I. Overview of the utility of MRI in acute spinal trauma.

Although CT continues to be of great importance in the evaluation of the spine after acute trauma, MRI is gaining acceptance and is considered indispensable in some situations. At our institution, in all patients who have suffered head trauma and have an immobilized cervical spine, a CT of the cervical spine is obtained at the same time as the head CT. In these patients, 3 mm thick spiral sections (pitch=1) from C1 to C7 are obtained and obviate the need for cervical spine radiographs. A reduced charge is billed for this examination, which has been found to be cost effective in these patients. If doubt remains, the region-of-interest is re-studied using 1 mm thick sections. If the CT examination is normal and there are no neurological symptoms, the diagnostic evaluation of the patient is terminated. If the CT is normal but neurological symptoms are present, MRI is obtained. If the examination is abnormal in absence of neurological symptoms, MRI is not performed. That is, MRI is reserved for patients with neurological symptoms or those in whom the suspicion of an underlying lesion may change the surgical approach. Our MR protocol for the acutely injured spine includes sagittal T1- and FSE T2-weighted images and axial T1- and GRE 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 need to be obtained using a low flip angle technique which increases the visualization of susceptibility effects, making acute hemorrhages more visually obvious. For purposes of this review, I will discuss the utility of MR to image the spine, spinal cord (and nerves), and vascular structures in the setting of acute trauma, mostly involving the cervical region.

**Bones**

The evaluation of the fracture site is better performed with CT. If a question as to the etiology underlying an acute spinal fracture (particularly thoracic and lumbar) arises, MRI is essential. Findings which tend to indicate a non-pathologic (non-tumor) underlying etiology are: a fracture line within the collapsed vertebral body, absence of soft tissue mass, retropulsed bone fragments into the spinal canal, presence of fluid inside the collapsed vertebra, and normal signal intensity. Diffusion MRI is also helpful, as osteoporotic compression fractures are of low signal intensity and pathologic compression fractures are bright. MRI may also discover unsuspected fractures, particularly involving the sacrum. These patients present with lower extremity pain and a normal lumbar spine MRI examination. MRI may also show unsuspected fractures of vertebral end-plates, particularly in patients with injuries induced by hyperextension. Evaluation of the facet joints is easily done using the parasagittal images. These images allow one to make the diagnosis of perched facets and dislocated facets. Small facet joint fractures may be missed on MR images and require CT evaluation. MR is the optimal imaging method for the evaluation of the capsular ligaments (see below).

**Ligaments**

MR is the only imaging technique which permits visualization of the ligaments. Torn ligaments usually correlate with instability and indicate the need for internal fixation. In the cervical region, the integrity of the transverse ligament in fractures of C1 is readily evaluated.
Patients with Jefferson-type injuries and a ruptured transverse ligament need immediate internal fixation. In patients with the so-called "hangman’s fracture," particularly types 2 and 3 (severe), MRI may show disruption of the posterior longitudinal and capsular ligaments. There is no clear benefit from MRI in patients with dens fractures and absent neurological symptoms. However, patients with dens fractures and neurological symptoms do need to undergo spinal MRI to exclude an injury to the spinal cord. Hyperextension injuries resulting in the so-called “tear drop” fracture show only disruption of the anterior longitudinal ligament and, thus, MRI is not indicated. MRI is, however, indicated in patients with hyperextension injuries and neurological symptoms. MRI is not indicated in patients with acute whiplash injuries. Disruption of capsular ligaments is seen in patients with pedicolaminar fractures and correlate with instability. Hyperextension dislocations are characterized by severe ligamentous injuries but rebound to normal bone alignment. Thus, despite the absence of obvious fractures, the injury is significant. MRI is indicated in these individuals and shows disruptions of the spinal ligamentous complex, which correlates with significant instability. In patients with interfacetal dislocations, parasagittal MR images clearly depict the injury, showing the bone abnormality as well as torn capsular ligaments.

**Discs**

MRI allows for identification of disc abnormalities in acute spinal trauma. In Hangman’s fractures and Chance-type fractures, the disc is disrupted and may be herniated. True post-traumatic disc herniations are uncommon. However, in the presence of severe trauma, disc herniations are seen in 42% of cervical injuries. Also, patients with bilateral facet dislocations have an increased incidence of disc herniations. In the setting of severe hyperextension injuries, disc herniations are found in nearly 50% of cases. Patients with acute anterior spinal cord syndrome have a nearly 100% incidence of disc herniations. Patients with the following neurologic sequelae are also at an increased risk for disc herniations: complete or incomplete deficits, Brown-Sequard syndrome, and central cord syndrome. Most post-traumatic disc herniations occur in the cervical region (C5-6=40%, C6-7=23%, and C4-5=19%). The neurological deficits correspond well with the level of the disc herniation. Most acute post-trauma disc herniations are bright on T2-weighted images and may be associated with epidural hematoma. Acute intravertebral disc herniations (Schmorl nodes) may result in pain and show contrast enhancement but need no treatment. The incidence of post-traumatic disc herniations in the thoracic and lumbar regions is not yet determined.

**Epidural and Subdural Spaces**

Only 15% of all epidural hematomas occur as a consequence of trauma. Most occur 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 hematoma may also follow lumbar puncture or spinal surgery. While most spontaneous epidural hematomas are venous in nature, those following trauma are thought to be arterial in origin. Unlike the spontaneous ones, post-trauma epidural hematomas are ventral in location. Most are found in the thoracic, lumbar, and sacral regions and are uncommon in the cervical spine. Epidural hematomas have a biconvex shape, while subdural hematomas conform to the shape of the spinal canal. Subdural hematomas are less common in the spine. Identification of a subdural hematoma dictates the need for the surgeon to open the dura for adequate evacuation. They are extensive and often involving the ventral and dorsal spaces. At the end of the thecal sac in the sacrum they compress the sac resulting in the so-called ‘Mercedes Benz’ sign. Most epidural and subdural hematomas are slightly bright on T1- and T2-weighted images but dark on T2* images.

An unusual complication of acute trauma is the formation of extramedullary CSF-filled cysts in either the epidural or subdural spaces. These are probably equivalent to subdural hygromas.
occurring intracranially, and I have seen them only in the presence of severe spinal trauma. These cysts may compress the spinal cord, resulting in neurological deficits.

**Spinal Cord**

Acute injuries to the spinal cord may be categorized as contusions, transection, and vascular anomalies. Spinal cord contusions may be hemorrhagic or non-hemorrhagic. Type 1 injuries show inhomogenous T1 signal, central dark T2 signal, and surrounding edema. They represent intramedullary hematoma and these patients have a poor prognosis. In type 2 injuries, the findings reflect only edema in the spinal cord and these patients tend towards a favorable prognosis. Type 3 injuries show mottled signal abnormalities on all imaging sequences, which may be related to minute hemorrhagic foci and these patients have an intermediate prognosis. In patients with “central cord syndrome”, there is a contusion of the spinal cord. In my experience, most of these are non-hemorrhagic contusions, but hemorrhagic foci in the central aspect of the spinal cord are also relatively common. In these patients, the presence of hemorrhage portrays a worse prognosis. Spinal cord injury may occur even in absence of bone/ligamentous injury. This is more commonly seen in children than in adults and in the past has been called “spinal cord injury without radiographic abnormality (SCWIORA)”. Children with an antecedent of trauma even in the face of normal radiographs and/or CT should be imaged with MR to exclude spinal cord injury. DTI may play a role in detection and grading of spinal cord injuries by showing low FA in areas of injured cord.

**MR Imaging Classification of Spinal Cord Injuries According to Kulkarni.**

<table>
<thead>
<tr>
<th>Type injury</th>
<th>T1 signal</th>
<th>T2 signal (particularly on gradient echoes)</th>
<th>Prognosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1 (hematoma)</td>
<td>Isointense</td>
<td>Low with rim of high signal related to edema</td>
<td>poor</td>
</tr>
<tr>
<td>Type 2 (edema)</td>
<td>low or isointense</td>
<td>High</td>
<td>relatively good</td>
</tr>
<tr>
<td>Type 3 (mixture of edema/hematoma)</td>
<td>low or isointense</td>
<td>Mottled</td>
<td>poor to fair</td>
</tr>
</tbody>
</table>

Spinal cord transection is more common in children. In adults, there is generally severe accompanying bone trauma. MR reveals that the injured spinal cord may appear nearly transected (which has the same implications as complete transection) or in shreds. MR 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 after a difficult delivery. This is more common following difficult breech deliveries, but I have also seen it in head presentations complicated by pelvic disproportion. In these children, the spinal cord may be directly injured or may be damaged as a sequela of stretching the cord and its vascular supply, resulting in infarctions. These infarctions are more common at the cervico-thoracic junction which is a watershed zone.
Vascular injury to the spinal cord is rare following trauma or surgery (particularly aortic interventions). 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 conal infarcts are the sequela of the repair of abdominal aortic aneurysms. Spinal cord infarcts may occur secondary to rib fractures (with occlusion of the intercostal arteries). DWI may show high signal intensity (and low ADC) in the infarcted spinal cord (similar to cerebral infarctions).

**Vertebral arteries**

Patients with cervical spinal injuries and ascending neurological deficits may be candidates for evaluation of the vertebral arteries. It is quoted that 40% of patients with severe cervical spine fractures have either symptomatic or asymptomatic injuries to the vertebral arteries. The presence of a vascular injury may indicate the need for anticoagulation. Because these patients may have other injuries which prevent anticoagulation, such as epidural hematomas, they are better imaged with MR. The vertebral arteries may be occluded, dissected, or show pseudoaneurysm formation. Occluded and dissected vertebral arteries are well depicted by MRI and MRA, but suspected pseudoaneurysms need confirmation with catheter angiography. Evaluation of possible dissection needs careful review of the source images, as the arteries may only appear diffusely narrowed on the MIP MR images. Since the intramural clot tends to be acutely bright, it may be difficult to separate it from the normal fat in the foramen transversarium without fat suppression techniques. Occlusion of a vertebral artery in presence of a contralateral normal one has little clinical significance. However, dissection of one vertebral artery (even if the contralateral one is normal) may predispose the patient to emboli and chronic recurrent neurological events. Patients with a complete neurological deficit have a higher incidence of vertebral artery injury than those with incomplete injuries.

**II. Imaging of specific types of spinal trauma.**

**Cervical spine:**

Biomechanically, the cervical spine may be divided into two segments: base of skull to C2 (upper) and C3-7 (lower). The C3 vertebra represents a transitional segment and may behave as part of the upper or lower regions. The upper segment is shorter and has considerable rotational and lateral motion, while the lower has considerable rotational and anteroposterior motion. Each of these segments responds differently to trauma, and the mechanisms leading to fractures are also distinct for each region. Overall, the most common reasons for surgery in the upper segment are trauma and congenital anomalies, while in the lower segment they are degenerative disease and trauma. Plain films and CT optimally evaluate bone injuries while MR imaging allows for visualization of ligaments and spinal cord injury. At our institution, all patients with suspected cervical spine trauma undergo a screening spiral CT using 3 mm thick sections from the base of the skull to C7. This has been proven to be a cost-effective means of evaluating these patients. If a fracture is present, detailed (1-2mm thick sections) CT views and multiplanar reformations are done through the region-of-interest.

**Upper cervical spine injuries.**

a. Occipito-atlantal dislocation: This injury may be subluxation or a dislocation. The latter is generally fatal. The displacement may be forward, 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 or posterior occipito-atlantal 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 greater than one, an anterior dislocation is present. Occipital condyle fractures are rare and more commonly seen in association with atlanto-occipital dislocations than with other injuries.

b. Jefferson fractures: These bursting fractures result from axial loading upon the lateral masses of C1 by the occipital condyles. Forces applied to the vertex of skull are responsible for Jefferson type fractures. These are fractures through the anterior or posterior aspects of the ring of the atlas (classic type). These fractures may be unilateral or bilateral. Generally, there is no spinal cord injury as the canal “decompresses” and becomes widened with the fractures. Some patients may, however, be symptomatic due to the presence of hematoma in the epidural space. Occipital condyle fractures do not commonly accompany Jefferson fractures.

c. Dens fractures: These fractures are traditionally divided into three types. Type 1 involves the tip of the dens and may not exist purely as a fracture. They tend to be small and of questionable clinical significance. An os odontoideum is probably a non-united type 1 fracture. Type 2 fractures involve the base of the dens and are the most common type and probably the only which are true dens fractures. There is a 30-50% chance of nonunion in Type 2 fractures. Type 3 fracture is not a true dens fracture but a fracture involving the body of the axis. Impaction of the dens into the body of C2 may result in the so-called “fat axis body” sign. Vertical fractures of the dens are a fourth and less common type. The mechanism responsible for all dens fractures is poorly understood, but hyperextension is believed to play a major role. All of these fractures are difficult to visualize if they are minimally displaced.

d. Hangman's fractures: These fractures result from severe hyperextension leading to breaks in the pars interarticularis of C2 (traumatic spondylolisthesis). When accompanied by bilateral interfacetal dislocations of C2 on C3, they are one of the most severe injuries the cervical spine may sustain with preservation of life. They are graded from 1-3 depending upon their severity. 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 2nd intervertebral disc. Spinal cord injury is common with Hangman's type 3 fractures but less common in the types 1 and 2 fractures. Hangman’s fractures may occasionally be unilateral.

Lower cervical spine injuries.

a. Interfacetal dislocations: The following table addresses the clinical and radiographic features of unilateral (UID) and bilateral interfacetal (BID) dislocations. We obtain CT and MR imaging in all patients with UID and BID. Parasagittal imaging allows for easy recognition of these injuries, particularly with multivolume CT scanning. Although these injuries are more common in the lower cervical segment, they are also found in the upper segment (particularly at C2-C3). Both UID and BID may be considered as “pure” soft tissue injuries although impaction of the facets at the time of trauma may lead to fractures. The use of the term “locked” when referring to these injuries is misleading as BID is an unstable injury.
Radiographic features of interfacetal dislocations.

<table>
<thead>
<tr>
<th>Type</th>
<th>Mechanism</th>
<th>Facets</th>
<th>Lack of stability</th>
<th>Vertebral body displacement</th>
<th>Spinal cord injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unilateral</td>
<td>Flexion, rotation</td>
<td>one</td>
<td>+</td>
<td>Less than 50%</td>
<td>+</td>
</tr>
<tr>
<td>Bilateral</td>
<td>Hyperflexion</td>
<td>two</td>
<td>+++</td>
<td>More than 50%</td>
<td>++</td>
</tr>
</tbody>
</table>

b. Compression fractures: A simple wedge compression fracture appears as decreased height of the anterior aspect of a vertebral body. However, disruption of the spinal ligaments may be present and inferred from the presence of “fanning” of the spinous processes. A compression fracture accompanied by a vertical component is termed a “bursting” fracture. In this type of injury, the disc implodes into a vertebra dispersing its fractures. This is an unstable injury.

c. Flexion teardrop fracture: Severe flexion leads to a compression fracture in which the anterior aspect of the injured vertebral body becomes detached. The entire ligamentous complex is disrupted and there is a hyper-kyphotic angulation of the cervical spine, which often results in compression of the spinal cord. The name of this injury derives from the shape of the fracture fragment.

d. Hyperextension dislocation: This injury is generally not accompanied by fractures and represents pure soft tissue ligamentous damage. As such, it is perhaps the only cervical spinal injury where MR imaging is the most important diagnostic tool. In these patients, there is momentary dislocation due to hyperflexion and then a return to normal. There may be disruption of the anterior cervical muscles, anterior and posterior longitudinal ligaments, disruption of the ligamentum flavum, capsular ligaments, and the intervertebral disc.

Thoracic and lumbar fractures.

a. Compression fractures: These fractures result from axial loading and flexion. They may involve any region of the spine but are more commonly encountered at T2-T10. If only the anterior column (anterior 1/3 of the vertebral body) is involved, the fractures may be considered stable. With involvement of the middle and posterior columns, they are considered unstable and require surgical stabilization and fusion. Approximately 40% of these patients have bone fragments displaced posteriorly into the spinal canal which may produce neurologic symptoms by virtue of compressing the spinal cord. These fragments may be identified with CT, MR imaging, or intraoperative sonography.

b. Chance type injuries: The fulcrum of the thoracolumbar spine is located at the T12-L1 level, therefore severe flexion of this region results in Chance type fractures. The T12-L2 segment may be considered as a different biomechanical segment as it is the region where most of the voluntary flexion in thoracic and lumbar spine occurs. More than 65% of all thoracolumbar fractures involve T12 to L1. In the Chance type injuries, there are horizontal fractures traversing the posterior elements and vertebral bodies, unilateral or
bilateral interfacetal dislocations, and shears of the intervertebral disks. More than 50% of patients with these fractures have intra-abdominal injuries. Chance type fractures are unstable.

c. Osteoporotic versus pathologic fractures: Acutely, MR imaging (as well as CT) is unable to differentiate between these two types of fractures. Both show low T1 signal and high T2 signal intensity. However, three about months after the injury, the bone marrow in osteoporotic fractures should return to normal or near-normal signal intensity, while that of pathologic fractures (secondary to underlying tumor) remains of low signal intensity. The following table reviews the MR imaging findings in these two types of fractures. Diffusion weighted imaging shows that acute compression fractures due to osteoporosis have high signal while those which are pathologic have low signal intensity.

<table>
<thead>
<tr>
<th>Type of fracture</th>
<th>T1</th>
<th>T2 (FSE)</th>
<th>DWI</th>
<th>w/Gadolinium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osteoporotic</td>
<td>High signal</td>
<td>high signal, reflecting edema</td>
<td>Low signal</td>
<td>+</td>
</tr>
<tr>
<td>Pathologic</td>
<td>Low signal</td>
<td>high signal, reflecting combination of edema and tumor</td>
<td>High signal</td>
<td>++</td>
</tr>
</tbody>
</table>

MR Imaging of Osteoporotic vs. Pathologic Vertebral Fractures