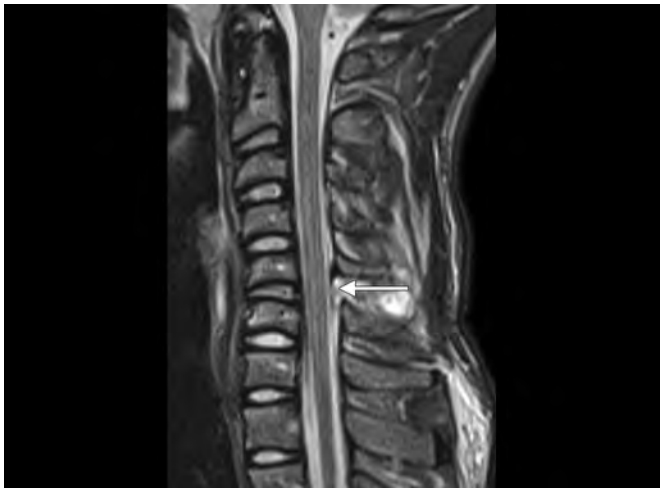


Fig. 4.11: Hyperflexion injury. Sagittal T2 image demonstrates high signal in the inter and supraspinous ligaments consistent with posterior ligamentous complex injury. Disruption of the ligamentum flavum is noted as well (arrows).

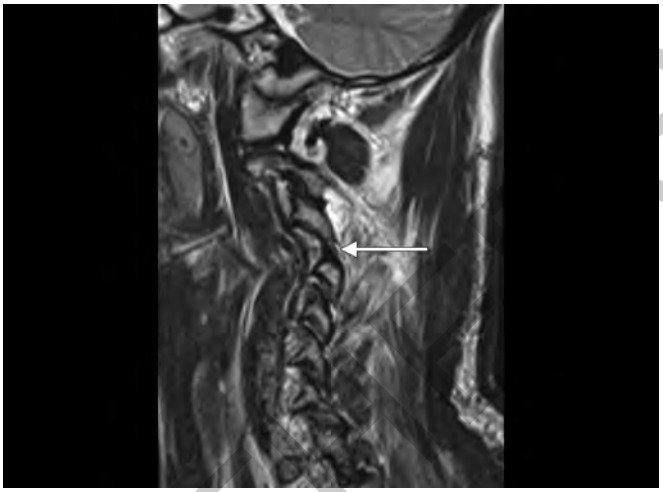


Fig. 4.12: Bilateral interfacetal dislocation. Off-midline sagittal T2 magnetic resonance imaging demonstrates almost complete anterior dislocation of the facet of C4 with respect to C5 (arrow).

spondylitic changes. In approximately two third of patients with hyperextension dislocation injury, the intact anterior annulus causes an avulsion fracture of the anterior inferior margin of the affected vertebral body. This fragment is larger in the transverse dimension than height with an almost horizontally oriented fracture line. Hyperextension teardrop fracture is an avulsion fracture of the anterior inferior margin of the vertebral body caused by the ALL. This injury most commonly occurs at the C2 level and in older, osteoporotic individuals. Less commonly, it may occur at lower levels in nonosteoporotic patients. The fracture fragment can be distinguished from the avulsion fracture seen with hyperextension dislocation by the obliquity of the fracture line (approximately 45° from vertical) and the relative greater height of the fragment.

Hyperflexion injuries result from impact to the top or back of the head with the neck in flexion, especially common in diving injuries. These injuries include hyperflexion sprain, wedge fractures, bilateral interfacet joint dislocation, and hyperflexion teardrop fracture. Hyperflexion sprain refers to the disruption of the posterior ligament attachments between adjacent vertebrae. These include disruption of the nuchal ligament, interspinous ligaments, facet capsular ligaments, and the PLL. On plain radiographs, this injury may be recognized by abnormal widening between adjacent posterior elements, and subtle, acute kyphotic angulation at the level of injury.

On MRI, high-signal edema and blood products within the posterior ligamentous structures on T2-weighted images are confirmatory (Fig. 4.11). Diagnosis of this injury is important because it may be associated with chronic neck pain and a significant incidence of failure of ligamentous healing in patients managed nonsurgically.

Wedge fractures share the posterior ligament disruption of hyperflexion sprain, but in addition, there is an impaction fracture of the superior end plate of the vertebral body. The inferior end plate remains intact. There is greater loss of vertical height anteriorly, resulting in the typical wedge shape of the vertebral body seen in the lateral plain radiograph or coronal CT reformation. Bilateral interfacetal joint dislocation (Figs. 4.12 and 4.13) occurs with greater forces. There is disruption of the posterior ligamentous structures as with the hyperflexion sprain. In addition, there is disruption of the annular fibers of the intervertebral disc, the ALL, and complete bilateral dislocation of the facet joints. The inferior articular processes of the upper vertebra become lodged in the neural foramina anterior to the superior articular process of the lower vertebra, preventing reduction. This injury is sometimes referred to as bilaterally locked facets, erroneously implying mechanical stability. On CT, this injury is diagnosed by the presence of anterior displacement of the upper vertebra by one half or more of the width of the lower vertebral body. The "naked" articular surfaces of the dislocated facets are usually also visible. Magnetic resonance imaging reveals these features, as well as detects the presence of the commonly associated herniated disc or epidural hematoma. In facet dislocations, 50% or more of patients may have significant disc herniations that necessitate anterior discectomy and fusion to avoid additional compression of

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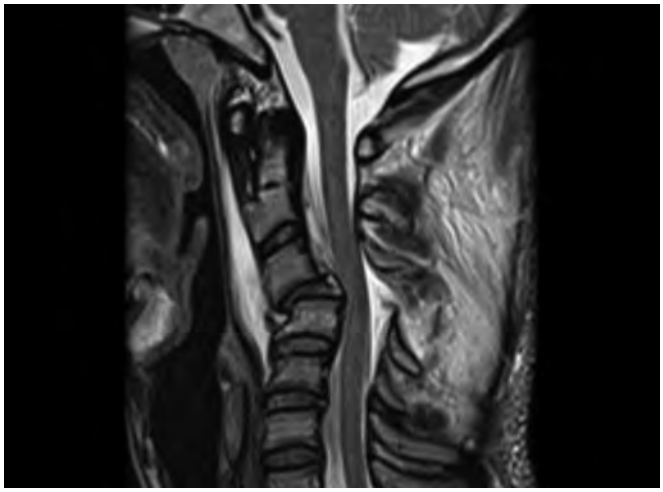


Fig. 4.13: Bilateral interfacetal dislocation. Sagittal magnetic resonance imaging of a patient who had severe spine hyperflexion injury demonstrates anterior dislocation of C3 on C4. The ligament flavum, anterior and posterior longitudinal ligaments, are disrupted. There is abnormal increase in signal in the prevertebral soft tissues, involving the posterior ligamentous complex.



Figs. 4.14A and B: (A) Sagittal computed tomography reformats of the cervical spine demonstrate a typical flexion teardrop injury with an anterior triangular fracture fragment of the anteroinferior aspect of the vertebral body of C5 [arrow in (A)] and retropulsion of its posterior vertebral body fragment into the spinal canal. (B) Sagittal T2 short tau inversion recovery demonstrates high signal in the C5 and C6 vertebral bodies, the retropulsed posterior cortex of C5, and high signal intensity in the cord consistent with cord contusion. There is also focal disruption of the posterior longitudinal ligament [arrow in (B)] and high signal in the inter- and supraspinous ligaments consistent with posterior ligamentous complex injury.

the spinal cord after reduction. More than half also have vertebral artery injuries that can be depicted on MR angiography.[54] Computed tomography is helpful to evaluate fractures of the articular masses, which may interfere with attempts at reduction.

Hyperflexion teardrop fracture occurs with even greater magnitude forces. This injury shares the posterior ligamentous disruption of the other hyperflexion injuries, but additionally, there is a large triangular fracture fragment of the anterior inferior margin of the upper vertebral body (Figs. 4.14A and B). There is associated severe narrowing of the spinal canal due to retropulsed bone fragments with almost universally severe spinal cord injury. The larger size of the triangular fragment and the presence of distraction of the posterior elements indicating the flexion mechanism can distinguish this fracture from the similarly named hyperextension teardrop fracture.

Vertical compression injuries occur with impact to the top of the head with the spine straight. These injuries include the Jefferson burst fracture of C1 discussed above and the burst fracture of the lower cervical spine. Burst fractures of the vertebral body are thought to occur when vertical compressive forces are transmitted through the intervertebral disc, with radial outward forces generated in the vertebral body. This causes a vertical fracture, with lateral dispersion of the vertebral body fragments. On plain radiographs, widening of the uncovertebral joints or visualization of the vertical fracture line indicates this. Computed tomography may aid in identifying this vertical fracture line and the frequently associated fractures of the pedicles or lamina. Magnetic resonance imaging is especially helpful in detecting herniated disc fragments, which are also common.[19]

Less common mechanisms of injury may lead to recognized fracture patterns. For example, a combination of flexion and rotational forces may result in unilateral facet dislocation. This injury may be distinguished from bilateral facet dislocation by the presence of anterolisthesis approximately 25% (vs. 50% for bilateral) (Table 4.2). Unilateral facet dislocations are also associated with a high incidence of vertebral artery injury. Lateral force vectors may lead to isolated fracture of the uncinate processes. Combined extension and rotation forces may lead to fractures of articular pillar or pedicolaminar fracture.

Thoracic Spine

The normal thoracic spine is well stabilized by the rib cage, thoracic musculature, and steeply oriented facet joints; thus, fractures are uncommon, except with severe trauma. Because of the normal fixed thoracic kyphosis, axial forces are transformed into flexion equivalents and most injuries

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Table 4.2: Radiographic features of interfacetal dislocations.

Type	*Mechanism*	*Facets*	*Lack of stability*	*Vertebral body displacement*	*Spinal cord injury*
Unilateral	Flexion, rotation	One	+	<50%	+
Bilateral	Hyperflexion	Two	+++	>50%	++

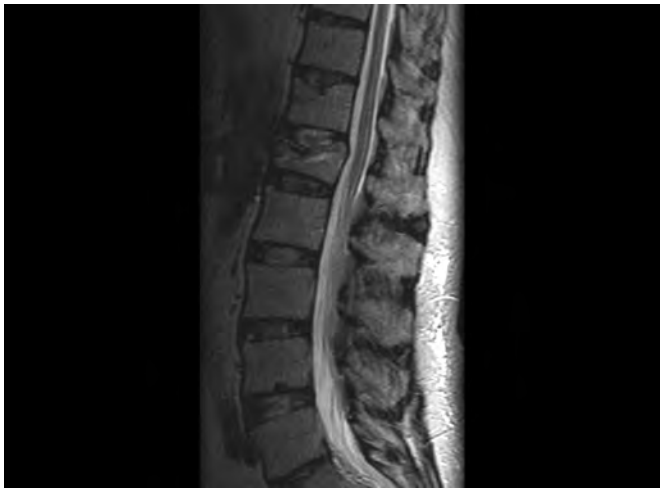


Fig. 4.15: Acute compression fracture of L1. Sagittal T2 magnetic resonance demonstrates a wedge-type fracture deformity of the anterior body of L1.



Fig. 4.16: Fracture dislocation. Sagittal T2-weighted magnetic resonance imaging demonstrates posterior dislocation of T11 with respect to T10. Extensive ligamentous injury and soft tissue injury involving all three columns are demonstrated. The spinal cord is severely injured.

are related to hyperflexion. These injuries most commonly include compression type fractures and flexion fracture dislocations.[57] Plain radiographic evaluation of the thoracic spine may be difficult due to superimposed structures of the shoulder girdle and ribs. In all cases, CT is especially valuable. Compression fractures are considered "simple" wedge fractures if only the anterior third of the vertebral body is involved (Fig. 4.15). Severe fractures involve the middle and posterior vertebral body as well, with the potential for posterior displacement or retropulsion of bony fragments into the spinal canal.[58] These fractures are considered unstable and are treated surgically. Disruption of the PLL may indicate the need for an anterior surgical approach to allow reduction of retropulsed fragments. In contrast, patients with an intact PLL may have good results with posterior fusion. Disruption of the ALL occurs in up to 25% of thoracolumbar fractures.[48] Magnetic resonance imaging can be useful in identifying ALL and PLC disruption seen in 30–40% of the more severe thoracic fractures.[60] Presence of ligamentous disruption may result in delayed instability in patients managed without surgical fusion.[61] Fracture dislocations occur with larger magnitude of forces. There is frequently marked dislocation with accompanying severe spinal cord injury (Fig. 4.16). Magnetic resonance imaging provides valuable information regarding spinal canal narrowing, cord injury, and the presence of associated epidural hematoma. Up to 50% of unstable thoracic spine fractures or dislocations may have an associated herniated disc and thus MRI is important for surgical planning in these patients.[57]

Thoracolumbar Junction and Lumbar Spine

The thoracolumbar junction (T12-L2) is the most common site of spine fracture after the cervical spine. Most of the injuries to the lumbar spine and thoracolumbar junction are related to abnormal flexion or vertical compression forces. Common types of injuries at this level include wedge, burst, and Chance fractures. Wedge fractures result when flexion forces lead to a fracture of the vertebral body only, without involvement of the posterior elements.[59] Characteristically, there is greater loss of height in the anterior body than in the posterior. Plain radiographs are diagnostic in most cases. Classification into simple and severe wedge fractures is similar to that of the thoracic spine. If there is a question of posterior element fractures or

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Fig. 4.17: Burst fracture. Sagittal computed tomography image demonstrates a burst fracture involving L3 with retropulsion of fragments into the canal. There is a spinal process fracture of L2.

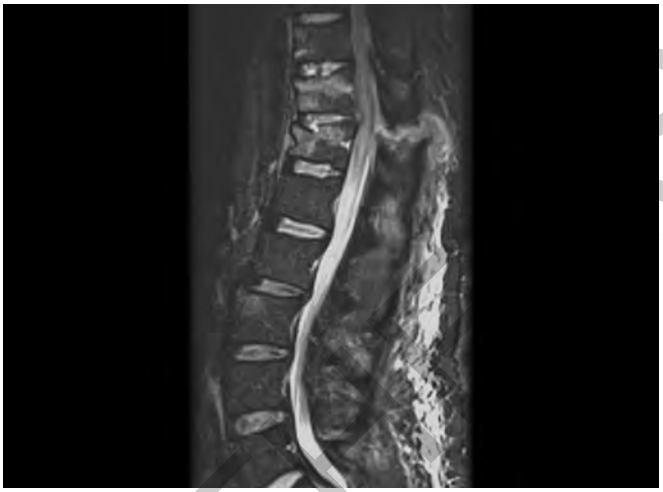


Fig. 4.18: Chance-type fracture. Sagittal short tau inversion recovery image demonstrates horizontal fracture through the vertebral body of T12 in association with anterior vertebral body wedging. Note the injury to the posterior osteoligamentous complex and the contiguous linear horizontally oriented fracture in the vertebral bodies of T11.

posterior retropulsion of fragments, CT provides clarification and assessment of the residual spinal canal diameter. Burst fractures in the lumbar spine are diagnosed when there is a vertically oriented fracture of the vertebral body with lateral dispersion of the fracture fragments (Fig. 4.17). There are usually associated fractures in the posterior elements. This injury can be recognized on plain radiographs by identifying the vertical fracture line or widening of the interpedicle distance on the frontal projection. Computed tomography is useful to characterize the associated posterior element fractures and assess spinal canal impingement. Magnetic resonance imaging provides assessment of the conus medullaris or spinal nerve roots in patients with neurologic deficits.

The Chance fractures are defined as horizontally oriented fractures, which pass through the spinous process, lamina, and vertebral body (Fig. 4.18). This injury occurs exclusively at the thoracolumbar junction.[62,63] This unusual injury is thought to be the result of distractive forces generated when the spine is flexed about a fulcrum point, such as a car lap seat belt. This has prompted the use of the term "seat belt injury" to describe this and associated injuries. Injuries in which the horizontal plane of disruption passes through the intervertebral disc or posterior ligaments, rather than the vertebral body or posterior bony elements, can be considered variations of the Chance fracture. Magnetic resonance imaging may demonstrate the ligamentous components of the variant forms of injury, along with any conus medullaris or nerve root injuries. An association with significant intraperitoneal injuries in up to 50% of patients with Chance fractures has prompted some authors to suggest routine CT scan of the abdomen in all patients with this type of injury.[62]

Magnetic Resonance Imaging of Benign Versus Malignant Vertebral Fractures

Distinguishing benign from malignant vertebral fractures can be challenging (*see* Chapter 6). Conventional MRI can provide valuable clues in making this distinction. Fractures are benign if they show no abnormal bone marrow signal, or slight, band-like signal abnormality adjacent to the fractured end plate. Malignant nature is indicated if there is abnormal marrow signal involving or expanding the pedicle. Diffuse, poorly defined marrow signal abnormalities are also suggestive of malignancy.[64,65] Of course, enhancing soft tissue extending beyond the fractured vertebra suggests malignancy. In many cases, uncertainty remains even after careful analysis of the conventional MRIs. Several studies using diffusion-weighted imaging may help resolve these uncertain cases (*see* Chapter 2). Benign fractures due to trauma or osteoporosis have high apparent diffusion coefficient (ADC), whereas those that are pathologic have lower ADC.[66-68]

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Mauricio Castillo MD FACR is a distinguished Professor of Radiology and Division Chief of Neuroradiology at the University of North Carolina, School of Medicine, Chapell Hill, North Carolina, USA. He is the author of over 600 articles, 25 books, and 150 book chapters. He currently serves as President-elect of the American Roentgen Ray Society (ARRS), past President of the American Society of Neuroradiology (ASNR) and editor emeritus of American Journal of Neuroradiology (AJNR).

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