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REVIEW

Imaging of post-surgical treatment and of related complications in spinal trauma

F. Caranci[1] · G. Leone[2] · L. Ugga[2] · E. Cesarano[3] · R. Capasso[1] · S. Schipani[1] · A. Bianco[4] · P. Fonio[5] · F. Briganti[2] · L. Brunese[1]

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Abstract Spinal trauma is a devastating event with a high morbidity and mortality. The rationale of imaging is to diagnose the traumatic abnormalities and characterize the type of injury, to estimate the severity of the lesions, to evaluate the potential spinal instability. In case of spinal instability, the goals of operative treatment are decompression of the spinal cord canal and stabilization of the disrupted vertebral column. Particularly, diagnostic imaging, mainly by CT and MR, has a main role in the post-treatment evaluation. The neuroradiological evaluation of the postoperative spine requires a general knowledge of the surgical approach to each spinal region and of the normal temporal evolution of expected postoperative changes. The neuroradiologist should evaluate the devices implanted, their related complications and promptly alert the surgeon of acute complications, mainly vascular and infective. During the follow-up, it is mandatory to know and search chronic complications as pseudomeningocele, accelerated degenerative disease, arachnoiditis, peridural fibrosis. Knowledge of specific complications relating to each surgical approach will assist the neuroradiologist in interpretation of postoperative images.

Keywords Spinal trauma · Spinal stability · Spinal instability · Postoperative spine · MRI · CT

✉ F. Caranci
ferdinandocaranci@libero.it

[1] Department of Medicine and Health Sciences “V. Tiberio”, University of Molise, Via F. De Sanctis 1, 86100 Campobasso, Italy

[2] Neuroradiology Unit, Department of Advanced Biomedical Sciences, Federico II University, Naples, Italy

[3] Radiology Section, Health Service, Navy Command of Brindisi, Brindisi, Italy

[4] Department of Cardiothoracic and Respiratory Sciences, Second University of Naples, Naples, Italy

[5] Radiology Unit, Department of Surgical Sciences, University of Torino, Turin, Italy

Introduction

Spinal trauma is a devastating event with a high morbidity and mortality and many additional medical, psychological, social, and financial consequences for patients. Motor vehicle accidents account for about half of reported spinal injury cases. Falls are the next most common cause, followed by acts of violence and sporting activities [1–5]. The rationale of imaging is to diagnose the traumatic abnormalities and characterize the type of injury, to estimate the severity, to evaluate the potential spinal instability [6–9].

Spinal stability indicates that the bony and ligamentous elements of the spinal column will remain in the same relative positions without shifting or separating from each others overtime. On the other hand, spinal instability indicates that, without stabilization, the spinal elements may shift and induce additional neurologic, soft tissue, or osseous injury [10, 11].

The management of the spinal trauma can be conservative or surgical according to spinal stability that can be assessed using specific score systems as the Cervical Spine Subaxial Injury Classification and Scoring system (SLICS) [12] and the Thoracolumbar Injury Classification and Scoring system (TLICS) [13].

Clinical and surgical management

Patients with minor fractures or those with stable lesions do not undergo surgery. Nonoperative management of unstable spinal fractures includes the use of spinal orthotic vests or braces to prevent rotational movement and bending [14]. Cell-based therapy using human blood-derived CD133(+) cell populations, which are believed to represent a hematopoietic/endothelial progenitor fraction, seems to be useful to promote the repair of injured spinal cord and other districts in animal models and/or in vitro models [15–18]. The goals of operative treatment are decompression of the spinal cord canal and stabilization of the disrupted vertebral column [19]. Approaches to the anterior upper cervical spine can be generally defined as transoral and retropharyngeal. The transoral approach is used to access the atlantoaxial complex. The retropharyngeal approach can be divided into the anteromedial and anterolateral on the basis of the carotid sheath position. In the same way, the approach to the lower cervical spine can be divided into anteromedial and anterolateral to the carotid sheath. The posterior approach is a common and generally safe approach to the cervical spine allowing for direct access to the posterior elements from the skull base to the thoracic spine [20]. Posterior screw plating is a common method of fusion. Multiple different techniques are utilized for screw placement with the objective of solid placement, which avoids the cord, roots, and vertebral arteries. Approaches to the thoracic spine can be categorized as anterior (transthoracic, transsternal, and thoracoscopic) and posterolateral. The anterior approaches to the lumbar spine include the transperitoneal and the retroperitoneal ones [21]. A variety of spinal fusion techniques are available to the surgeon, including posterior fusion, posterior lateral fusion, anterior lumbar interbody fusion, posterior lumbar interbody fusion, and extreme lateral interbody fusion [22].

Neuroradiological evaluation: modality and technical pitfalls

Radiographic examination (Fig. 1) has some limits, because it cannot evaluate soft tissue structures and it is of little value in the noninstrumented postoperative spine [23–27].

At present, computed tomography (CT) with multiplanar reconstruction (MPR) is considered the modality of choice for imaging bony detail and assessing osseous formation and implant position (Fig. 2) [28]; moreover, CT provides better evaluation of fusion progression and status than dynamic radiography for patients who have undergone interbody fusion for lumbar spinal disorders [29].

A limitation of CT scans is the beam-hardening artifact caused by the metallic prosthesis, which causes difficulty in the evaluation of the spinal canal; however, they are less common with titanium implants than with stainless steel because of the lower beam attenuation coefficient of titanium [30–34].

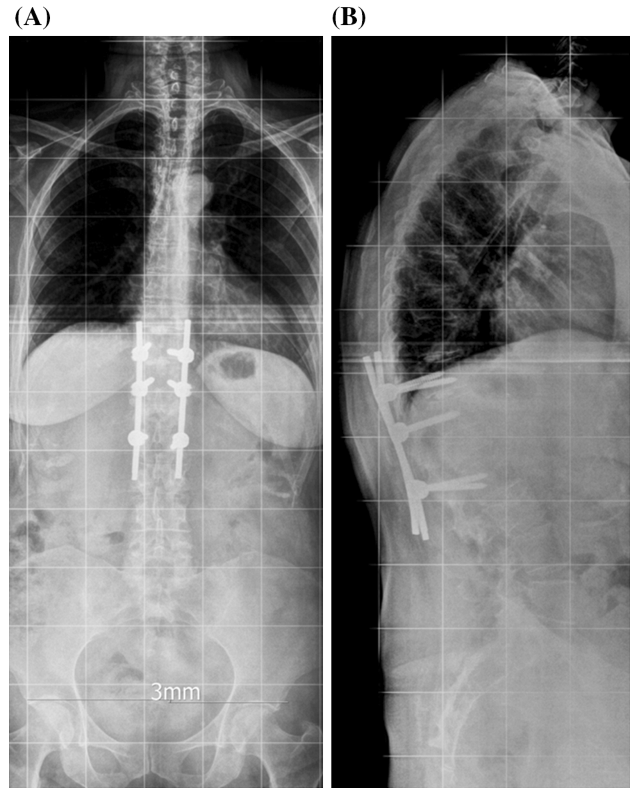


Fig. 1 **a**, **b** Antero-posterior and latero-lateral X-rays: L1 traumatic collapse treated by posterior stabilization with bars and transpedicular screws at D11, D12, and L2

Magnetic resonance (MR) imaging is the preferred imaging modality in the evaluation of the postoperative spine because it allows the assessment of bone marrow, soft tissues, nerve roots, and above all spinal cord (Fig. 3) [35–40]. For routine imaging of the postoperative spine, sagittal and axial MR images are usually obtained. In the sagittal plane, T1- and T2-weighted images offer complementary information. With the introduction of the titanium pedicle screws and specialized pulse sequences, there has been considerable improvement in the MR imaging evaluation of the postoperative spine [41]; in these patients, it is recommended to use lower magnetic field (1.5 T instead of 3 T).

Neuroradiological evaluation: devices

Plates and screws are devices designed to stabilize vertebral elements in fusion surgery. Cages are cylindrical metallic prosthesis are used to reconstruct anterior spinal column after corpectomy providing immediate segmental stability (Fig. 4). They are not designed as a standalone devices, but they are mainly implanted in association with posterior hardware [42].

Device implantation can induce image degradation, related to metal prostheses/implants, that appears as beam-

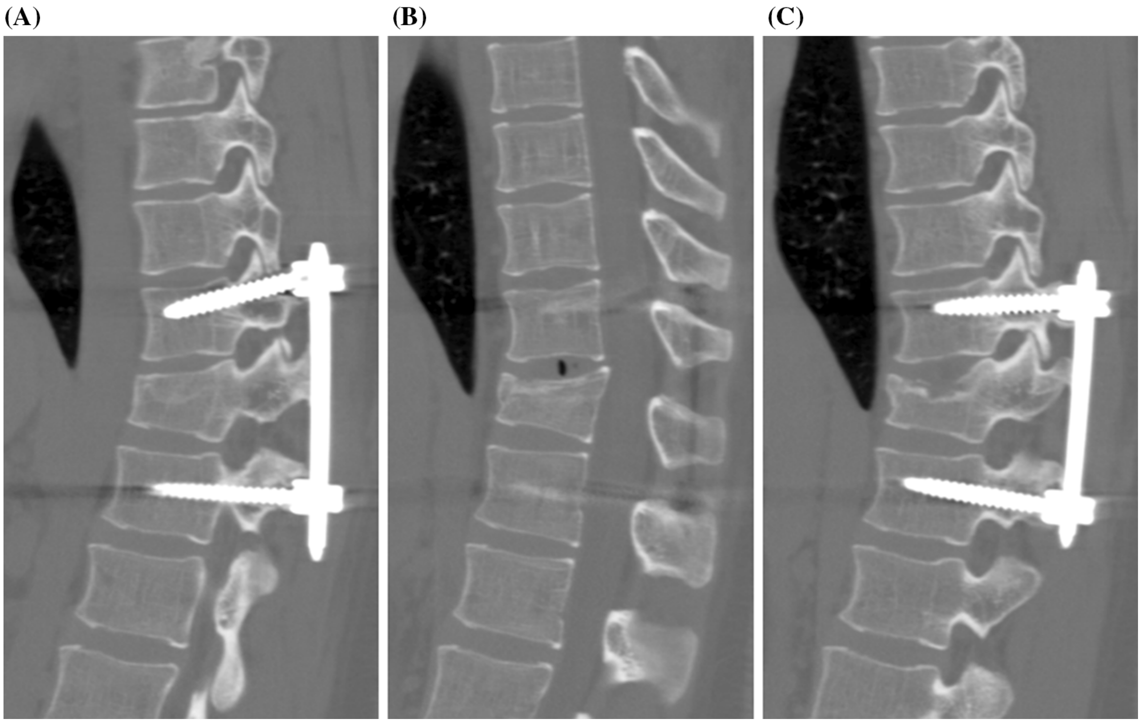


Fig. 2 **a–c** CT MPR sagittal reconstructions. L2 traumatic collapse treated by posterior stabilization with bars and transpedicular screws at L1 and L3, correctly positioned

hardening artifact and blooming artifact on CT and susceptibility artifact on MR (Fig. 5).

Use of high peak voltage (kilovolts peak), high tube charge (milliampere-seconds), narrow collimation, and thin sections can reduce metal-related artifacts on CT [43].

MR sequences should not include Gradient-Echo, but preferably Fast Spin-Echo (FSE) techniques, with larger field of view (FOV) and smaller voxel size. Frequency encoding direction should be chosen along the long axis of the hardware (so artifact projects on hardware) [44].

Neuroradiological evaluation: normal postoperative changes

Normal postoperative changes should be differentiated from early complications; the neuroradiologist should be aware of these findings in order to avoid imaging misinterpretations [45–47].

Edema and granulation tissue at operative site are expected postoperative changes [48, 49]. Complex fluid in surgical bed may simulate infected fluid collection or pseudomeningoceles. Marrow changes and fluid associated with intervertebral fusion may simulate appearance of spondylodiscitis. Nerve roots enhancement can be identified in early postoperative period and resolves spontaneously [50–52].

Neuroradiological evaluation: complications related to hardware devices

- **Hardware failure**
  It is due to a fractured or malpositioned metallic implant that produce a malfunction of the hardware with pseudoarthrosis (failure of progression to solid osseous fusion). This complication may appear on CT imaging as an area of lucency and/or sclerosis along the implant or at vertebral body-graft interface.
- **Screws malposition**
  Pedicle screws in the thoracolumbar spine and lateral mass screws in the subaxial cervical spine are commonly used in combination with plates, hooks, or rods for spinal fusion. Complications due to this approach are related to the proximity to adjacent neural and vascular structures. Optimal screw placement is along the medial aspect of the pedicle without breaching the cortex, entering the neural foramen or extending beyond the vertebral body cortex (Fig. 2) [53]. The most common reported complication of pedicle screws is medial angulation of the screw with violation of the medial cortex (Fig. 6), resulting in irritation of the nerve root. Lateral angulation may also occur (Fig. 7) and it is especially important in the cervical spine, where the screw may traverse the foramen transversarium and

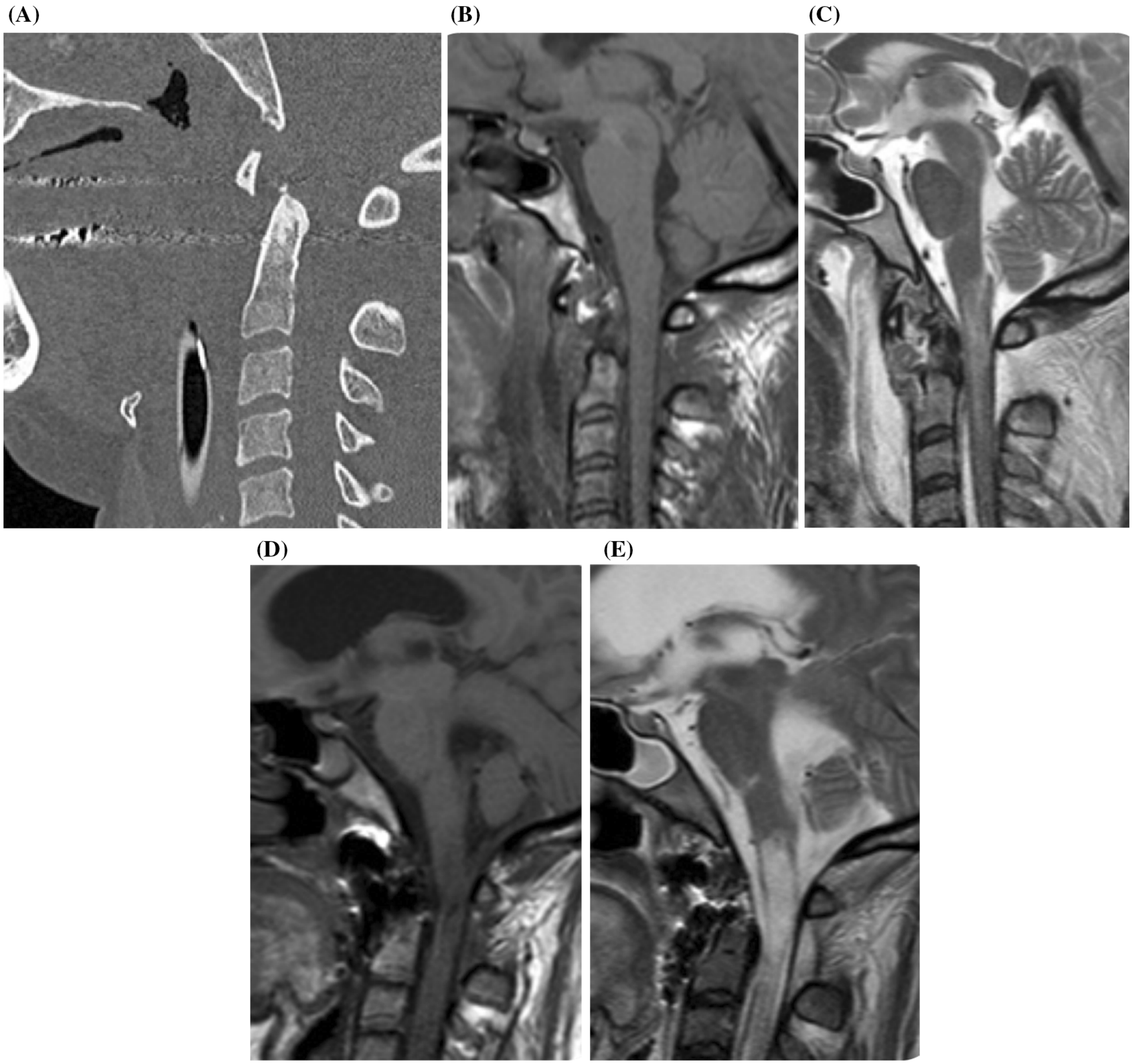


Fig. 3 **a** CT MPR sagittal reconstruction: atlantoaxial dislocation with odontoid posteriorly dislocated. **b**, **c** MR, T1- and T2-weighted sagittal sections: bulbo-medullary junction, compressed by odontoid, shows swelling and T2-w hyperintense signal due to edema; note also pre-vertebral hematoma. **d**, **e** MR, T1- and T2-weighted sagittal sections: control after odontoid removal shows a cavitary evolution of the bulbo-medullary damage

potentially compromise the vertebral artery. Improper screw placement may also lead to traversing the anterior cortex of the vertebral body, sometimes abutting the aorta. Similarly, when evaluating anterior plate and screw fixation the screws may over-penetrate and lead to dural, cord, or nerve root injury. Such complications can be avoided by using intraoperative fluoroscopy.

Neuroradiological evaluation: acute complications

- **Hemorrhage**
  Imaging of spinal hematoma is best performed using MR; it better shows the size, characteristics, and extent of postoperative hematoma. A biconvex epidural mass can occasionally be seen on CT, although multiplanar reconstructions (MPR) better demonstrate its extent.

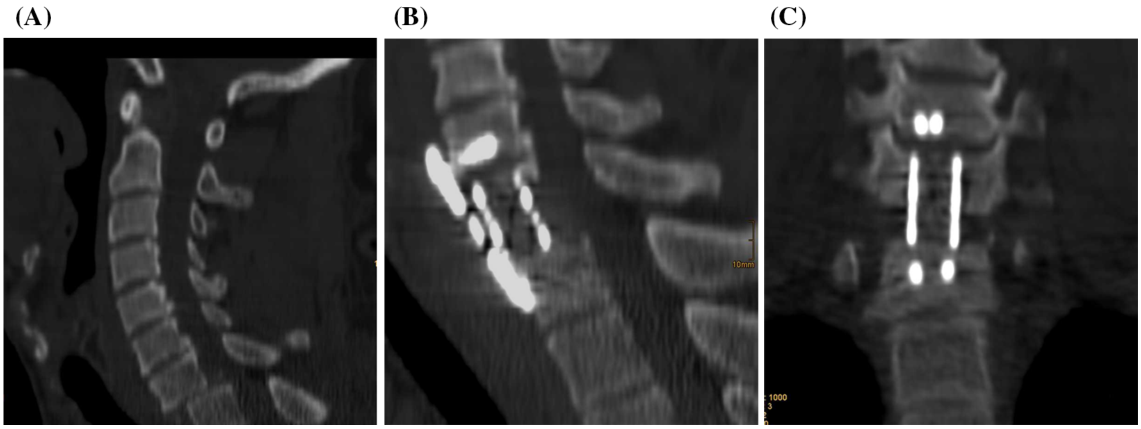


Fig. 4 **a** CT MPR sagittal reconstruction: C7–D1 fracture-dislocation (peduncle/lamina). **b**, **c** CT MPR sagittal and coronal reconstructions: surgical treatment by vertebral drawing and prosthesis positioning anteriorly fixed by transvertebral screws

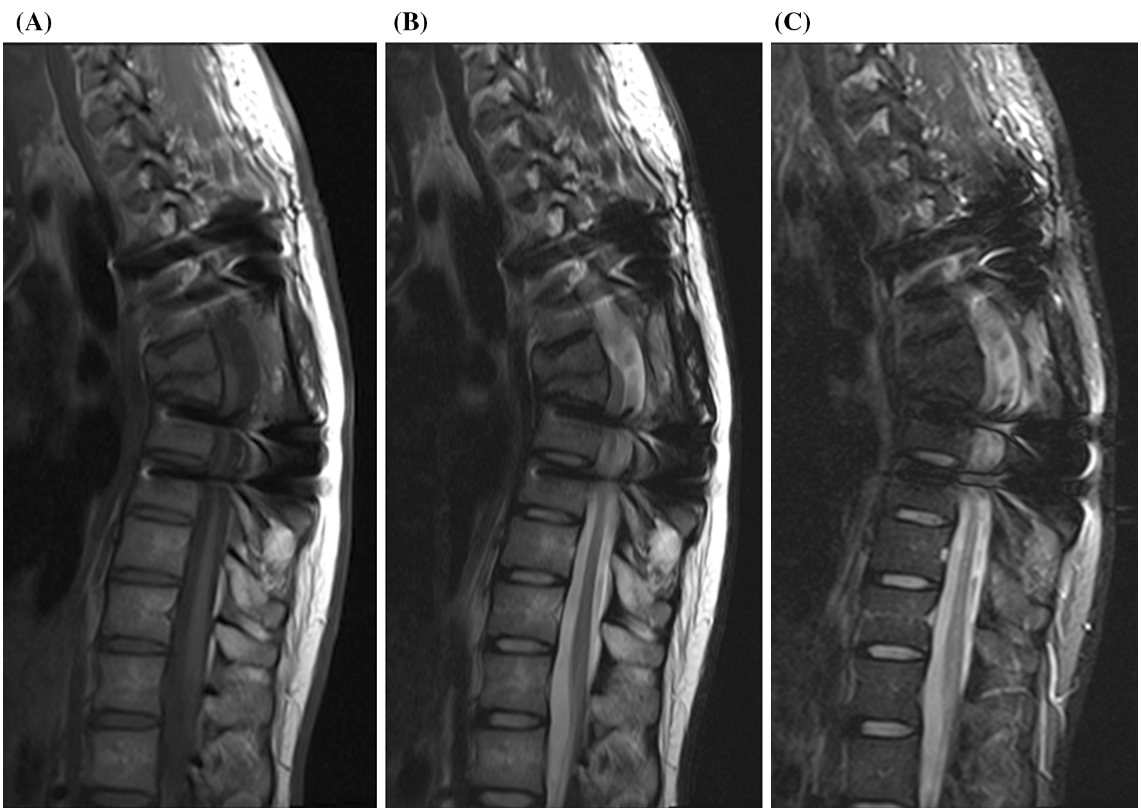


Fig. 5 **a–c** MR, T1-, T2- and STIR-weighted sagittal sections: D7 and D8 traumatic collapses treated by laminectomy and posterior stabilization; presence of susceptibility artifacts generated by bars and transpedicular screws

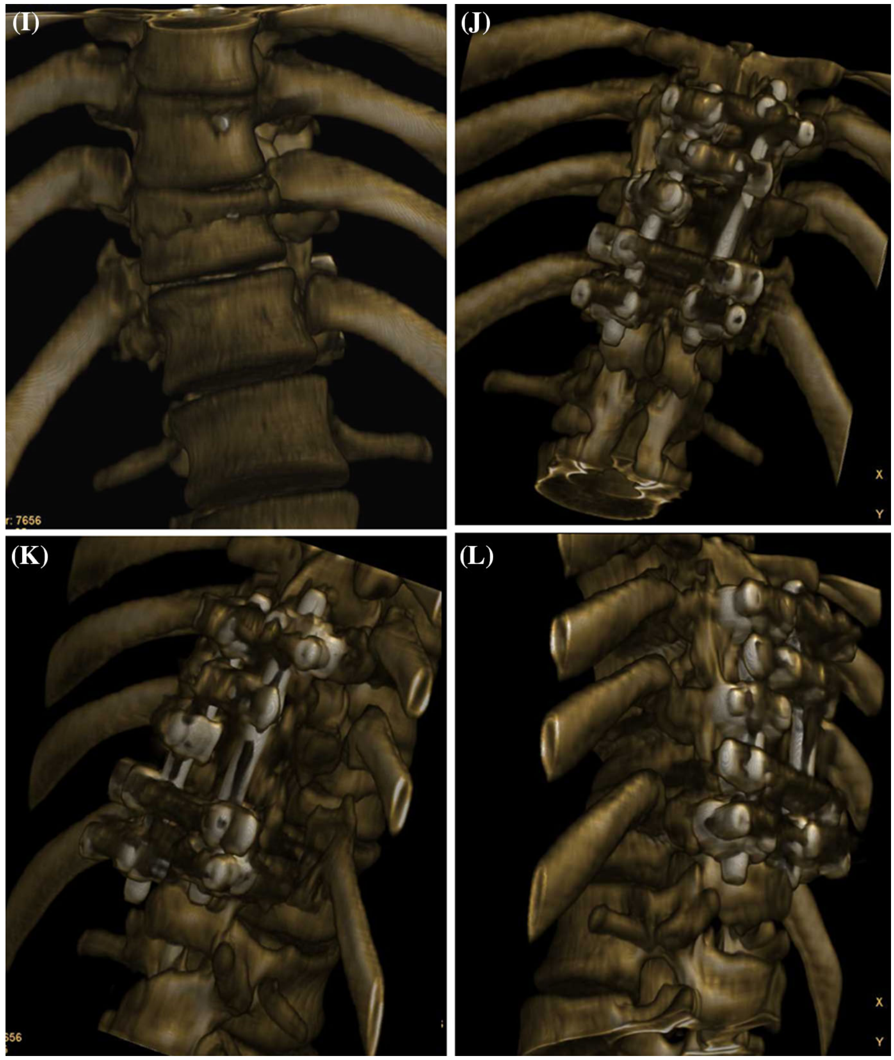
The MR signal characteristics of hematoma vary with the age of blood products. In the first 24 h, an epidural hematoma is isointense to the cord on T1W images and is usually hyperintense, although it may be heterogeneous, on T2W images. By 48 h, the hematoma appears hyperintense on both T1W and T2W sequences [50, 54, 55].

Subdural hematoma is less common than the epidural variety. It appears at CT as a hyperdense lesions within the dural sac, distinct from the adjacent low-density epidural fat; its appearance is more often clumped or lobulated and conforms to the dura.

- **Medullary infarct**
  Ischemia of the spinal cord is due to a iatrogenic radicular artery occlusion. On MRI it presents as an area of hyperintensity on T2-weighted images within cord (Fig. 8) with the central "owl's eye" pattern involving usually more than one vertebral body

Fig. 6 **a–d** CT axial section; **e–h** CT MPR sagittal and coronal reconstructions; **i–n** volume rendering reconstructions. D11 traumatic collapse treated by laminectomy and posterior stabilization with bars and transpedicular screws at D10 (correctly positioned), D11 (left positioned) and D12 (right screw mildly medially positioned)

Fig. 6 continued



segment. Diffusion-weighted imaging (DWI) shows a hyperintense lesion due to diffusion restriction for the cytotoxic edema.

- **Postoperative infection**

  Despite the development of prophylactic antibiotics and advantages in surgical technique and postoperative care, wound infection continues to compromise patient outcome after spinal surgery.

  Plain radiographs of the spine are rarely useful for the diagnosis of early infection. In the setting of discitis, on radiographs and CT loss of disk height and end plate erosion should be evidenced, while, in latent infections, lucencies may be present around orthopedic hardware. Imaging of advanced cases may show vertebral body collapse.

  MRI is the most useful study to diagnose postoperative infections. On MR imaging, suspicious features include low T1-w signal intensity involving the intervertebral disk and the adjacent vertebral bodies with corresponding high T2-w signal intensity. Gadolinium enhancement improves the diagnostic accuracy of MRI and should be used whenever infection is suspected. There may be diffuse or rim contrast enhancement of the disk space and avid contrast enhancement of the adjacent vertebral marrow. Findings must be interpreted based on the timing since the index procedure was performed; in fact, the neuroradiologist should be aware by potentially confounding conditions as tissue edema from noninfectious causes, that can occur in the early postoperative period.

Neuroradiological evaluation: chronic complications

- **Accelerated degenerative disease**

  Following spinal fusion, the spinal segments cranial or caudal to the surgical bed are at increased risk for accelerated degeneration. These changes are related to the new biomechanics, free radical-induced oxidative

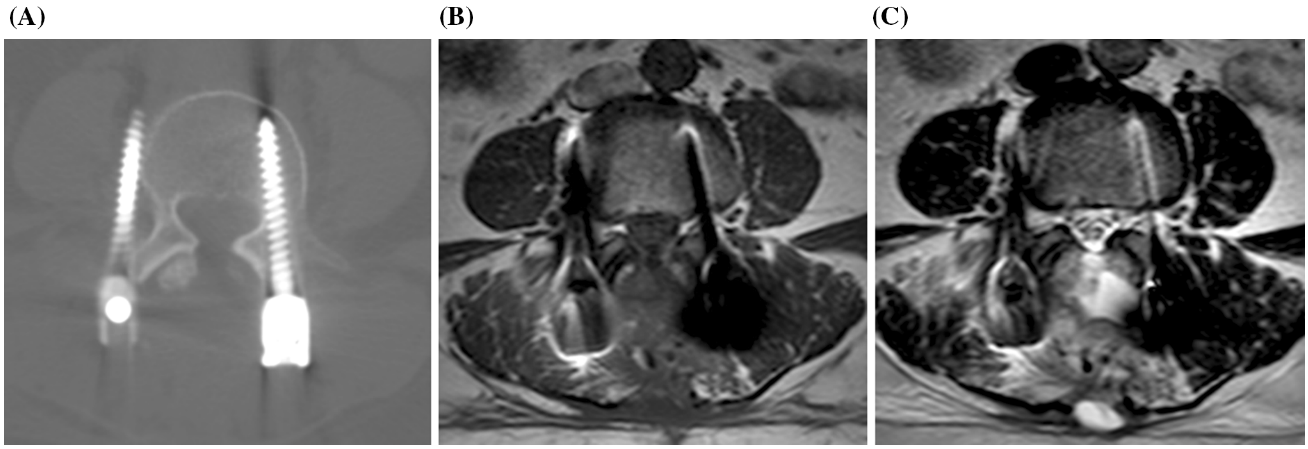


Fig. 7 **a** CT axial section; **b**, **c** T1- and T2-weighted axial sections. Right transpedicular screw laterally positioned

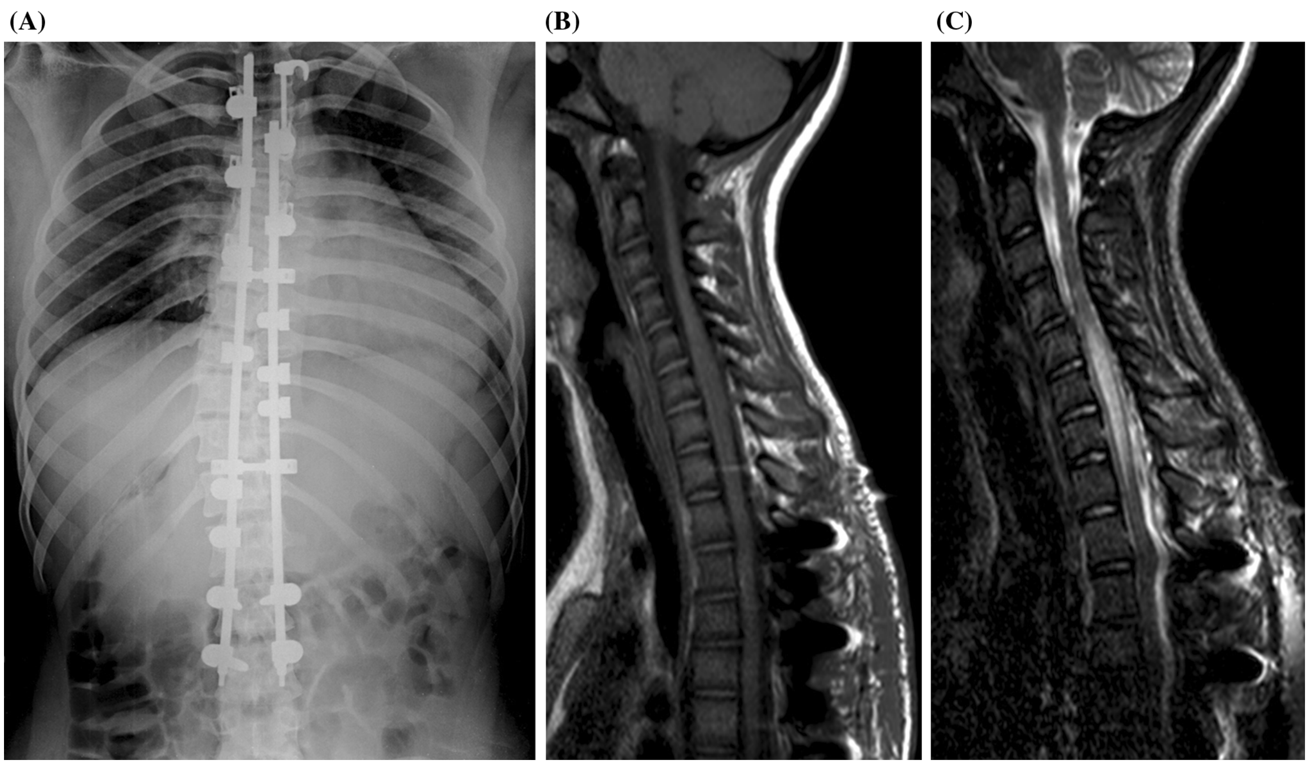


Fig. 8 **a** Antero-posterior X-ray: severe scoliosis treated by metallic distractor. **b**, **c** T1- and STIR-weighted sagittal sections: C5–D1 spinal cord swelling with T2-w hyperintense signal related to medullary ischemia

damage and weight distribution, also associated with reduction in overall flexibility and motion of the spine [56, 57].

CT findings of degenerative disk disease at transitional level include loss of disk space height, disk vacuum phenomenon, bony endplate osteophytes, facet degenerative arthropathy with foraminal stenosis, anterolisthesis or retrolisthesis, disk bulge, protrusion or extrusion and central canal stenosis. Typical findings seen in degenerative disk and facet disease are the loss of signal within intervertebral disk on T2-w images and degenerative endplate changes [58].

- **Pseudomeningocele/CSF leak**

  A cerebrospinal fluid (CSF) leakage syndrome, without or with pseudomeningocele formation, leading to intracranial hypotension may be caused by a dural tear or durotomy at the time of surgery. Although many remain asymptomatic, pseudomeningoceles can compress or herniate the spinal cord and nerve roots.

  The incidence is higher in the thoracic and lumbar spine than in the cervical spine. A pseudomeningocele is defined as a CSF-containing cyst in contiguity with the thecal sac, although the dural connection may be difficult to be visualized directly on CT or MR imaging. The cyst is not lined by meninges and usually does not contain neural elements, although they may occasionally herniate into the cyst. On CT and MR imaging, the density and signal characteristics, respectively, follow that of CSF unless complicated by hemorrhage or infection. There may be a thin rim of peripheral enhancement in uncomplicated cases. Intracranial findings of CSF leakage syndrome include diffuse dural thickening and enhancement, sagging midbrain, subdural hygroma/hematoma, descent of the cerebellar tonsils, and enlarged veins or dural sinuses. Imaging of the spine may show epidural fluid collections and/or paraspinal fluid, dilation of the epidural venous plexus, and diffuse dural thickening and enhancement [59]. Localization of a CSF leak provides important information for the surgeon to guide further treatment. If there is uncertainty regarding the presence and/or location of a CSF leak, radionuclide cisternography may delineate the site of CSF leak. CT myelography may directly visualize the site of leak in approximately 70% of cases. Finally, the investigational use of MR imaging myelography with low-dose intrathecal gadolinium chelate or heavily T2-weighted sequences has also been reported to be helpful. Treatment options for these lesions include conservative management, epidural blood patch, lumbar subarachnoid drainage, and lumbo-peritoneal shunt placement. Surgical repair, usually by primary dural closure, remains the definitive treatment modality for iatrogenic symptomatic pseudomeningoceles.

- **Arachnoiditis**
  The etiology of arachnoiditis in postoperative spine is not well understood. Potential factors resulting in arachnoiditis include the surgical procedure itself, intrathecal blood, postoperative infection, prior use of myelographic contrast material or intraspinal injections of anesthetic agents, and use of anti-inflammatory or chemotherapeutic agents. Arachnoiditis has a spectrum of MR imaging findings with variable enhancement of clumped nerve roots, an "empty" thecal sac with the nerve adhered to the dural walls, or mass-like filling of the thecal sac. Three imaging patterns of spinal arachnoiditis have been described [60]. In the first pattern, there is central clumping of nerve roots within the thecal sac into a single conglomerate or several thickened cords. The second pattern is the "empty thecal sac" sign: nerve roots are peripherally displaced and adhered to the meninges, with only the homogeneous T2 hyperintense signal of CSF within the thecal sac. The third pattern of arachnoiditis leads to the formation of an inflammatory mass that may fill the thecal sac. MR imaging shows a relatively nonspecific soft tissue mass that may or may not enhance on contrast-enhanced MR imaging studies, depending on the level of active inflammation.
- **Peridural fibrosis**
  Peridural fibrosis consists of scar tissue that causes adherence of neural elements to adjacent structures and restricts their mobility. Some authors have described peridural fibrosis as a radiological entity independent of clinical symptoms, while others have concluded that diffuse epidural scarring correlates to symptoms, but small focal scarring does not [61].
  The lack of mobility may cause clinical symptoms or predispose patients to nerve root irritation from the adjacent disk, herniated disk material, or osteophytes. Peridural fibrosis can also cause mass effect and/or direct mechanical compression. CT imaging in the setting of postoperative peridural fibrosis will show nonspecific soft tissue infiltration with enhancement after intravenous contrast administration. MR imaging shows an intermediate signal infiltrative soft tissue within the epidural space, often along the surgical tract and surrounding nerve roots. Occasionally, peridural scar may appear mass-like with effacement of the normal nerve root size or enlargement secondary to cicatrization. After intravenous contrast administration, there is diffuse homogeneous enhancement that may be present for years after surgery. Occasionally, involved nerve roots may show some degree of enhancement [62–65].

Conclusions

The evaluation of the postoperative spine remains a challenging matter even with all the advances in imaging technology. The radiologist needs to be familiar with the possible surgical techniques used for each spinal segment, expected postoperative progress, and surgical hardware. He must have not only knowledge of the general complications that may occur in spinal surgical interventions but specific ones for each kind of approach as well.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standards For this type of article, formal consent from a local ethics committee is not required.

Informed consent Informed consent was obtained from all patients before diagnostic examination.

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