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Imaging of Spinal Trauma

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Approximately 30,000 injuries to the spinal column occur in the United States each year. Most injuries are secondary to blunt trauma (motor vehicle accidents, falls, sports injuries), although penetrating trauma accounts for approximately 10% to 20% of the cases. Roughly 2% to 3% of blunt trauma victims are affected, with the incidence of cervical spinal trauma being increased in those with significant craniofacial trauma. Approximately 40% to 50% of spinal injuries produce a neurologic deficit, often severe and sometimes fatal [1]. Survival is inversely correlated with patient age, and mortality during initial hospitalization approaches 10% [2]. Because most patients affected are young, the costs of lifetime care and rehabilitation are extremely high, often exceeding $1,000,000 per individual [3]. Plain radiography, CT, and MR imaging may all be used in the evaluation of the spinal column and are often complementary.

Indications for imaging

Pain, neurologic deficit, distracting injuries, altered consciousness (caused by head injury, intoxication, or pharmaceutical intervention), and high-risk mechanism of injury have been shown to be appropriate, highly sensitive clinical indications for spinal imaging. In the multicenter National Emergency X-Radiography Use Study led by Hoffman and coworkers [4], 34,069 blunt trauma patients underwent cervical spine imaging, 4309 (12.6%) of whom did not meet the clinical criteria for imaging discussed previously. A total of 818 injuries were reported in this study, eight occurring in the group that would not otherwise have been imaged. Two of those injuries were clinically significant. Overall sensitivity for clinical evaluation was approximately 99.6%. Similarly, the Canadian C-Spine Rule study identified patients judged to be ‘‘low risk’’ (ambulatory, without midline tenderness or immediate onset of pain, able to attain a sitting position, victims of simple rear-end motor vehicle crashes). Such low-risk patients who could actively turn their heads 45 degrees in both directions were deemed not to require imaging. Overall sensitivity of clinical criteria in this study was 100% [5]. Similar clinical criteria have been evaluated in the thoracic and lumbar spine. Frankel and coworkers

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[6] reported 100% sensitivity when the clinical criteria of back pain, the presence of a neurologic deficit, a Glasgow Coma Scale score of 8 or less, a fall from a height of 10 feet or more, ejection from a motorcycle, or involvement in a motor vehicle accident with speeds greater than 50 miles per hour were applied.

Cervical spine imaging

In the setting of acute spinal trauma, CT scanning has been shown to be more time efficient [7,8] and significantly more sensitive for fracture detection than plain films [9–16]. Multidetector CT provides superior evaluation of bony anatomy and pathol-

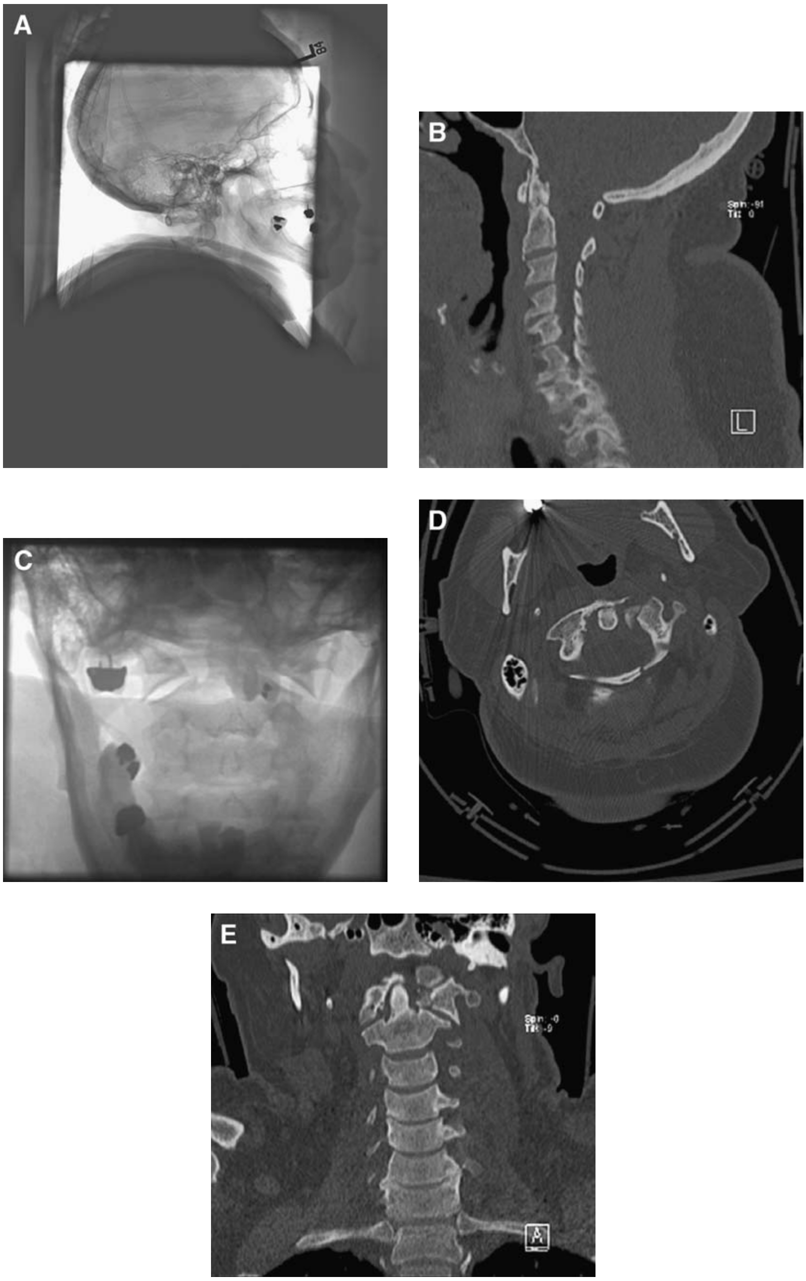

Fig. 1. (*A*) Lateral plain film is quite limited, imaging only to C2, demonstrating irregularity and possible fractures of C2. (*B*) Sagittal reformatted view reveals a fracture through the base of the odontoid. (*C*) Open mouth odontoid view demonstrates lateral displacement of the lateral masses of C1. (*D* and *E*) Axial CT scan and coronal reformatted view reveal a markedly comminuted fracture of the atlas with lateral displacement of the left lateral mass.

ogy. Images may be rapidly acquired and reconstructed at narrow intervals (eg, 1 mm) with edge-enhancing algorithms. Multiplanar and three-dimensional images can subsequently be created [Fig. 1]. In a number of studies, the sensitivity of CT scanning for cervical spinal fracture detection has been reported to be between 90% and 99% with specificities of 72% to 89%. In contrast, the reported sensitivity of plain films has ranged from 39% to 94% with variable specificity. Sensitivity of plain films has inversely correlated with severity of trauma sustained [9–16]. Multiple studies have demonstrated the limitations of plain radiography in the cervical spine, particularly at the craniocervical and cervicothoracic junctions. In a 1995 study by Link and coworkers [17], patients with substantial head trauma (Glasgow Coma Scale 3–6) underwent axial CT scanning of the craniocervical junction. Eighteen percent of patients had fractures of C1, C2, or occipital condyles. Eight of nine occipital condyle fractures and 13 of 33 fractures of C1 or C2 were not seen on plain films. Although most condylar fractures are stable, these injuries may be a cause of persistent pain, produce cranial nerve deficits, or lead to vertebrobasilar vascular injury or compromise [Fig. 2]. Furthermore, 6 of 13 fractures of C1 or C2 seen on CT only were unstable. Similarly, Nunez and coworkers [18] compared lateral plain films with helical CT of the cervical spine performed with 5-mm collimation and sagittal and coronal reformatted images. Thirty-two of 88 fractures detected by CT were not seen on limited plain film evaluation, and one third of those fractures were clinically significant or unstable.

In addition, a number of centers have reported CT scanning in moderate- to high-risk trauma patients to be a more cost-effective screening modality than plain radiography when the costs of missed injuries and preventable paralysis (including the costs of prolonged hospitalizations, rehabilitation, lost productivity, and malpractice suits) are taken into account [10,11]. Delays in diagnoses of clinically significant cervical spine injuries have been reported in approximately 5% to 23% of patients in various series, most of which used plain radiography as the initial screening modality. Neurologic deterioration (possibly secondary to mismanagement) occurred in 10% to 50% of these patients [19]. In contrast, development of a secondary neurologic deficit occurred in only 1.4% of patients whose injuries were detected on initial screening in Reid and coworkers' cohort [20]. CT is rapidly becoming the initial screening modality for osseous spinal pathology in adults, particularly those judged to be at moderate to high risk for spinal fracture based on mechanism of injury and clinical data.

Thoracic and lumbar imaging

Thoracic and lumbar spinal injuries also affect approximately 2% to 3% of blunt trauma victims and are associated with an approximately 40% to 50% incidence of neurologic deficit. CT scanning has been shown to be superior to plain films for detection and characterization of fractures. In a 1995 study by Campbell and coworkers [21], 20% of unstable burst fractures (involving the posterior vertebral body cortex) of the thoracic and lumbar spine were misdiagnosed as stable wedge compression fractures (single-column injuries) by plain films. CT better detected fractures of the posterior elements, malalignment, and intracanalicular fragments. Given the frequency with which many vic-

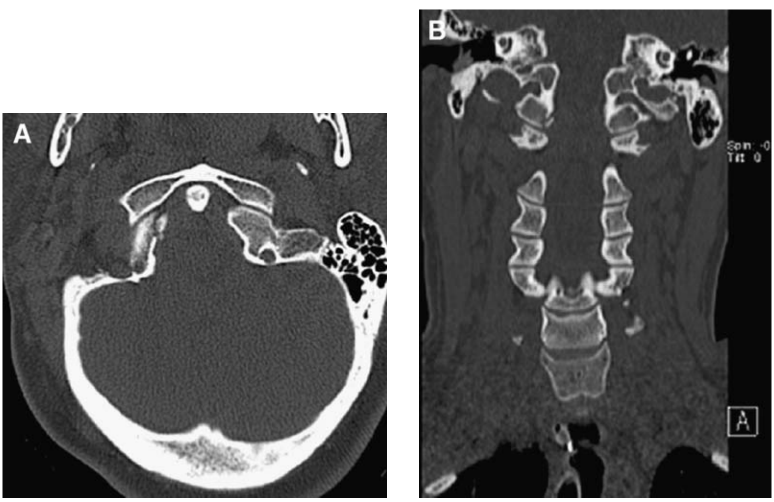

Fig. 2. (*A* and *B*) Axial and coronal reformatted CT scans demonstrate a mildly displaced fracture of the right occipital condyle.

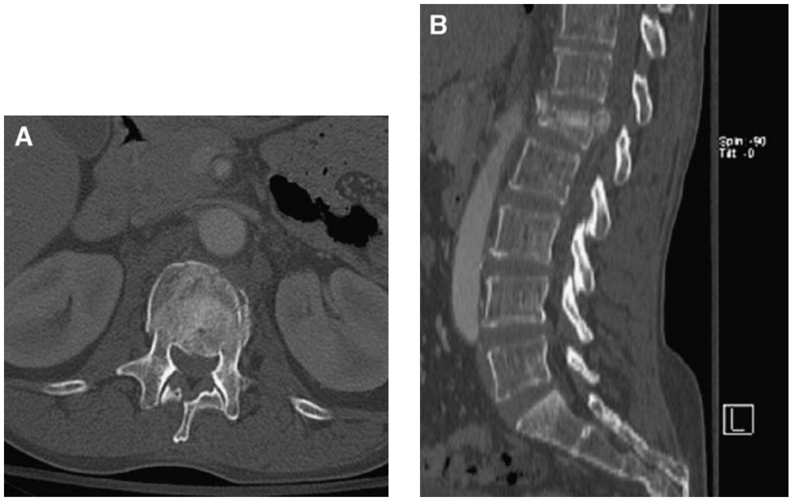

Fig. 3. (*A*) Axial reconstructed CT image reveals a comminuted burst fracture of L1 with retropulsed posterior cortex and a large prevertebral hematoma. (*B*) Sagittal reformatted view demonstrates marked loss of height of the vertebral body with retropulsed cortex and canal compromise.

tims of blunt trauma undergo multidetector CT scanning of the chest, abdomen, and pelvis, the use of reformatted images from visceral protocol CT scans to evaluate the spine has dramatically increased [**Fig. 3**] [22–25]. When compared with plain radiography in the study by Sheridan and coworkers [22], visceral CT scans reformatted at 2.5-mm intervals with sagittal and coronal reconstructed views were shown to improve sensitivity for detection of lumbar fractures from 95% to 97% and of thoracic fractures from 62% to 86%. Detail and likely sensitivity can be further improved with reformatting performed at 1-mm intervals.

Concerns about radiation dosing

Although CT scanning has been shown to be more time efficient and in certain circumstances more cost effective than plain radiography, there is a significant increase in radiation exposure associated with CT screening [26,27]. Adelgeis and coworkers [28] reported an approximately 50% increase in mean radiation dose to the cervical spine in pediatric patients for helical CT compared with conventional radiography. When organ-specific doses were examined, the results were even more concerning. Rybicki and coworkers [29] found an approximately 10-fold increase in radiation dose to the skin (28 versus 2.89 mGy) and an approximately 14-fold increase in dose to the thyroid (26 versus 1.80 mGy) with CT examination of the entire cervical spine (using 3-mm collimation, pitch of 1.5:1, 120 kV [peak], and 240 mA and single lateral radiograph) rather than a four- to five-view radiographic series.

Screening of pediatric patients

Spinal injuries in children occur somewhat less commonly than in adults, with pediatric spinal injuries accounting for approximately 2% to 5% of all such injuries. The types of injuries sustained in children, particularly younger children (under age 8), also differ from those sustained in adults. Mechanisms of injury often differ with age. The upper cervical spine is most often affected in children, and dislocations and cord injuries without associated fractures occur more often in children than in adults [30,31]. Furthermore, the tissues and organs of children, particularly those under age 5, are more prone to development of radiation-induced malignancies, because of increased radiosensitivity of certain organs; a longer expected lifetime in which to develop a cancer; and frequent failure of adjustment of scanning parameters (eg, tube current) based on patient size [26]. Multiple series have demonstrated little improvement in detection of fractures and malalignment with CT compared with plain films in the pediatric population [28,32], with substantial increases in radiation exposure reported with CT. Many normal anatomic variants in children, however, may mimic fractures and warrant additional evaluation with CT or MR imaging [33]. Because children often require sedation for CT scanning, the improvements in time efficiency and length of emergency department stay observed in adults undergoing CT screening are often not appreciated in children [32]. Given these differences between children and adults, spinal trauma screening protocols must be modified for the pediatric population. Plains films may be used as the initial screening modality with CT

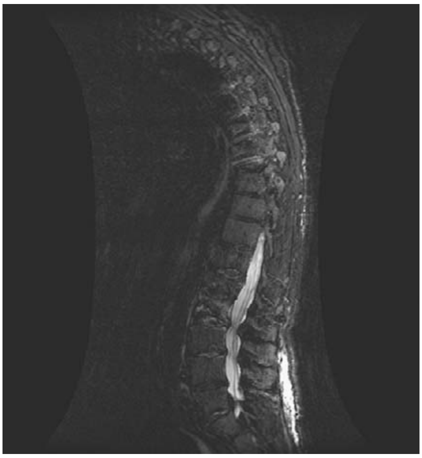

Fig. 4. Sagittal STIR image is notable for compression deformities of the T12 through L2 vertebrae. Marrow edema is present within L2, indicative of fracture acuity.

scans limited to areas of interest. Reductions in tube current and increases in table and gantry rotation speeds may be used to reduce radiation exposure [26,34]. MR imaging has a larger role in the evaluation of pediatric spinal trauma because of the increased incidence of spinal cord injury without radiographic abnormality.

MR imaging

MR imaging, with superior tissue characterization, provides the best evaluation of soft tissue pathology and essentially the only direct evaluation of the spinal cord [3]. Information obtained regarding disks, ligaments, hematomas, and the spinal cord is often complementary to the evaluation of osseous pathology provided by CT scanning [3]. MR imaging with STIR or fat-saturated T2-weighted sequences may also detect additional regions of bone edema and aid in the determination of acuity of osseous injuries [Fig. 4]. MR imaging is indicated in the setting of spinal trauma when a neurologic deficit is present or when there is clinical suspicion of a soft tissue or vascular abnormality. High-resolution, heavily T2-weighted sequences can be used (as an alternative to myelography) for the detection of potential nerve root avulsions and pseudomeningocele formation [Fig. 5]. MR imaging may also be used to evaluate posttraumatic sequelae, such as myelomalacia, syrinx formation, cord tethering, and development of arteriovenous fistulas.

Many safety considerations arise when performing MR imaging in trauma victims with suspected spinal injury. Many such patients are critically ill and require extensive monitoring and ventilatory support. Ventilators and pulse, blood pressure, and oxygenation monitors must be MR imaging compatible. Spinal precautions must be maintained at all times. Fixation devices, such as halos, may be fitted with MR imaging–compatible vests that contain graphite, thereby minimizing image degradation. Traction devices may impede table motion and may prove a danger to the patient and the MR imaging personnel, should they become projectiles [35]. Additional concerns arise in patients who have suffered penetrating trauma with retained metallic fragments [36,37]. The practice of imaging patients with retained spinal bullets is controversial. Most firearm ammunition is nonferrous but rarely is the composition of the retained projectile known. At least theoretically, a ferrous fragment may become mobile in the magnetic field and produce additional neurologic damage. Multiple small case series have, however, reported no adverse affects in patients with bullets within or in proximity to the spinal canal. In many of these

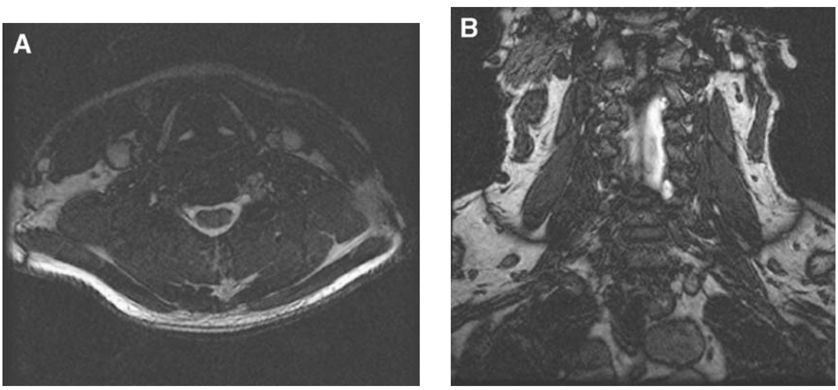

Fig. 5. (*A* and *B*) Axial and coronal high-resolution heavily T2-weighted images (FIESTA sequence) reveal a small pseudomeningocele in the left neural foramen and absence of the traversing nerve root, indicative of a nerve root avulsion.

Fig. 6. Sagittal STIR image demonstrates an acute compression fracture of C5 with extensive bone edema and retropulsion, resulting in effacement of the ventral cerebrospinal fluid space. There is abnormal signal intensity within the cord with associated expansion, representing contusion, extending from C4 through C7. There is also a large prevertebral hematoma, and there is extensive signal abnormality within the interspinous ligaments and posterior paraspinal musculature.

cases, management was altered by the MR imaging findings [38].

Canal and foraminal compromise and cord compression, in the presence or absence of acute fracture, are well evaluated with MR imaging. Spondylotic changes, disk herniations, and epidural and subdural hematomas may all narrow the canal and neural foramina. Thin-section T2-weighted gradient echo images provide optimal evaluation of degenerative changes. T2-weighted images can best detect areas of cord signal abnormality, representing contusion and adversely effecting patient prognosis [Fig. 6] [3,39].

Ligamentous and soft tissue injuries are best detected on fat-saturated T2-weighted images. The normal anterior and posterior longitudinal ligaments are seen as continuous, thin, hypointense structures along the ventral and dorsal surfaces of the vertebral bodies on sagittal images. The ligamenta flava and intraspinous ligaments may also be directly evaluated. When injury has occurred, focal areas of increased T2-weighted signal intensity or frank discontinuities in the ligaments may be seen [Fig. 7] [3,39].

Clinical issues

Instability

Stability of the cervical spine is best assessed with a functional examination that includes flexion and extension views. Such an examination, however, should be reserved for alert, cooperative patients with a normal neurologic examination and without radiographic evidence of injuries that are almost certainly unstable. Because of pain and muscle spasm present at the time of acute injury, patient motion is often limited. As such, delayed flexion and extension views (obtained 7–10 days following the injury) may be more informative. Instability is diagnosed when there is more than 3.5-mm horizontal displacement between the flexion and extension positions. Other findings suggestive of instability include displaced apophyseal joints, widened disk spaces, loss of over 30% of the vertebral body height, and the presence of a prevertebral hematoma. For those patients not suitable for flexion and extension radiography, MR imaging can be obtained. MR imaging directly images the ligaments and soft tissues of the cervical spine and can be used to infer stability or instability in such patients [39].

Whiplash

Whiplash injuries are exceedingly common, frequently following rear-end motor vehicle accidents with hyperflexion and hyperextension of the neck. Reported symptoms include neck pain or stiffness, paresthesias, upper extremity pain, jaw pain, and headaches. Recovery is often somewhat delayed, taking weeks or months. Most patients, however, report resolution of symptoms within a year of the injury; in the Quebec Task Force study, 97% of such patients reported resolution of symptoms, although 10% to 42% of patients in other studies have reported the development of chronic neck pain [40–42]. The etiology of whiplash symptoms

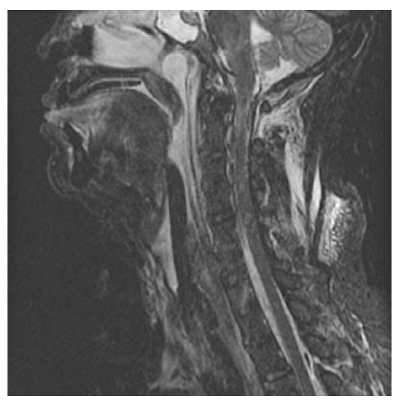

Fig. 7. Sagittal STIR image demonstrates extensive soft tissue and ligamentous injury with increased signal intensity throughout the posterior paraspinal musculature, interspinous ligaments, and prevertebral space. A distraction injury at C1-2 was suspected and verified on additional sequences and on CT. There is signal abnormality at the pontomedullary junction and within the spinal cord at C2.

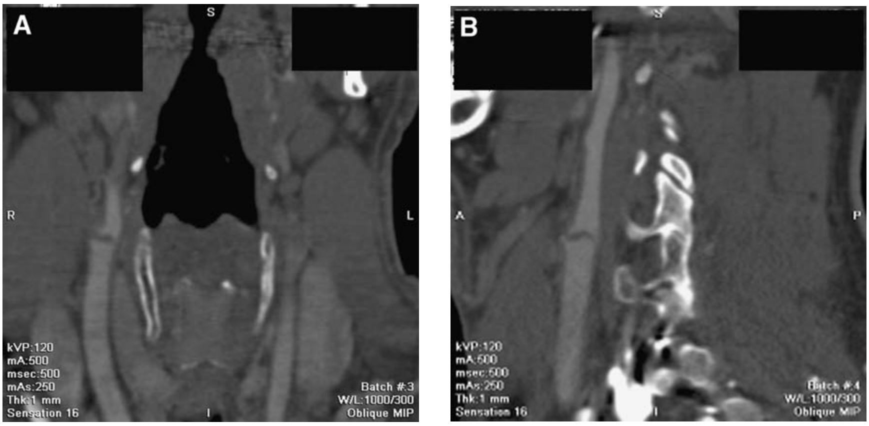

Fig. 8. Coronal (*A*) and sagittal (*B*) reformatted maximal intensity projections reveal a linear defect in the proximal right internal carotid artery. This was a blunt injury (struck in neck by hockey puck).

Fig. 9. (*A* and *B*) Axial CT scans demonstrate comminuted, mildly displaced fractures of the facet joints and a fracture of the right pedicle extending into the foramen transversarium. (*C*) Two-dimensional time-of-flight MR angiography demonstrates occlusion of the right vertebral artery in its midcervical portion. (*D*) Axial fat-saturated T1-weighted image at the level of the facet fractures does not reveal a flow void in the right vertebral artery. Hyperintensity within the right vertebral artery likely represents thrombus. There is surrounding signal abnormality, hematoma, indicative of dissection.

and the role of imaging in their evaluation remain controversial. Proposed causes include muscle tears; ligamentous injuries; apophyseal joint injuries; temporomandibular joint injuries; discogenic disease; perineural scarring; and facet, pillar, end plate, or vertebral body fractures. In the acutely injured patient with whiplash, Ronnen and coworkers [43] have suggested that imaging is not cost effective. In their study of 100 such patients who underwent MR imaging within 3 weeks of injury, only 1 had an abnormality directly attributable to the trauma. Similar findings were reported by Borchgrevink and coworkers [44] in a group of 40 patients studied within 2 days of injury. Many additional studies have found imaging, other than initial screening, to be of limited value [45]. Imaging is, however, more likely to play a role in the evaluation of the persistently symptomatic patient. Jonsson and coworkers [46] did find eight acute disk herniations in 24 patients who had neck pain for 6 weeks or more following injury. Management strategies are even more controversial [41]. Steroids, analgesics, soft collars, immobilization, activity limitation, physical therapy, exercise, radiofrequency neurotomies, acupuncture, diskectomies, fusion procedures, and steroid, botulinum toxin, and anesthetic injections have all been used. Many have been shown to be of limited or no benefit. In small, often uncontrolled series, high-dose methylprednisolone given within 8 hours of injury has

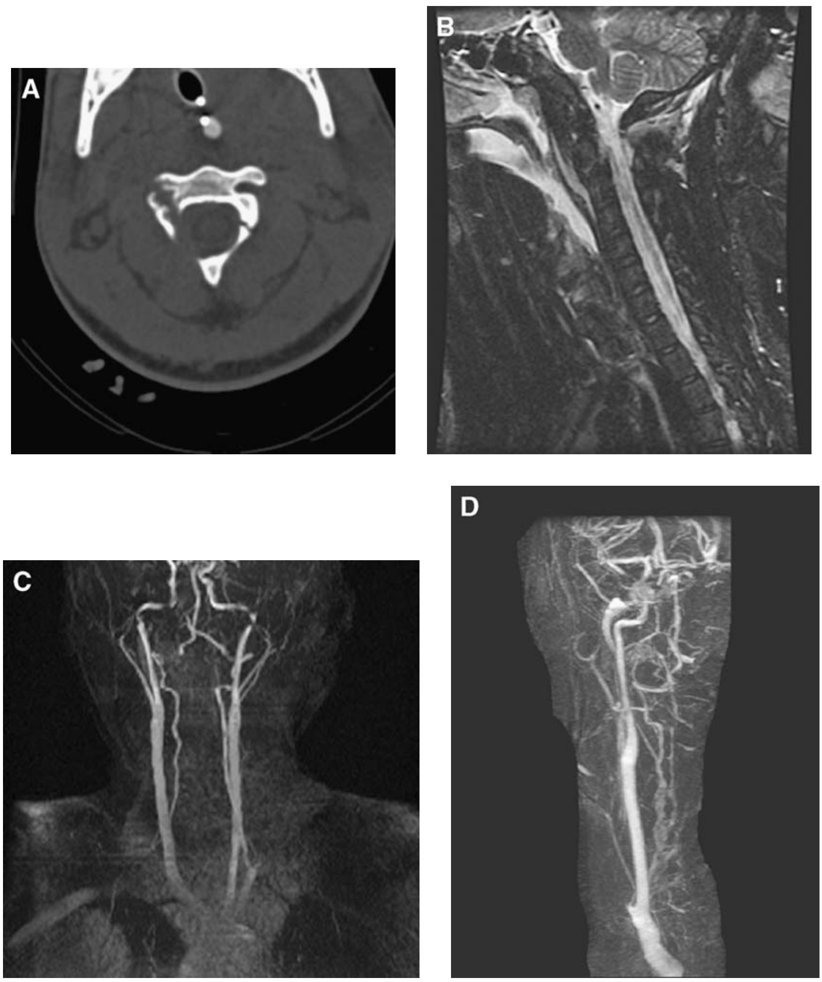

Fig. 10. (*A*) Axial CT scan demonstrates a fracture of C2 extending through the right foramen transversarium and left lamina. (*B*) Sagittal T2-weighted MR image is notable for a mildly displaced fracture of C2 with edema at the fracture site and a large amount of prevertebral soft tissue swelling. (*C*) Two-dimensional time-of-flight MR angiogram reveals marked irregularity of the right vertebral artery at the C1-2 level. (*D*) Gadolinium-enhanced three-dimensional time-of-flight MR angiography is notable for extensive venous opacification, predominantly within the spinal canal, secondary to a vertebrovenous fistula, subsequently confirmed on conventional angiography.

been shown to reduce sick leave, active exercise has been shown to reduce somatic complaints, and trigger point injections with botulinum toxin have provided short-term pain reduction [41]. Radiofrequency neurotomies and intra-articular local anesthetic injections have been shown in multiple studies to improve patient symptomatology, particularly neck pain and headache [41].

Vascular injury

The incidence of vascular injury in all victims of blunt trauma is less than 1%. It is substantially higher, however, in certain subsets of patients deemed high risk [47–51]. The incidence of vertebral arterial injury following major blunt cervical spinal trauma has been estimated to be as high as 24% to 46%; most of these lesions are, however, asymptomatic [48–50]. Screening for vascular injury is indicated in patients with otherwise unexplained neurologic deficits; in patients who sustained hyperextension and hyperflexion injuries; and in those with severe blunt trauma to the neck (including that produced by seat belts) [**Fig. 8**]. Other indications for screening include cervical spine or skull base fractures (particularly those adjacent to or involving vascular foramina), and penetrating injuries adjacent to vascular structures [47–51]. Multiple modalities have been used for detection, evaluation, or treatment of vascular injuries [52–55]. In the absence of contraindications, MR imaging and MR angiography may be used for optimal detection of mural hematoma and dissection [**Fig. 9**] [52]. Pseudoaneurysms may be present at the time of injury or may develop following

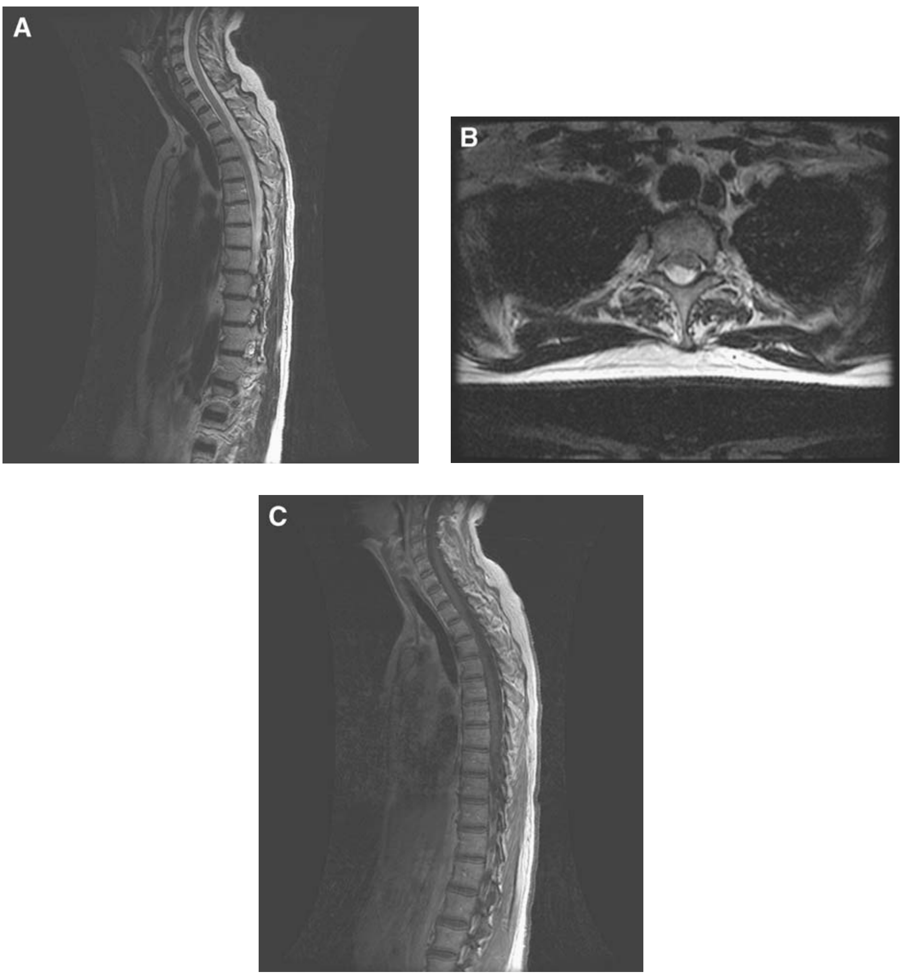

Fig. 11. (*A* and *B*) Sagittal and axial T2-weighted images demonstrate anterior and left lateral displacement and compression of the upper thoracic cord by an intradural extramedullary lesion with signal intensity characteristics of cerebrospinal fluid (an arachnoid cyst, likely resulting from adhesions in the subarachnoid space). This could alternatively represent adhesion/cord tethering/cord herniation. (*C*) Gadolinium-enhanced sagittal T1-weighted image reveals no pathologic enhancement.

dissections. Pseudoaneurysms and arteriovenous fistulae may also be detected with MR imaging and MR angiography, but are optimally studied with conventional angiography. Traumatic vertebral arteriovenous fistulae most often occur in the lower cervical spine and may produce various neurologic and nonneurologic symptoms, including pulsatile tinnitus; neck pain; dizziness and syncope (caused by steal phenomena); and paralysis [Fig. 10]. In cases of penetrating trauma in stable patients, CT and CT angiography may be superior for detection of direct puncture injury and for delineation of trajectory of the penetrating instrument [53,54]. Retained metallic fragments may, however, degrade such studies. Conventional angiography with potential for endovascular therapy is certainly warranted in cases of active hemorrhage, new-onset cerebral ischemia in patients without contraindications to thrombolysis, suspected arteriovenous fistulae, expanding pseudoaneurysms, and when noninvasive modalities have been inconclusive [47–51].

Subacute and chronic injuries

Although some patients recover some neurologic function in the months and years following injury, others suffer progressive neurologic deterioration. Worsening myelopathy, ascending neurologic level, worsening pain, worsening sensory deficit, increased spasticity, and autonomic dysfunction may occur. Possible etiologies include myelomalacia, syrinx formation, continued or progressive cord compression, instability, and development of adhesions with associated cord tethering [56]. Adhesions and tethering may be suggested when loculated collections of cerebrospinal fluid are seen and when the cord appears abnormal in course, position, or configuration (caused by compression) [Fig. 11]. The imaging appearance of myelomalacia is that of ill-defined signal abnormality with associated cord atrophy Cystic myelomalacia is often associated with chronic or recurrent cord compression. Microcysts may initially develop in areas of prior hemorrhage, demyelination, or ischemia. These microcysts may coalesce, and syrinx formation may ultimately result [Fig. 12]. On MR imaging, signal-intensity characteristics of the syrinx cavity typically follow those of cerebrospinal fluid, although they may differ if proteinaceous fluid is present. Additionally, the spinal cord appears focally expanded. In patients with previous spinal cord injuries and new neurologic deficits, syrinx formation is common. Symptomatic intramedullary cysts or syrinx cavities may be treated with surgical drainage or shunting [3,39].

Vascular injury was discussed in greater detail previously, and is the topic of a more focused discussion elsewhere in this issue. Briefly, arterial dissections, transections, and arteriovenous fistulae may occur at the time of injury with progression or regression of luminal compromise, development and enlargement of pseudoaneurysms, and development of venous hypertension over time. MR imaging and MR angiography may directly image the vascular pathology or reveal indirect signs of it, such as cerebral infarction resulting from dissections or pseudoaneurysms or cord swelling and enlarged pial veins seen with arteriovenous fistulae.

Fig. 12. Sagittal T2-weighted image demonstrates cystic myelomalacia of the cord at C4 and C5. There has been fusion of the C4 and C5 vertebrae. A disk-osteophyte complex is present at C6–7.

Summary

Spinal trauma often has devastating consequences. Well-controlled clinical trials have established guidelines for appropriate use of imaging and clinically based screening. As technology has evolved, multidetector CT scanning has assumed a significant role as a primary screening modality, although radiologists and clinicians must be conscious of the increased radiation dose that accompanies it, particularly when children are being imaged. MR imaging is often a complementary examination, providing improved soft tissue detail of the spinal cord, disks, and ligaments. Vascular injuries have been increasingly recognized in association with spinal trauma, and MR angiography, CT angiography, and conventional angiography all have roles in their detection and possible treatment. Lastly, patients with spinal injuries may suffer progressive neurologic deterioration, and imaging again has a role in their diagnosis and management.

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