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Imaging of the spine: New possibilities and its role in planning and monitoring therapy

Marek Sąsiadek, Paweł Szewczyk

Department of General Radiology, Interventional Radiology and Neuroradiology, Wrocław Medical University, Wrocław, Poland

Author's address: Marek Sąsiadek, Department of General and Interventional Radiology and Neuroradiology, Wrocław Medical University, Borowska 213 Str., 50-556 Wrocław, Poland, e-mail: mareks@rad.am.wroc.pl

Summary

The latest advances in spine imaging are discussed, focusing on new developments in CT and MRI techniques. The aim of contemporary imaging of the spine is to provide very precise assessment of pathological lesions to enable optimal treatment planning and follow-up. The modern multidetector CT units allow a detailed evaluation of the bony structures of the spine and the monitoring of surgical treatment. A modern generation of MRI equipment allows for precise localization of spinal lesions before the surgical procedure. New MRI techniques, especially diffusion tensor imaging, open new possibilities for advanced diagnosis and follow-up of diseases of the spine. The possibilities of the new CT and MR techniques in particular pathological lesions of the spine are presented.

Key words: spine diseases • CT • MRI • diffusion tensor imaging

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Background

The main imaging methods in the diagnosis of the spine are plain films, computed tomography (CT), and magnetic resonance imaging (MRI), supplemented by less commonly used modalities such as vascular studies (Doppler sonography, CT angiography, MR angiography, digital subtraction angiography), nuclear medicine studies (bone scintigraphy, PET/CT), and myelography (exceptionally, because of its invasiveness).

The greatest progress has occurred in MR diagnostics. In addition to conventional MR sequences, several new MR techniques, such as MR myelography, steady-state sequences (CISS, FIESTA), and fat-suppression techniques, were developed in the 1990s [1,2]. Recently there have been attempts to introduce advanced imaging modalities of the spinal cord, such as diffusion-weighted imaging (DWI), diffusion tensor imaging (DTI), functional magnetic resonance imaging (fMRI), and MR spectroscopy (MRS) [3–10]. These techniques, although widely used in the brain, are difficult to adopt for the spinal cord due to its small dimensions and many technical problems. Another new development is provided by functional (motion) imaging using open or vertical MR units as well as axial-loaded imaging [11,12]. There are also new possibilities in CT diagnostics thanks to the development of muldidetector CT equipment which allows obtaining high-quality multiplanar and three-dimensional (3D) reconstructions of the spine. On the other hand, progress in the software enables demonstrating spinal structures as well as materials used during surgery, such as implants and cement, very precisely [13–16].

The advances in the imaging of the spine are accompanied by those in the treatment of the spine and spinal cord diseases, especially using surgical methods. Thus the role of contemporary imaging is not only to diagnose the disease, but also to provide precise details for treatment planning and follow-up. The aim of this review is to discuss the value of advanced CT and MR imaging in the planning and monitoring of the treatment of the spine and spinal cord diseases.

New Possibilities of CT Imaging

The advances in CT diagnostics of the spine are associated with the introduction of multidetector CT units, especially those with 32, 64, or more detectors, as well as advanced software. This enables detailed imaging of bony spine structures in any plane. The ability to produce very thin slices results in visualization of very small lesions of the vertebrae. Multidetector CT myelography can show the outline of nerve

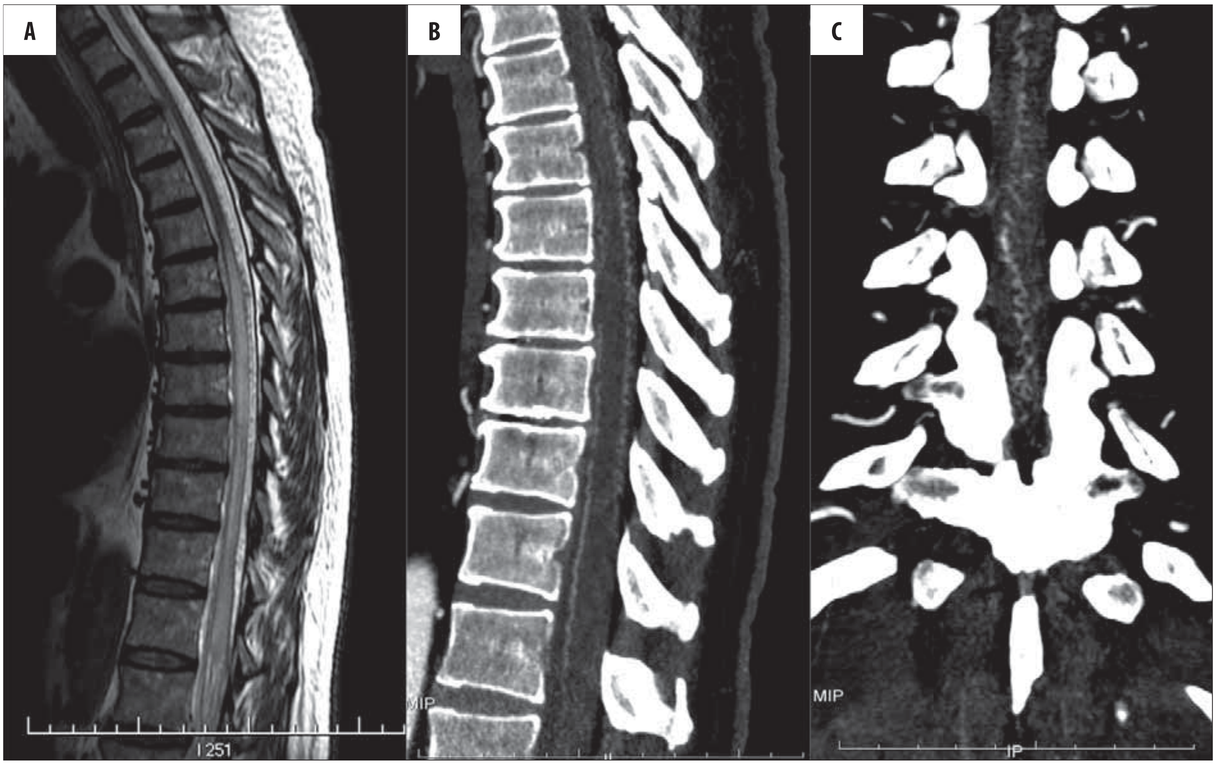

Figure 1. Dural arteriovenous fistula. (**A**) MRI: T2-weighted sagittal image reveals diffuse spinal cord edema. There are multiple small serpiginous foci of signal void at the surface of the spinal cord which may be compatible with pathological vessels. B, C. CT angiography: sagittal (**B**) and coronal (**C**) reconstructions. Pathological vessels of dural arteriovenous fistula are clearly visible.

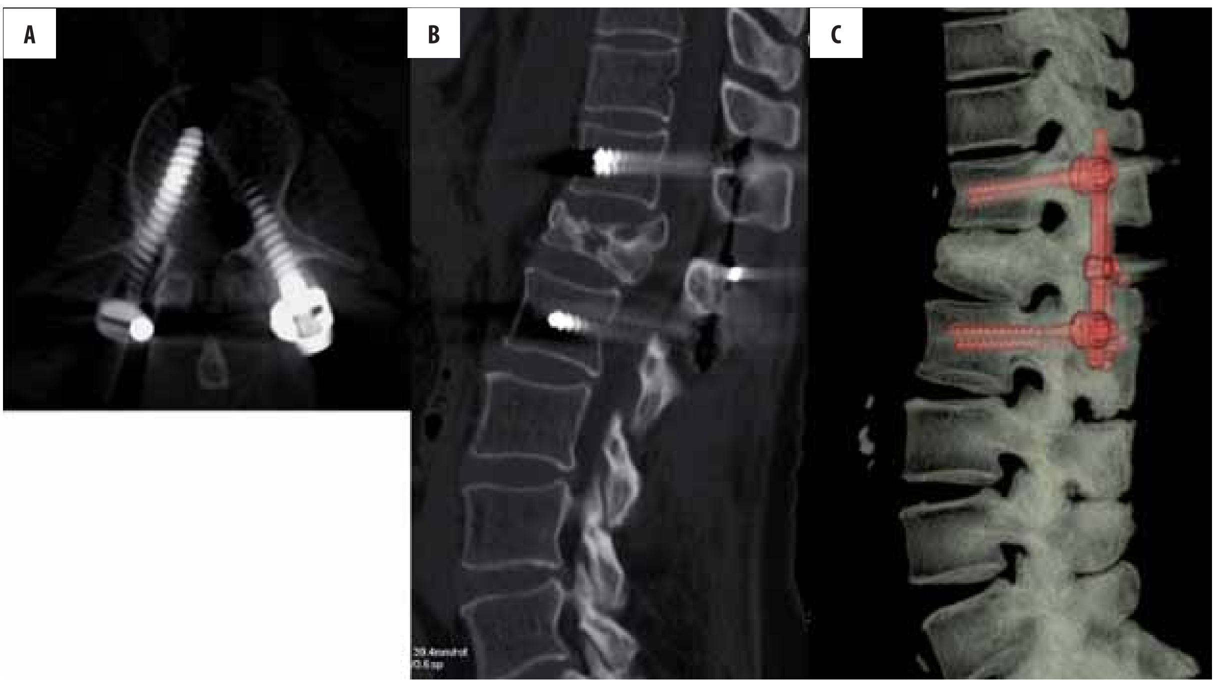

Figure 2. Fracture of the L1 vertebral body treated with internal stabilization. CT: plain scan (**A**), sagittal multiplanar reconstruction (**B**) and 3D color reconstruction (**C**) provide a precise visualization of the relationship between the metal implants and the vertebral structures.

roots crossing the thecal sac very precisely. On the other hand, high-resolution multidetector CT angiography can visualize not only large vessels, such as vertebral artery, but also small vascular channels in the spinal canal, for example in patients with vascular malformations [17–19] (Figure 1).

Many surgical procedures may be performed under CT guidance. Internal stabilization requires introducing screws through the pedicles into the vertebral bodies (Figure 2). The position of the screws in the pedicles can be controlled with CT [15]. CT is also a very good tool to control the pla-

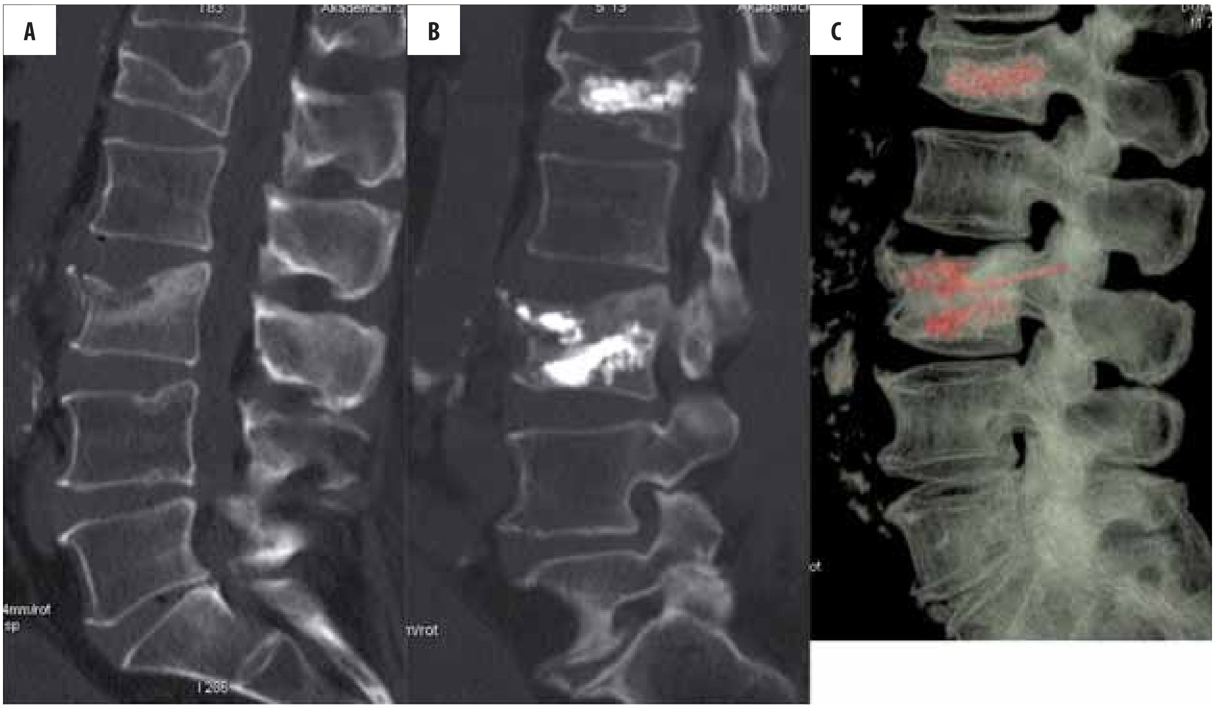

Figure 3. Fracture of the L1 and L3 vertebral bodies treated with vertebroplasty. CT: sagittal multiplanar reconstructions before (**A**) and after (**B**) the procedure as well as 3D color reconstruction (**C**) after the procedure. The distribution of the cement implemented in the vertebrae is very well visible.

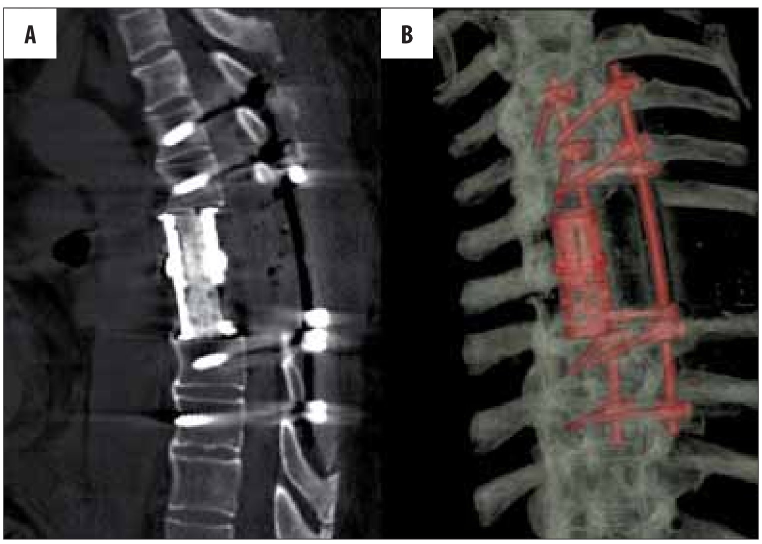

Figure 4. Vertebrectomy and internal stabilization in a patient operated on due to huge neurofibroma. Multiplanar reconstruction (**A**) and 3D color reconstruction (**B**) clearly show the positions of the implants and their relationship to vertebral structures.

cement of cement during vertebroplasty (Figure 3) or position of a balloon during kyphoplasty [16,20].

Follow-up CT, including multiplanar and 3D reformats, enables precise evaluation of both the vertebrae and implants used during the operation [14]. It can easily detect any misalignment of the vertebrae as well as lytic or sclerotic changes. The position of implants may be very clearly demonstrated on high-resolution multiplanar and, especially, color-coded 3D reformats. The latter combine precise 3D visualization of the vertebrae with a color presentation of surgical devices such as rods and screws used during internal stabilization (Figures 2–4).

New Possibilities of MR Imaging

The modern MRI units provide very good resolution of both vertebral structures and the content of the spinal canal. The high image and spatial resolution of T2-weighted images allows for very good delineation of even very small lesions in the spinal cord. On the other hand, the use of the newly designed T2-weighted fat-suppression technique enables precise detection and assessment of the extent of any lesion in the vertebral and paravertebral soft tissues. The same technique combined with post-contrast T1-weighted images provides excellent visualization of contrast enhancement and thus the precise

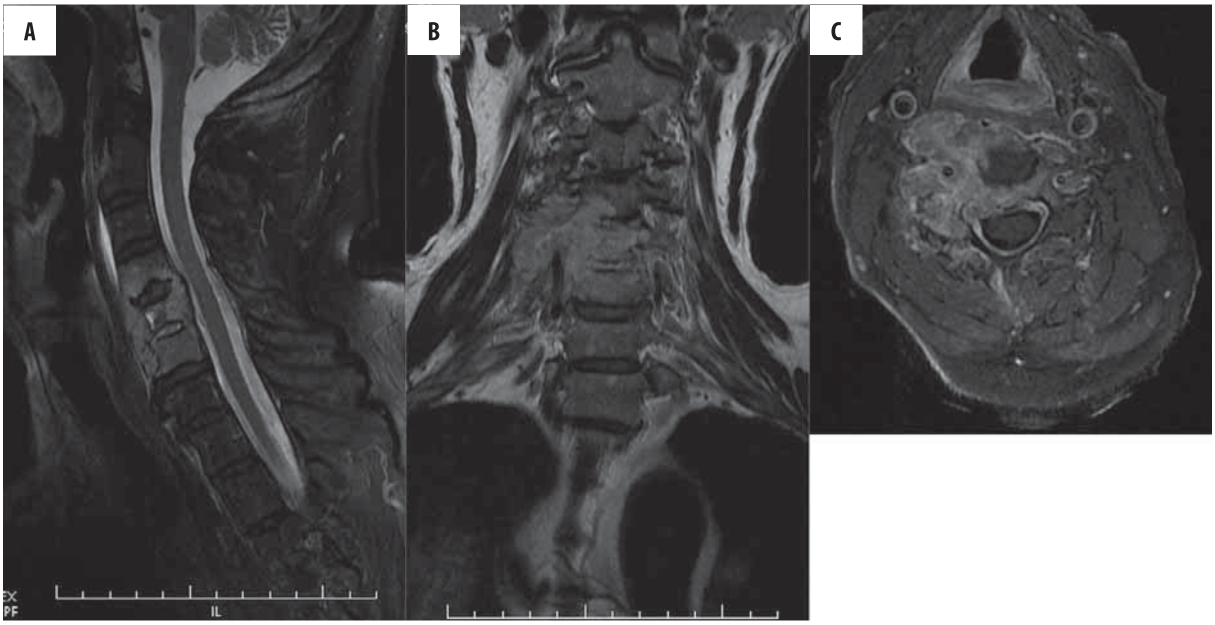

Figure 5. Diffuse neoplasmatic infiltration of the vertebral and paravertebral area. MRI: sagittal T2-weighted fat-suppression sagittal (**A**), coronal T1-weighed post-contrast (**B**) and axial T1-weighted fat-suppression post-contrast images very precisely demonstrate the extent of infiltration in the vertebrae, spinal canal, intravertebral foramina, and paravertebral soft tissue, including the brachial plexus area.

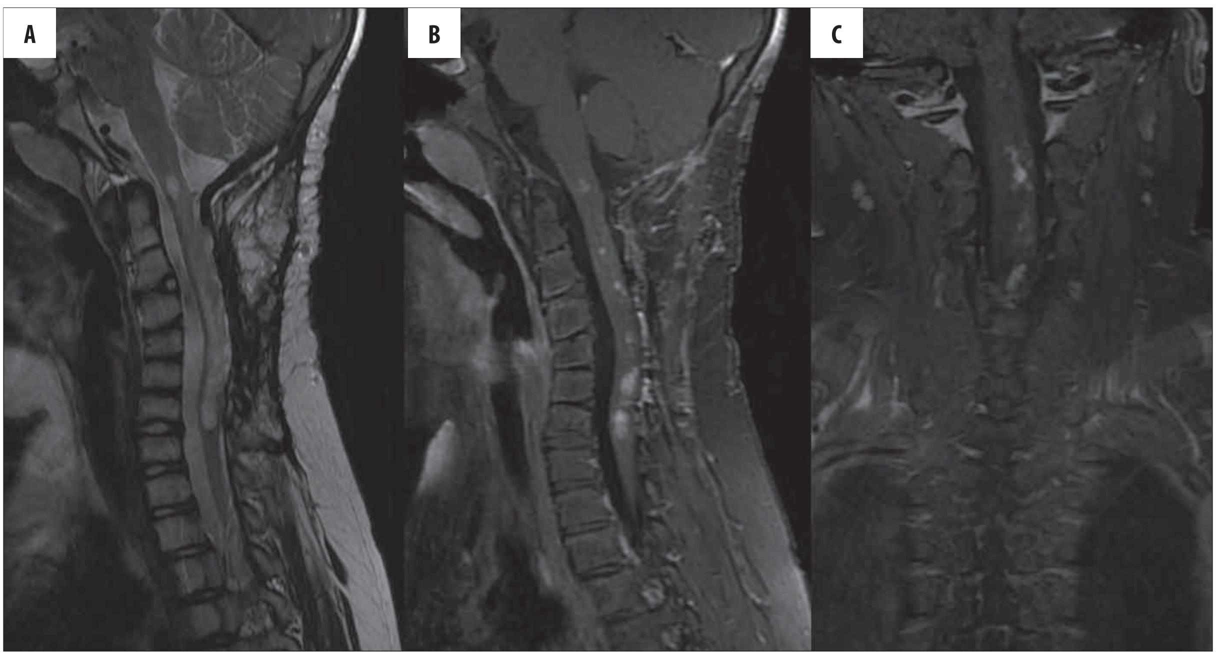

Figure 6. Large intramedullary tumor. MRI: sagittal T2-weighted fat-suppression (**A**), sagittal (**B**), and coronal (**C**) T1-weighted fat-suppression post-contrast images clearly visualize the extent of the tumor and contrast enhancement in the spinal cord.

assessment of the relationship between the lesion and vertebral and paravertebral structures [1].

Fat-suppression techniques are especially useful in evaluating extradural neoplasms (Figure 5), while steady-state sequences (CISS, FIESTA), which provide very good delineation of the spinal cord's outline, are of great value in assessing the relationship between intradural extramedullary tumor and the spinal cord. Due to the very good resolution of contemporary MR units, intramedullary tumors can be visualized precisely, especially in contrast-enhanced images (Figure 6). Moreover, diffusion tensor imaging (DTI) studies, including tractography, allow an assessment of the displacement or deterioration of spinal cord tracts by intramedullary tumors. The degree of damage to the spinal cord's white matter can be evaluated quantitatively using fraction anisotropy (FA) and mean diffusivity (MD) calculations [6] (Figure 7).

In traumatic changes, MRI provides excellent evaluation of injury to the spinal cord, both contusion/edema lesions and hemorrhagic foci. The former are well visible in high-resolution T2-weighted images, while the latter can be

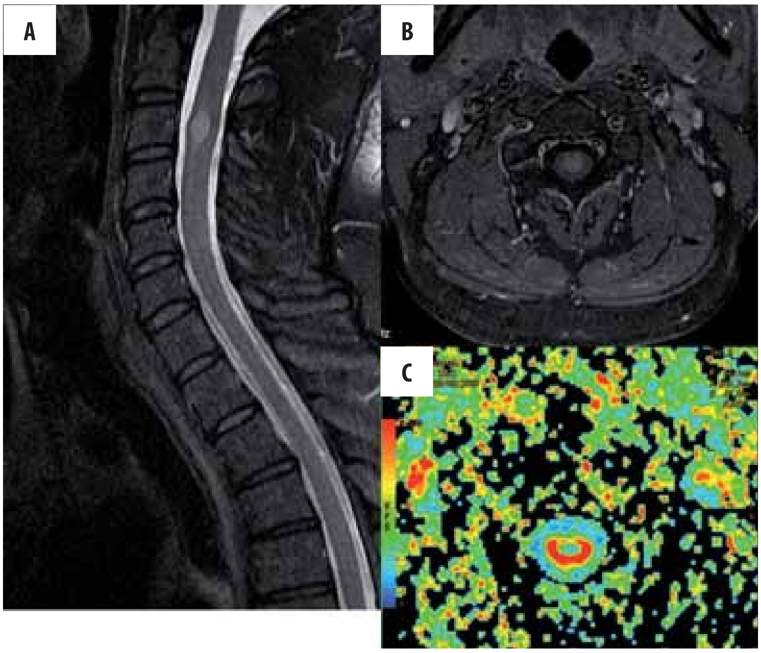

Figure 7. Small intramedullary tumor. MRI: sagittal T2-weighted (**A**), axial T1-weighed fat-suppression (**B**) and diffusion tensor axial (**C**) images. Plain sequences clearly show the tumor, while DTI provides visualization of the displacement of the spinal cord's white matter tracts.

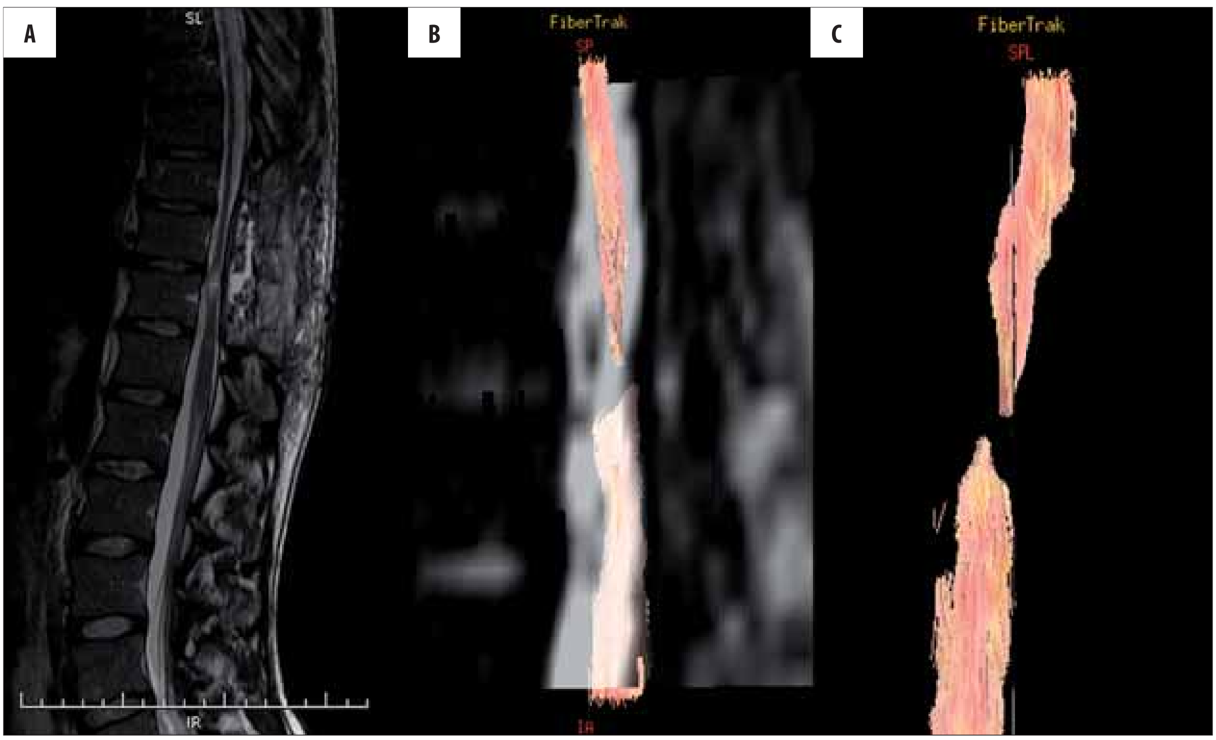

Figure 8. Traumatic injury of the spinal cord. MRI: sagittal T2-weighted image (**A**) shows thinning of the spinal cord and a hyperintense focus at the T12 level. Diffusion tensor images (**B, C**) reveal complete disruption of the white matter tracts at the level of the above lesion.

precisely detected on gradient-echo (GRE) or susceptibility-weighted (SWI) images. DTI shows in these cases damage to the spinal cord's tracts, which again can be evaluated quantitatively with FA and MD measurements [3,6,7] (Figure 8).

MRI also enables detailed visualization of avulsion injury of nerve roots emerging from the spinal cord. Their relationship to the spinal cord, dural sac, intravertebral foramen, and other structures, as well as the main finding, which is pseudomeningocele, could be easily visualized on heavily T2-weighted or MR myelography images [21]. In ambiguous cases, contrast enhancement allows for differentiation between pseudomeningocele and neuroma or other extramedullary tumors. On the other hand, high-resolution MRI can detect very subtle avulsion injuries without pseudomeningocele by the lack of visualization of the affected nerve root in the vicinity of the spinal cord (Figure 9).

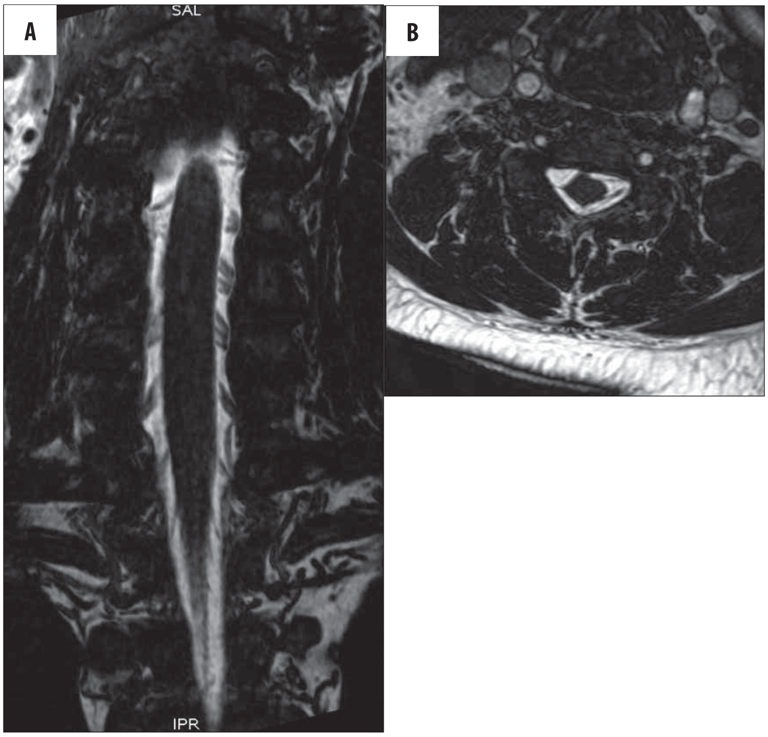

Figure 9. Traumatic avulsion injury of the right C6 spinal root. High-resolution sagittal (**A**) and axial (**B**) T2-weighted images reveal lack of the right C6 root (compare with the normal appearance on the left).

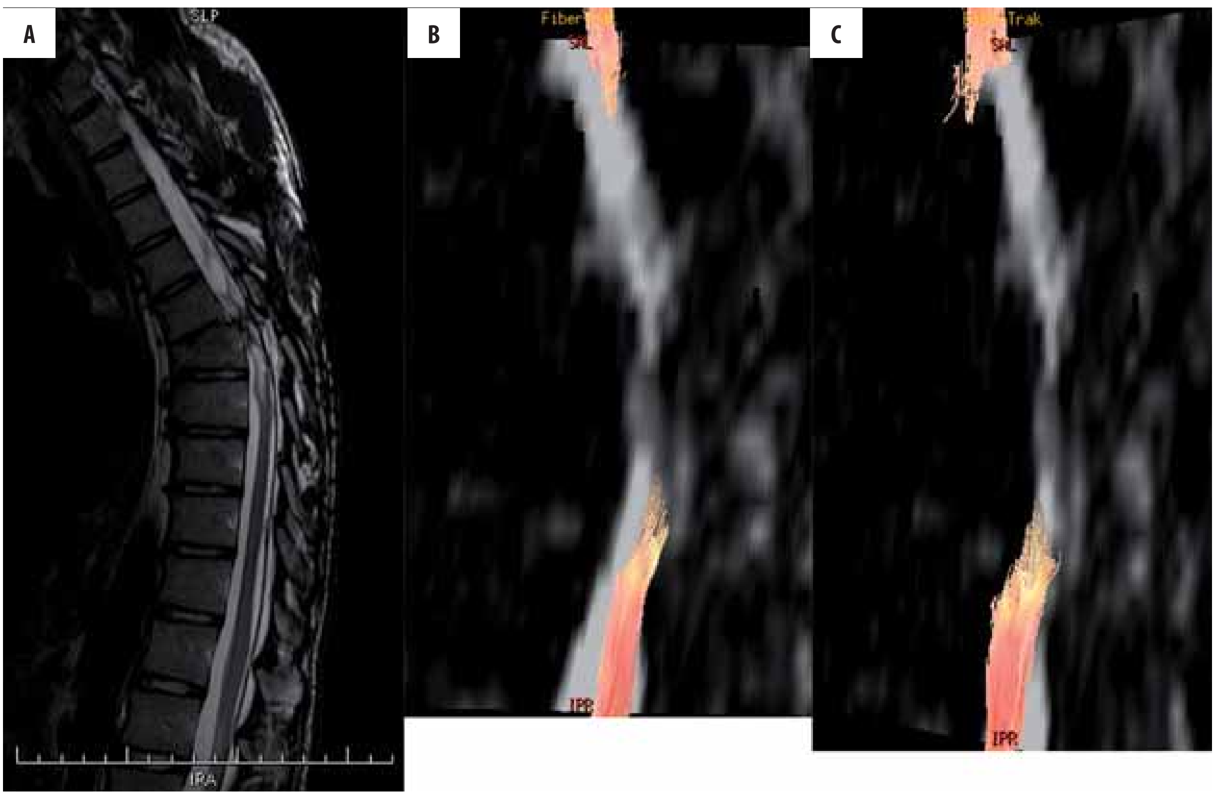

Figure 10. Severe traumatic injury of the spinal cord. MRI: the sagittal T2-weighted image (**A**) shows a large hyperintense area in the spinal cord, compatible with the damage. A diffusion tensor image (**B**) confirms complete long segment disruption of the white matter tracts. DTI after implementation of stem cells (**C**) reveals new white matter tracts in the upper part of the injury.

Recently, a method of treating severe spinal cord injuries with the implantation of stem cord cells has been developed. With the DTI technique it is possible to follow the results of this procedure [22]. In our institution we have performed DTI studies in a few patients treated with this method which revealed some recovered white matter fibers of the spinal cord (Figure 10).

It is hoped that the advances in MRI techniques will improve diagnostic efficiency in degenerative spine disease. Motion or axially loaded MRI using open or vertical MR units can show the real size of disk herniation or the degree of spinal stenosis [11,12]. In cases of degenerative myelopathy resulting from compression of the spinal cord by a herniated disc or osteophytes, DTI with measurements of FA and MD can detect an injury of the spinal cord which may be invisible in a plain MR study. There are also attempts to develop functional MRI (fMRI) and MR spectroscopy (MRS) studies of the cervical spinal cord; however, until now the results are not clear enough to allow introducing these methods to clinical protocols [8–10].

Vascular malformations of the spinal canal are usually well visible on plain MRI studies, especially with modern high-resolution sequences. However, contrast-enhanced MR angiography may provide good visualization of pathological vessels and thus help establish the levels which should be explored during conventional digital subtraction angiography [23]. On the other hand, the degree of spinal cord impairment due to the chronic edema which usually accompanies spinal arteriovenous fistula may be evaluated using a quantitative DTI study.

Conclusions

The introduction of multidetector CT units enables a detailed visualization of spine pathology, especially of the bony structures, and it is of great value in surgical treatment and follow-up. The new generation of MRI equipment allows the precise localization of spine lesions before surgical procedures. New MRI techniques, especially diffusion tensor imaging, open new possibilities for the precise diagnosis and follow-up of spine diseases.

References:

1. Sąsiadek M, Bem Z: Zastosowanie uzupełniających technik badania MR w diagnostyce chorób kręgosłupa lędźwiowo-krzyżowego. Rez Magn Med, 1997; 5: 53–56
2. Sąsiadek M: Mielografia rezonansu magnetycznego w schorzeniach kręgosłupa lędźwiowo-krzyżowego. Pol Przegl Radiol, 1996; 61: 391–93
3. Thurnher MM, Law M: Diffusion-weighted imaging, diffusion-tensor imaging, and fiber tractography of the spinal cord. Magn Reson Imaging Clin N Am, 2009; 17(2): 225–44
4. Voss HU, Watts R, Ulug AM et al: Fiber tracking in the cervical spine and inferior brain regions with reversed gradient diffusion tensor imaging. Magn Reson Imaging, 2006; 24(3): 231–39
5. Carballido-Garnio J, Xu D, Hewitt D et al: Single-shot fast spin-echo diffusion tensor imaging of the lumbar spine at 1,5 T and 3 T. Magn Reson Imaging, 2007; 25(5): 665–70
6. Vargas MI, Delavelle J, Jlassi H et al: Clinical application of diffusion tensor tractography of the spinal cord. Neuroradiology, 2008; 50(1): 25–29
7. Shanmuganathan K, Gullapalli K, Zhuo J et al: Diffusion tensor MR imaging in cervical spine trauma. AJNR Am J Neuroradiol, 2008; 29(4): 655–59
8. Stroman PW: Magnetic Resonance Imaging of Neuronal Function in the Spinal Cord: Spinal fMRI. Clinical Medicine & Research, 2005; 3(3): 146–56
9. Kendi AT, Tan FU, Kemi M et al: MR spectroscopy of cervical spinal cord in patients with multiple sclerosis. Neuroradiology, 2004; 46(9): 764–69
10. Holly LT, Freitag B, McArthur DL, Salamon N: Proton magnetic resonance spectroscopy to evaluate spinal cord axonal injury in cervical spondylotic myelopathy. J Neurosurg Spine, 2009; 10(3): 194–200
11. Kong MH, Hymanson HJ, Song KY et al: Kinetic magnetic resonance imaging analysis of abnormal segmental motion of the functional spine unit. J Neurosurg Spine, 2009; 10(4): 357–65
12. Li G, Wang S, Passias P et al: Segmental *in vivo* vertebral motion during functional human lumbar spine activities. Eur Spine J, 2009; Mar 20. [ahead of print]
13. Skrinkas T, Clemons M, Friedman O et al: Automated CT-based analysis to detect changes in the prevalence of lytic bone metastases from breast cancer. Clin Exp Metastasis, 2009; 26(2): 97–103
14. Krupski W, Majcher P, Fatyga M, Złomaniec J: Przestrzenne obrazowanie 3D TK kręgosłupa lędźwiowo-krzyżowego po operacyjnym leczeniu kręgozmyku L5-S1 spondylodezą tylno-boczną. Ortop Traumatol Rehabil, 2003; 5(2): 243–47
15. Nottmeier EW, Seemer W, Young PM: Placement of thoracolumbar pedicle screws using three-dimensional image guidance: experience in a large patient cohort. J Neurosurg Spine, 2009;10(1): 33–39
16. Piston MB, Herber S, Koch U et al: CT-guided vertebroplasty: analysis of technical results, extraosseous cement leakages, and complications in 500 procedures. Eur Radiol, 2008; 18(11): 2568–78
17. Lai PH, Weng MJ, Lee KW et al: Multidetector CT angiography in diagnosing type I and type IVA spinal vascular malformations. AJNR Am J Neuroradiol, 2006; 27(4): 813–17
18. Si-Ja G, Meng-Wei Z, Xi-Ping L et al: The clinical application studies of CT spinal angiography with 64-detector row spiral CT in diagnosing spinal vascular malformations. Eur J Radiol, 2008; May 20 [ahead of print]
19. Edelman CS, Leong H, Cashem TA et al: Advanced noninvasive imaging of spinal vascular malformations. Neurosurg Focus, 2009; 26(1): E9
20. Gjertsen O, Schellhorn T, Nakstad PH: Fluoroscopy-guided sacroplasty: special focus on preoperative planning from three-dimensional computed tomography. Acta Radiol, 2008; 49(9): 1042–48
21. Hendrich B, Sąsiadek M, Turek T et al: Porównanie wartości mielografii MR i mielografii rentgenowskiej w diagnostyce urazowych uszkodzeń splotu ramiennego. Pol J Radiol, 2003; 68(2): 23–29
22. Ellington BM, Schmit BD, Gourab K et al: Diffusion heterogeneity tensor MRI: mathematics and initial applications in spinal cord regeneration after trauma – biomed 2009. Biomed Sci Instrum, 2009; 45: 167–72
23. Mull M, Nijenhuis RJ, Backes WH et al: Value and limitations of contrast-enhanced MR angiography in spinal arteriovenous malformations and dural arteriovenous fistulas. AJNR Am J Neuroradiol, 2007; 28(7): 1249–58