EDITORIAL

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Imaging of Degenerative Spine Disease – the State of the Art

Obrazowanie w chorobie zwyrodnieniowej kręgosłupa – obecny stan wiedzy

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Abstract

The authors review the current state of imaging of degenerative spinal disease (DSD), which is one of the most common disorders in humans. The most important definitions as well as short descriptions of the etiopathology and clinical presentation of DSD are provided first, followed by an overview of conventional and advanced imaging methods that are used in DSD. The authors then discuss in detail the imaging patterns of particular types of degenerative changes. Finally, the current imaging algorithm in DSD is presented. The imaging method of choice is magnetic resonance, including advanced techniques – especially diffusion tensor imaging. Other imaging methods (plain radiography, computed tomography, vascular studies, scintigraphy, positron emission tomography, discography) play a supplementary role (**Adv Clin Exp Med 2012, 21, 2, 133–142**).

Key words: spine degeneration, intervertebral disc degeneration, magnetic resonance imaging.

Streszczenie

Autorzy przedstawiają obecne poglądy na temat obrazowania choroby zwyrodnieniowej kręgosłupa (ch.zw.kr.), która jest jedną z najczęstszych schorzeń u ludzi. W pierwszej części pracy omówiono najważniejsze definicje oraz opisano krótko etiopatogenezę i objawy kliniczne ch.zw.kr., po czym przedstawiono standardowe i zaawansowane metody diagnostyczne stosowane w ch.zw.kr. Następnie omówiono szczegółowo zmiany obrazowe w poszczególnych typach zmian zwyrodnieniowych kręgosłupa, wreszcie przedstawiono bieżący algorytm obrazowania w ch.zw.kr. Metodą obrazową z wyboru jest rezonans magnetyczny (MR), wraz z zaawansowanymi technikami, zwłaszcza obrazowaniem tensora dyfuzji (DTI). Inne metody obrazowe (radiografia konwencjonalna, tomografia komputerowa, badania naczyniowe, scyntygrafia, pozytronowa tomografia emisyjna, dyskografia) odgrywają rolę uzupełniającą (**Adv Clin Exp Med 2012, 21, 2, 133–142**).

Słowa kluczowe: zwyrodnienie kręgosłupa, zwyrodnienie krążka międzykręgowego, obrazowanie rezonansu magnetycznego.

Degenerative spinal disease (DSD) is one of the most common disorders, affecting adults at every age, which means it is an important medical and social problem. The results of treatment of DSD depend strongly on precise diagnostics. With the development and increased availability of magnetic resonance (MR), imaging methods have become the most important tool in diagnosing DSD and planning its treatment.

The aim of this review is to present the current possibilities of various imaging modalities in diagnosing DSD and optimal diagnostic imaging algorithms in different types of degenerative disease.

Definitions

Degenerative spinal disease (DSD) is also called spondylosis or spondylosis deformans. A primary feature is that it involves the whole disco-vertebral unit (functional spinal unit) (see below), usually at multiple levels.

A disco-vertebral unit (functional spinal unit) is the complex of anatomic structures comprising a single segment of the spine. It consists of the intervertebral disc, adjacent parts of the vertebral bodies, facet joints, ligamenta flava and longitudinal ligaments at a given level. All the components of an FSU may be affected by degenerative spinal disease to varying degrees.

Spondyloarthrosis is one type of DSD; it mainly affects the facet joints and causes facet degeneration.

Degenerative disc disease (or discopathy) is another type of DSD, mainly affecting intervertebral discs.

Disc herniation and disc bulging are types of degenerative disc disease characterized by part of the disc or the whole disc protruding beyond the intervertebral space. Disc herniation is one of the most common and severe types of DSD.

It is important to remember that DSD affects many structures of the spine and it is not always equivalent to disc herniation or degenerative disc disease [1, 2].

Etiopathology

As the authors have noted elsewhere [3], degenerative changes of the spine are a part of normal aging; they start in late adolescence and progress with age. They may or may not manifest themselves clinically. Many factors can accelerate the formation of degenerative changes, e.g. developmental anomalies or infectious diseases of the spine. However, the most important factor is trauma, both acute and chronic, including chronic overload [3–5].

Degenerative disease is most often located in the lumbar spine, followed by the cervical and thoracic spine. The lower parts of the lumbar spine (segments L4–S1) and cervical spine (segments C4–C7) are the most commonly involved [3].

The first stage of disease is usually degenerative dehydration of the nucleus pulposus of the intervertebral disc, combined with the fissures in the adjacent annulus fibrosus (annular tears) and endplate cartilage microfractures [1, 2, 6, 7]. Annular tears (concentric, transverse or radial) are present in almost all individuals over 40 years of age and could thus be considered paraphysiological; however, some (especially radial tears) may result in disc herniation. Other forms of disc degeneration are the vacuum phenomenon (gas collections, mostly nitrogen) and calcifications [3].

Injury of the endplate cartilage, on the other hand, causes an aseptic reaction of the subchondral bone, with an increase in water content (aseptic spondylodiscitis). The further stages of vertebral body degeneration are fatty transformation and endplate sclerosis, as well as edge osteophytes [1–3, 6, 8]. Degeneration of the endplates may result in their irregularities (erosive osteochondrosis) or in intravertebral disc herniations (Schmorl's nodes) [3].

Facet joint degeneration appears as hypertrophy and osteophytes of the articular processes, with narrowing of the joint space, less commonly as the vacuum phenomenon, synovial hypertrophy or synovial cysts. Facet degeneration along with disc degeneration can lead to degenerative spondylolisthesis (anterolisthesis, i.e. anterior displacement of the upper vertebra, or retrolisthesis, i.e. posterior displacement of the upper vertebra) due to vertebral instability [1, 2, 6]. The involvement of the ligamenta flava results in their hypertrophy [3]. Longitudinal ligaments may be compressed or broken by disc herniation; posterior longitudinal ligaments may also ossificate (ossification of the posterior longitudinal ligaments: OPPL) [3].

All the changes mentioned above can lead to spinal stenosis, either central (narrowing of the central part of the spinal canal) or lateral (narrowing of the lateral recesses of the spinal canal and intervertebral foramina). Spinal stenosis can be accompanied by compression of the spinal cord, leading to its ischemia, edema, myelomalacia or gliosis [3, 9].

Clinical Presentation

The most common clinical symptom is back pain of variable severity, constant or intermittent, located at the levels of the involved segments of the spine [6, 10, 11]. Asymmetric disc herniation, lateral spinal stenosis or osteophytes compressing the nerve roots cause radicular pain along the affected root [6]. The same conditions may cause neurological deficits, e.g. weakness in the upper or lower extremities. Central spinal stenosis in the lumbar region may lead to neurological claudication, and in the cervical or thoracic regions to myelopathy due to chronic compression of the spinal cord [3, 6, 9].

Degenerative Spinal Disease – Imaging Methods

The two most important and most commonly used imaging modalities are plain X-ray films of the spine and magnetic resonance (MR). Other methods are performed much less frequently and

are currently considered supplementary imaging techniques.

Conventional radiographs of the spine are still useful as an initial study, enabling detection of major abnormalities, e.g. narrowing of the disc space (which is compatible with discopathy), osteophytes, degenerative sclerotization, scoliosis, spondylolisthesis and other congenital spine anomalies. In mild cases of DSD radiography can suffice as the only imaging study [1, 2, 7].

MR is the imaging method of choice, and should be used in all patients with long-term pain, radicular symptoms or neurological deficits [12]. MR allows for a complex assessment of degenerative changes in all the structures of the disco-vertebral unit – both the bony and soft tissue structures (see below).

Other methods are also currently used. Computed tomography (CT) was the primary diagnostic modality in DSD in the 1990s, but since then it has mostly been replaced by MR. Nowadays CT is a supplementary method to MR, especially in degenerative bony spinal canal stenosis [13]. Conventional myelography and radiculography and CT-myelography, which require intrathecal administration of the contrast medium, have been almost completely abandoned. Discography and CT discography are invasive studies, which are performed only in specialized centers and are often followed by therapeutic procedures like nucleolysis or nucleoplasty. Nuclear medicine methods (bone scintigraphy, PET/CT) are used in cases that require differentiation of DSD from neoplastic lesions. Vascular studies (Doppler sonography, CT angiography, MR angiography) should be considered in patients with cerebellar symptoms, which may be caused by osteophytes or disc herniations compressing the vertebral arteries [3, 14, 15].

Advances in Imaging Techniques

In the last two decades the possibilities for imaging DSD have significantly improved thanks to technological developments. The image quality in conventional radiography has been markedly improved thanks to digitalization (digital radiography) and post-processing, [16, 17]. Since the introduction of multidetector scanners, as well as advanced muliplanar and three-dimensional reconstructions, computed tomography provides very precise images of the bony spine structures, which can be depicted with high resolution [18–21].

However, the most rapidly developing modality has been MR. Thanks to technological improvements in MR equipment (fast gradient systems, parallel imaging, multielement phased-array coils), basic MR techniques including spin-echo (T1- and T2-weighted images), gradient-echo and fat saturation sequences are now characterized by high resolution and increased signal-to-noise ratio. In addition, many supplementary techniques have been introduced, e.g. steady-state sequences (like CISS or FIESTA), which provide excellent delineation of the outlines of disc herniations; MR myelography, a non-invasive technique that has replaced conventional and CT myelographies; and post-contrast sequences, which are especially useful in post-operative studies [14, 22].

Recently there have been attempts to apply advanced supplementary techniques, such as diffusion-weighted imaging (DWI) and diffusion tensor imaging (DTI), functional (motion) imaging, MR spectroscopy [23, 24] and functional MR (fMRI). The most promising of these methods seems to be DTI, which enables qualitative and quantitative evaluation of degenerative myelopathy. Motion imaging provides functional evaluations of the spinal structures, but it requires vertical MR units, which currently are not available in most MR departments; therefore, the alternative technique of axial loaded imaging is more commonly used. MR spectroscopy and functional MR provide interesting scientific results in degenerative myelopathy, but due to technical difficulties arising mainly from the small size of the spinal cord, these techniques have not yet been introduced into clinical practice [25, 26].

Imaging Characteristics of Particular Types of Degenerative Changes

Degeneration of the Intervertebral Disc

Degeneration of the intervertebral disc can in many cases be diagnosed on the basis conventional radiographs revealing narrowing of the intervertebral space with sclerotization and osteophytes of adjacent parts of the vertebral bodies. However, simple degeneration cannot be differentiated from disc herniation or bulging on the base of these findings. The method of choice is MR, which detects direct signs of degeneration: a decreased signal on T2 and T2*-weighted images (black disc disease), resulting from degenerative dehydration of the disc (Fig. 1) [1, 2, 6].

Disc herniation is visible on axial MR images as a focal displacement of the disc fragment beyond the intervertebral space, while disc bulging is seen

Fig. 1. MR, T2-weighted image, sagittal plane. Decreased signals in the L4/L5 and L5/S1 intervertebral discs, consistent with the degenerative process. At the L4/L5 level herniation of the degenerative disc is also visible

Ryc. 1. MR, obraz T2-zależny, przekrój strzałkowy. Obniżony sygnał krążków międzykręgowych L4/L5 i L5/S1, wskazujący na proces zwyrodnieniowy. Na poziomie L4/L5 dodatkowo jest widoczna przepuklina zwyrodniałego krążka

Fig. 2. MR, T2-weighted image, axial plane. Disc bulging with high intensity zone (HIZ) in its posterior part, probably representing an annular tear

Ryc. 2. MR, obraz T2-zależny, przekrój osiowy. Uwypuklenie krążka międzykręgowego (*bulging*) z ogniskiem wysokiego sygnału (HIZ) w jego tylnej części, prawdopodobnie odpowiadającemu pęknięciu pierścienia włóknistego

as symmetrical displacement of more than 180° of the disc's circumference. Disc bulging is traditionally considered the first stage of disc herniation; however, many authors regard it as a separate entity, because most bulging discs are asymptomatic. In many bulging discs, foci of increased signal on T2-weighted MR images (high intensity zones – HIZ) are visible, which are compatible with annulus fibrosus tears (Fig. 2) [3]. Such discs are regarded as being more likely to develop disc herniation, but most HIZs are asymptomatic [6, 27].

Disc herniations are divided into three types (stages): protrusion (focal displacement of the nucleus pulposus into the annulus fibrosus without a complete tear of the latter), extrusion (focal displacement of the nucleus pulposus into the annulus fibrosus with complete tearing of the latter) and sequestration (displacement of a disc fragment with no continuity with the intervertebral disc). MR enables differentiation among the different types of disc herniation on the basis of their shape and relationship to the posterior longitudinal ligament. Moreover, it is possible to differentiate recent (active) disc herniations from old (non-active) ones,

because the former have a partially increased signal on T2-weighted images and T1-weighted post-contrast images, due to the inflammatory reaction, while old herniations are black, due to dehydration and fibrosis (Fig. 3). Finally, MR enables excellent visualization of the relationship between a herniated disc and the adjacent structures of the spinal canal and intervertebral foramina, especially compression of the nerve roots and spinal cord. In disc herniation all of the capabilities of MR mentioned here are very important for the prognosis and treatment planning [1, 2, 6–8, 28].

Disc bulging and disc herniation can also be diagnosed with CT, but without most of the details mentioned above. On the other hand CT is superior to MR in detecting specific signs of disc degeneration: the vacuum phenomenon (gas produced in the degenerative process) and disc calcifications. These changes are seen on CT as foci of very low and very high density, respectively (Fig. 4A), while on MR both vacuums and calcifications are visible only in some cases, as low-signal areas (Fig. 4B) [3].

Degeneration of the Vertebral Bodies

The most common degenerative changes of the vertebral bodies are Modic lesions (types 1, 2 and 3) and osteophytes. The latter can be diagnosed easily on the basis of plain X-rays, but CT and especially MR can assess their relationship to
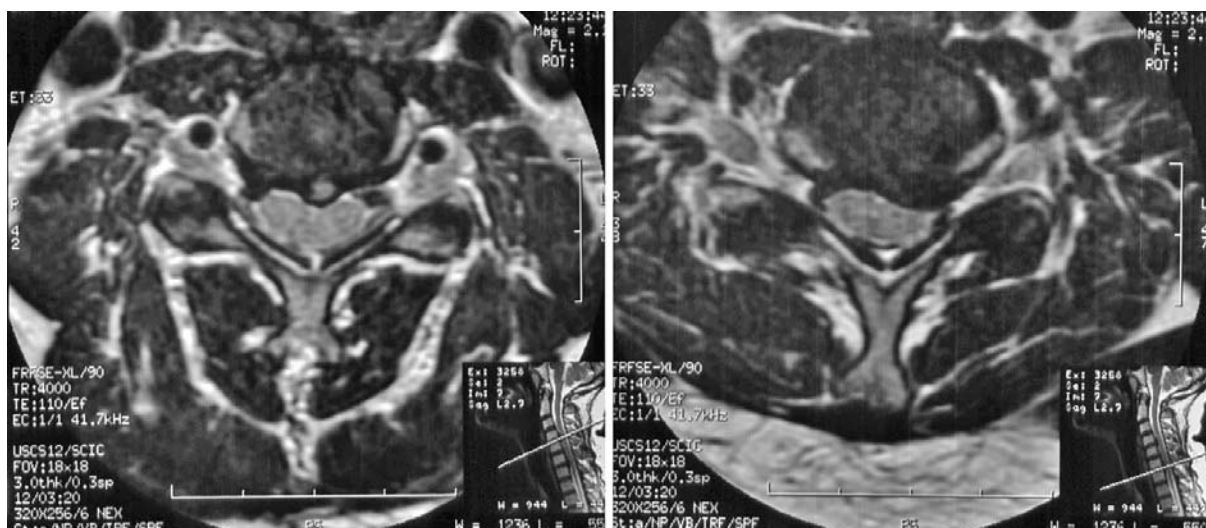
Fig. 3. MR, T2-weighted images, axial plane. Disc herniations in two different patients. Left image: recent (active) herniation with bright appearance; right image: old (inactive) herniation with dark appearance

Ryc. 3. MR, obraz T2-zależny, przekrój osiowy. Przepukliny krążków międzykręgowych u dwóch różnych pacjentów. Obraz po lewej: wczesna (aktywna) przepuklina o wysokim sygnale (jasna). Obraz po prawej: przewlekła (nieaktywna) przepuklina z niskim sygnałem (ciemna)

Fig. 4. Axial CT (A) and sagittal MR T1-weighted (B) images. Degenerative vacuum phenomenon visible as low-density (A) and low-signal (B) foci in the L4/L5 intervertebral disc

Ryc. 4. Osiowy obraz TK (A) i strzałkowy T1-zależny obraz MR (B). Zwyrodnieniowy objaw próżniowy widoczny jako ognisko niskiej gęstości (A) i niskiego sygnału (B) w krążku międzykręgowym L4/L5

the spinal canal, dural sac, intervertebral foramina, nerve roots and spinal cord [1, 2, 29].

Modic type 1 lesions (aseptic spondylodiscitis) can be diagnosed only with MR, which detects increased water content in the parts of vertebral bodies adjacent to the endplates (a decreased signal on T1-weighted images and an increased signal on T2-weighted and fat saturation images – Fig. 5). Modic type 1 lesions are believed to correlate with persistent pain and radicular symptoms, especially when located at the L5/S1 level. Modic type 2 lesions (fat-ty degeneration) can also be visualized only with MR, which reveals areas of increased signal on T1-weighted images and decreased signal on fat saturation images, which are compatible with increased fat content (Fig. 6). Modic type 3 lesions (sclerotic changes) can be seen on conventional radiography and CT as hyperdense areas and on MR as hypointense areas in all pulse sequences [29–32].

A special type of vertebral body degeneration is erosive osteochondrosis (endplate degeneration). It manifests as irregularities in the endplates'

Fig. 5. MR, sagittal plane, T2-weighted (upper row) and T1-weighted (lower row) images. There are hyperintense areas on the T2-weighted images and hypointense areas on the T1-weighted images in the L2 and L3 vertebral bodies, adjacent to the L2/L3 intervertebral disc, which are consistent with Modic type 1 degenerative changes

Ryc. 5. MR, przekrój strzałkowy, obrazy T2-zależne (górny rząd) i T1-zależne (dolny rząd). Widoczne są strefy hiperintensywne w obrazach T2-zależnych i hipointensywne w obrazach T1-zależnych w trzonach L2 i L3, przylegające do krążka międzykręgowego L2/L3, odpowiadające zmianom zwyrodnieniowym typu Modic 1

outlines and can be visualized on conventional radiography and CT; however, the best modality is once again MR. Erosive osteochondrosis, like Modic changes, is usually accompanied by degeneration of the adjacent intervertebral discs (Fig. 7) [2].

Degeneration of the Facet Joints

Degeneration of the facet joints is characterized by osteophytes and hypertrophy of the articular processes. Much less common signs are the vacuum phenomenon (gas in joint space) and facet joint synovial cysts. Facet degeneration and

Fig. 6. MR, sagittal plane, T1-weighted image. There are multiple hyperintense areas in the L2–L5 vertebral bodies, adjacent to interverebral discs, which are consistent with Modic type 2 degenerative changes

Ryc. 6. MR, przekrój strzałkowy, obraz T1-zależny. Widoczne są mnogie strefy hiperintensywne w trzonach L2–L5, przylegające do krążków międzykręgowych, odpowiadające zmianom zwyrodnieniowym typu Modic 2

its impact on the spinal canal (stenosis, compression of dural sac) can be easily assessed with both axial MR and CT images [2, 3]

Degeneration of the Ligamenta Flava

Degeneration of the ligamenta flava usually goes along with facet joint degeneration and can be assessed on axial MR and CT images as a thickening of the ligaments exceeding 4mm.

Degenerative Spondylolisthesis

Degenerative spondylolisthesis can easily be diagnosed on spine radiographs and CT, but MR provides the best evaluation of its impact on spinal canal structures.

Spinal Canal Stenosis

Degenerative changes of all the structures of the disco-vertebral unit may contribute to stenosis of the spinal canal, especially disc herniation or disc bulging, osteophytes of the posterior margins of the vertebral bodies, facet joint hypertrophy and osteophytes and/or thickening of the ligamenta flava (Fig. 8). There

Fig. 7. MR, sagittal plane, T2-weighted (left) and T1-weighted (right) images. There are irregularities of the vertebral endplates at the L2/L3 level, with a low signal in the adjacent intervertebral disc. This image is compatible with erosive osteochondrosis

Ryc. 7. MR, przekrój strzałkowy, obrazy T2-zależne (po lewej) i T1-zależne (po prawej). Widoczne są nieregularności płytek granicznych trzonów kręgowych na poziomie L1/L2, przy niskim sygnale przylegającego krążka międzykręgowego. Obraz ten odpowiada zmianom typu *osteochondrosis erosiva*

are two types of stenosis: central spinal stenosis, affecting the central part of the spinal canal, and lateral spinal canal stenosis, affecting the lateral recesses of the spinal canal and intervertebral foramina. Central canal stenosis is well visualized on both MR and CT axial images, while lateral stenosis is evaluated most reliably on parasagittal MR images. Stenosis is usually assessed visually on the basis of compression of the spinal canal structures. Another method is measurement of the canal, e.g. central spinal stenosis in lumbar region is diagnosed if the sagittal diameter of the canal is below 12 mm [1, 2, 6, 7, 33].

Changes in the Spinal Cord

Changes in the spinal cord in the course of the degenerative process result from chronic compression of the spinal cord by disc herniation or osteophytes. The only imaging method that can detect these changes is MR, which reveals foci of increased signals on T2-weighted images at the level of compression (Fig. 9). In many cases no changes are seen in the spinal cord despite clinical signs of myelopathy. Recently, diffusion tensor imaging has been found to be a valuable method in such cases, as decreases in the fractional anisotropy (FA) have been found at the compression level in normal-appearing spinal cords (Fig. 10) [25, 26].

An Imaging Algorithm in Degenerative Spinal Disease

In mild cases of degenerative spinal disease, manifesting as slight back pain, no imaging is necessary.

Fig. 8. MR, axial plane, T2-weighted image. Marked spinal stenosis with compression of the dural sac by a bulging disc, facet joint degenerative changes and thickened ligamenta flava

Ryc. 8. MR, przekrój osiowy, obraz T2-zależny. Znaczna stenoza kanału kręgowego z uciskiem worka oponowego przez uwypuklenie krążka międzykręgowego (*bulging*), zmiany zwyrodnieniowe stawów międzykręgowych oraz pogrubiałe więzadła żółte

In patients with persistent pain, plain X-rays should be performed to diagnose gross degenerative abnormalities (osteophytes, narrowing of the

Fig. 9. MR, sagittal plane, T2-weighted fat suppressed image. The spinal cord is compressed at the C4/C5 level by disc herniation anteriorly and thickened ligamentum flavum posteriorly. There is a hyperintense area within the spinal cord at this level, which is consistent with degenerative gliosis

Ryc. 9. MR, przekrój strzałkowy, obraz T2-zależny z supresją tłuszczu. Rdzeń kręgowy jest uciśnięty na poziomie C4/C5 przez przepuklinę krążka międzykręgowego od przodu i pogrubiałe więzadło żółte od tyłu. W obrębie rdzenia kręgowego na tym poziomie widoczne jest hiperintensywne ognisko, przemawiające za zwyrodnieniową gliozą
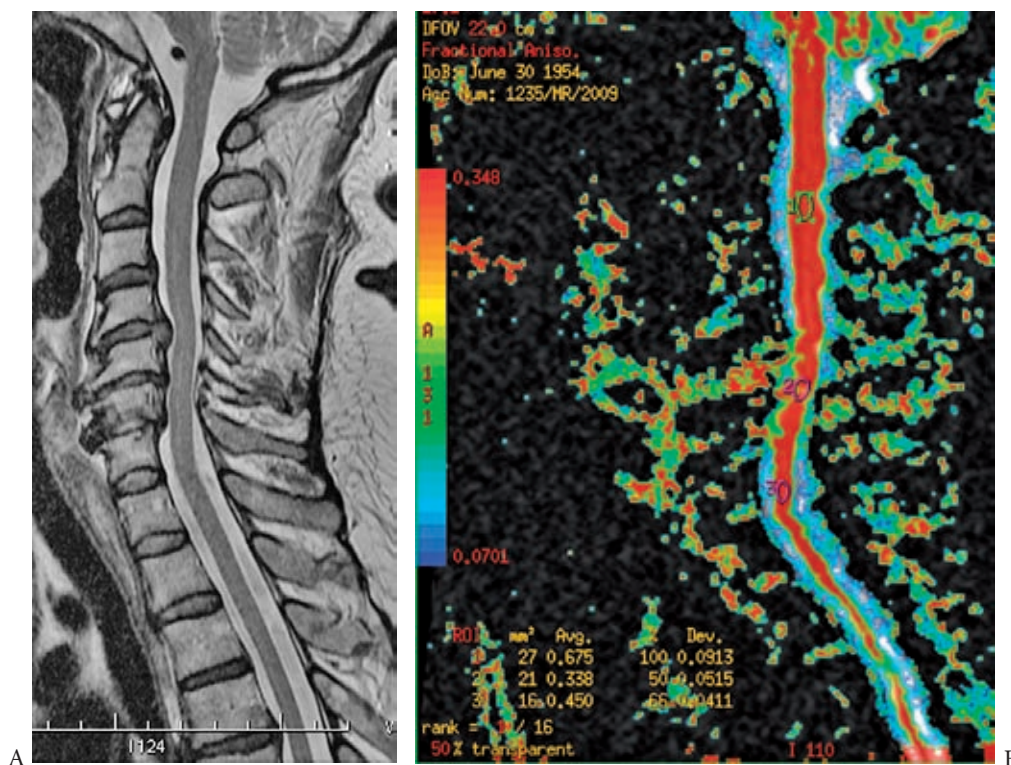

Fig. 10. MR, sagittal plane, T2-weighted image (left) and diffusion tensor imaging (DTI) (right). Spinal stenosis at the C4/C5, C5/C6 and C6/C7 levels with compression of the spinal cord. No abnormal signal is seen in the spinal cord at these levels. However, on the DTI there are multiple foci of decreased fractional anisotropy (FA) in the anterior part of the spinal cord, which are compatible with degenerative injuries of the spinal cord due to chronic compression

Ryc. 10. MR, przekrój strzałkowy, obraz T2-zależny (po lewej) i obrazowanie tensora dyfuzji (DTI) (po prawej). Stenoza kanału kręgowego na poziomach C4/C5, C5/C6 i C6/C7, z uciskiem rdzenia kręgowego. Nie wykazano nieprawidłowego sygnału rdzenia kręgowego na tych poziomach. W DTI są widoczne mnogie ogniska obniżonej frakcjonowanej anizotropii (FA) w przedniej części rdzenia, które wskazują na zwyrodnieniowe uszkodzenie rdzenia kręgowego spowodowane przewlekłym uciskiem

disc spaces, degenerative spondylolisthesis, etc.) and other findings (e.g. scoliosis, transitional vertebrae) as well to exclude large spine neoplasms.

Patients with severe persistent pain, radicular symptoms or neurological deficits should be examined with MR, which provides a complex assessment of the degenerative process in both soft tissue and bony elements. Plain MR with spin-echo, gradient-echo and fat saturation sequences is usually sufficient. In some cases, e.g. in postoperative patients, plain MR should be supplemented by contrast-enhanced sequences [34]. In patients with clinical signs of myelopathy, diffusion tensor imaging should be considered [25, 26].

CT is a supplementary method, used if detailed analysis of bone structures is needed, e.g. in spinal stenosis. CT should be also performed in patients with contraindications to MR.

If the differentiation between degenerative and neoplastic processes is not clear on the basis of MR and CT, nuclear medicine methods (bone scintigraphy and/or PET/CT) should be applied [2, 3].

In some patients with cerebellar symptoms, supplementary vascular studies of the vertebral arteries (Doppler sonography, CT angiography, MR angiography) should be considered [35].

Finally, some spine centers perform discography or CT discography to determine whether changes in a particular disc are responsible for a patient's symptoms and to establish access for interventional procedures such as nucleoplasty [2].

The authors concluded that imaging methods are the most important diagnostic modalities in degenerative spinal disease. The initial study is usually plain radiography, but the imaging method of choice is MR, which – thanks to technological developments – provides a more and more precise evaluation of degenerative changes. The role of other imaging modalities, such as CT, vascular studies, bone scintigraphy, PET/CT and discography, is supplementary. The imaging algorithm depends on the severity of the clinical symptoms and the results of previous imaging studies.

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