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Advances in Imaging of Vertebral and Spinal Cord Injury

Dr. Mitesh Ghadiali[1], Dr. Purvi Desai[2], Dr. Rahul Sharma[3]

Abstract: ***Imaging technology is an important part of the diagnosis and management of spinal trauma. Indications and findings in post-traumatic imaging of the vertebral column and spinal cord are reviewed. Methods: An extensive literature review was performed on the imaging of vertebral and spinal cord injury. Relevant images from a Level I trauma center were included as examples. Results: Imaging plays an important role in the evaluation of acute and chronic spinal injury. Spinal cord and soft-tissue injuries are best evaluated by magnetic resonance imaging (MRI), whereas spinal fractures are better characterized by computed tomography (CT). Vascular injuries can be evaluated using CT or MR angiography. Conclusions: Imaging using CT and MRI is essential in the management of spinal cord injuries, both in the acute and in the chronic settings. MRI shows the status of ligamentous integrity and visualizes internal derangement of the spinal cord. Vascular compromise can be diagnosed by MR and CT angiography. Plain radiography now has a more limited, adjunctive role, and the need for higher risk myelography has been minimized.***

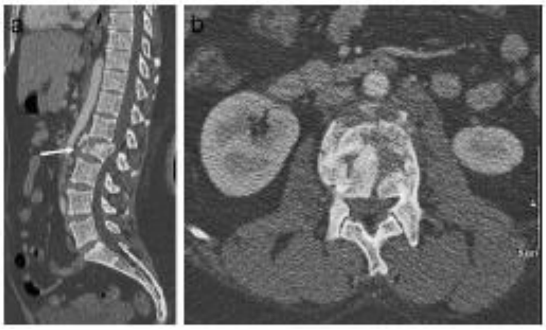
Keywords: Magnetic resonance imaging, , Computed tomography, Angiography, Fracture; Spinal cord injuries, Diffusion-weighted imaging; Diffusion tensor imaging

1. Introduction

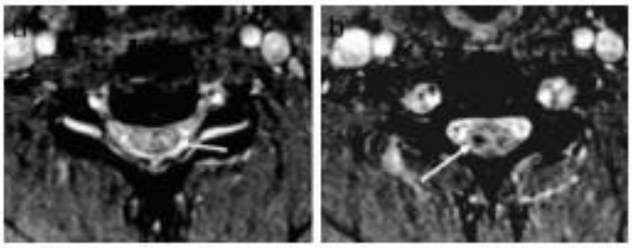
The past several decades have witnessed the rapid development of imaging technology that has dramatically transformed the diagnosis and management of vertebral injury and spinal cord injury (SCI). The advent of magnetic resonance imaging (MRI) has enabled the noninvasive visualization of the spinal cord in a manner previously unimaginable in the living person. An extensive spectrum of both acute and chronic SCI has been demonstrated and has been shown to have prognostic significance. The initial value of MRI in the detection and evaluation of fractures was thought to be limited, but with advances in knowledge and technique, it is now known to be considerable. Concurrently, computed tomography (CT) has also been further perfected and has supplanted plain radiography as the first-line modality for evaluating the traumatized vertebral column. MRI is capable of providing exquisite detail regarding the appearance of the spinal cord after injury. Such injuries can be subdivided into those that relate to extrinsic compression and those that traumatize the cord parenchyma itself.

2. Spectrum of Injury

Fractures with bony retropulsion, disk extrusions, and epidural hematomas can result in cord compression, often concomitantly. MRI will generally be successful, based on characteristic morphologic and signal criteria, in differentiating these compressive abnormalities. CT is a useful adjunct, certainly, in delineating bony detail and is important in preoperative planning. Preexisting spondylosis and spinal stenosis will accentuate the vulnerability of the cord to extrinsic compression, and the severity of cord compression has an adverse correlation with prognosis, independent from intrinsic cord injury. The spectrum of acute SCI includes (a) swelling, defined as a smooth enlargement of the cord contour; (b) edema, where internal signal demonstrates T1 and T2 prolongation (low and high signals, respectively) ; and (c) hemorrhage, where the signal alteration is somewhat complex and evolves temporally. Most reliably, acute intramedullary hemorrhage is seen as a focus of T2 shortening (hypointensity). Cervical cord hematomas have a strong correlation with a complete neurologic deficit: ASIA A, with the highest lesions carrying an increased risk of fatality (especially at the cervico-medullary junction in the setting of occipito-atlantal dislocation) . At any level, the cord is vulnerable to transection if the applied forces are sufficient. It should be noted, however, that a presumption of cord transection cannot be made, even with a severe fracture dislocation evident on CT. In the subacute to chronic time period, additional aspects of cord injury can become apparent. Myelomalacia demonstrates signal alteration equivalent to edema, that is, T2 hyperintensity and T1 signal intermediate between cord and CSF. Associated cord swelling tends to diminish compared with edema seen in the acute setting; however, in the early subacute period, a recent article has shown that the cephalo-caudal extent of cord edema can increase by an average of one full vertebral body level if imaging is performed 48 to 72 hours after injury, rather than within the first 24 hours. In recent years, an additional entity, progressive post-traumatic myelomalacic myelopathy (PTMM), has been recognized and is most relevant in the late subacute period (generally more than 2 months post injury). The etiology of this injury is not fully understood, but it likely represents a presyrinx state following disruption of normal transparenchymal CSF transit. A contributory role for cord tethering by adhesions has also been proposed, which may be amenable to intraoperative lysis. Typically, the progressive lesion ascends (often over a long segment) or descends from the site of original trauma. In certain cases, long after the initial injury, a chronic post-traumatic cord cyst or syrinx will develop. These can be identified as expansile structures that are isointense with CSF on all sequences and that are more sharply marginated compared with myelomalacia. Some cases of PPMM will evolve into syrinxes. Finally, cord atrophy is a well recognized long-term sequel to SCI and is the most common finding in patients imaged more than 20 years after the initial trauma. Atrophy has been defined as an anterior-posterior (A-P) dimension of 7 mm or less in the cervical cord and 6 mm or less in the thoracic region.



Burst fracture. (a) Sagittal CT demonstrates a burst fracture of the L2 vertebral body (arrow) with retropulsion of fracture fragments into the spinal canal. (b) Axial CT at the level of the burst fracture.



Cord contusion and hemorrhage. (a) Axial T2-weighted image in a different patient showing increased signal consistent with cord contusion (arrow). (b) Additional T2-weighted image images more inferiorly show signal dropout consistent with areas of cord hemorrhage (arrow).

3. Fracture Patterns and Ligamentous Disruption

Forces exerted on the vertebral column that can result in fracture include axial loading, hyperflexion, hyperextension, distraction, and rotational stress. A detailed analysis of spinal biomechanics is beyond the scope of this article, but it is important to identify certain patterns of injury that are evident on radiologic examinations, including plain radiography, CT, and MRI. Although MRI may be more valuable in evaluating soft-tissue structures, CT is superior for the characterization of fractures . Preexisting conditions, such as ankylosing spondylitis and diffuse idiopathic skeletal hyperostosis , increase the rigidity of the spine and the risk of fracture . Full evaluation of the entire spine should be considered after identification of a fracture, because there is an estimated 16% incidence of noncontiguous spine fractures. Axial loading generates a compressive force that creates a vertebral ''burst fracture'' . Typically, a sagittally oriented fracture line through the vertebral body is seen on axial CT images that are associated with a retropulsed fragment . The fracture line may also propagate through the neural arch posteriorly. At C1, this same force can result in a Jefferson fracture, where the anterior and posterior arches are disrupted. Hyperflexion also typically results in vertebral compression, often associated with anterolisthesis and facet perching or locking. Particularly in the cervical region, a flexion teardrop fracture can occur. These are typically larger fragments than extension teardrop fractures, which occur at the anterior-inferior corner of the vertebral body. In the thoracolumbar spine, the Chance or Chance-equivalent fracture is another common manifestation of a flexion injury. In such cases, a compression deformity of the vertebral body is associated with a horizontally oriented fracture that propagates through the pedicles and supporting ligaments. In the lower lumbar region, preexisting defects in the pars interarticularis (spondylolysis) are commonly seen and should not be mistaken for acute fractures.

Characteristics of hyperextension injuries include widening of the anterior disk space, retrolisthesis, and neural arch fractures, but without facet dislocation. Distraction injuries can occur in conjunction with rotation as well as other mechanisms, although ligamentous injury, particularly in children, can occur from a distraction mechanism alone. In such cases, axial images can be deceptively normal; the sagittal and coronal reconstructions are essential to demonstrate the magnitude of disk-vertebral and facet disruption. As previously reviewed, important ligamentous structures of the vertebral column include the anterior and posterior longitudinal ligaments, interspinous and supraspinous ligaments, and ligamentum flavum. Although injury to these structures can be inferred on CT, they are best visualized on MRI as continuous bands of hypointense signal. Ligamentous tears result in abrupt discontinuity, or if the tear is partial, the injury may be best seen as a focus of ill-defined soft-tissue hyperintensity on T2-weighted or STIR sequences.

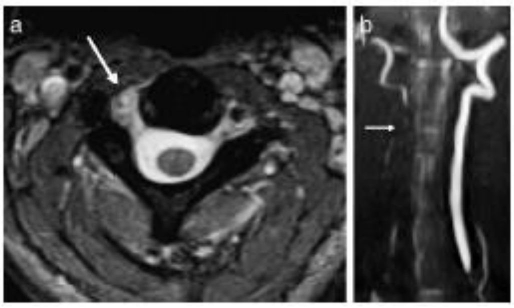
Ligamentous injury. Sagittal T2-weighted image showing injury to the anterior longitudinal ligament (black arrow) and posterior longitudinal ligament (white arrow) with subluxation and cord compression.

Hyperextension injury. Sagittal T2-weighted image in a different patient shows marked widening and distraction of C2–C3 disk space with cord compression and edema/hemorrhage (arrows).

4. Vascular Compromise

Relevant information can also be gleaned from observing the major arterial structures in the neck, even on standard MR sequences. Both T1- and T2-weighted images should demonstrate flow void in the carotid and vertebral arteries, although this phenomenon can be confounded by flow-related artifacts, especially on T1-weighted sequences . However, with the application of fat suppression to a T1-weighted axial sequence, an intramural hematoma can be detected in cases of nonocclusive dissection MR angiography can carry the analysis forward by visualizing hyperintense signal in the arteries, which are reconstructed into their anatomically recognizable morphology by maximum intensity projection algorithms. Artifactual flow gaps, which are occasionally problematic, can generally be eliminated if rapidacquisition, contrast-enhanced sequences are employed. Because of the risk of nephrogenic systemic fibrosis, a relatively recently elucidated complication of gadolinium chelates in patients with renal insufficiency , contrast-enhanced MR angiography is being utilized less often.

CT angiography, in comparison, has been shown to effectively demonstrate carotid and vertebral injury and in many institutions has become part of the standard imaging protocol if a cervical vertebral fracture has been documented by noncontrast CT . There is evidence that CT angiography may be preferable to MR angiography for evaluation of the vertebral arteries in a trauma setting. (43). However, the arterial visualization can be limited if the timing of the contrast bolus is suboptimal, and overlapping bony architecture can also be problematic. In general, with technical expertise and advances in image postprocessing, most practitioners are finding this modality quite useful. Detectable abnormalities include dissection, vascular occlusion, pseudoaneurysm formation, and free-contrast extravasation from an uncontained rupture. Differentiating minimal irregularity representing grade I dissection from artifact can be difficult, but this has lesser clinical import compared with the more severe injuries.



Vertebral artery injury. (a) Axial T2-weighted image demonstrates loss of the normal flow void within the right vertebral artery consistent with dissection (arrow). Note the normal dark flow void in the left vertebral artery.
(b) This was confirmed on a coronal maximum intensity projection view with MR angiography (arrow).

5. New Directions

Relatively new techniques that have shown potential utility in improving the diagnostic assessment of SCI include DWI, diffusion tensor imaging, MR spectroscopy, and functional MRI. Although much more widely used in the brain, DWI has on occasion detected SCI that was not seen on conventional sequences. Diffusion tensor imaging is an application of DWI that exploits diffusion anisotropy in white matter tracts of the central nervous system to visualize either their normal course or their disruption in the setting of pathology. Recent research has suggested that diffusion tensor imaging can demonstrate more extensive injury to the cord than has heretofore been evident, although to date histologic correlation has been lacking. MR spectroscopy is not routinely used in the assessment of SCI, but one investigation revealed that the concentration of N-acetyl aspartate in the thalamus was negatively correlated with neuropathic pain after SCI . An additional recent study demonstrated decreased N-acetyl aspartate within the injured spinal cord and possibly increased lactate, suggesting a role for ischemia in the development of myelopathy. In the realm of functional MRI, cortical activation after nonpainful anorectal stimulation has indicated the presence (in a significant subset of patients) of residual sensory pathways thought to be completely disrupted after injury. This work, if further validated, could result in reclassification of some patients judged to have a neurologically complete deficit.

6. Conclusions

Imaging of vertebral and SCI is an essential tool in patient management. CT and MRI are complementary in the assessment of vertebral fractures and vascular abnormalities. MRI is advantageous in the evaluation of ligamentous integrity and is unique in its visualization of internal derangement of the spinal cord, both in acute and chronic settings. Plain radiography has been reduced to a more limited, adjunctive role, and patients can now almost always be spared the discomfort and potential risks of myelography. An understanding of the varying manifestations of SCI has progressed, the significance of which will be enhanced by further advances in therapy, as well as by novel imaging techniques.

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