Główka P., Rubczak S., Gaweł D., Dudziński W., Nowak M., Kotwicki T. Magnetic resonance for degenerative intervertebral disc imaging – review of techniques. Issue Rehabil. Orthop. Neurophysiol. Sport Promot. 2017; 20: 52–59. DOI: 10.19271/IRONS-00042–2017–20

MAGNETIC RESONANCE FOR DEGENERATIVE INTERVERTEBRAL DISC IMAGING – REVIEW OF TECHNIQUES

Paweł Główka[1]
Szymon Rubczak[1]
Dominik Gaweł[2]
Witold Dudziński[3]
Michał Nowak[2]
Tomasz Kotwicki[1]
[1]Department of Spinal Disorders and Paediatric Orthopedics, Poznan University of Medical Sciences
[2]Department of Virtual Engineering, Poznan University of Technology
[3]Rehasport Clinic, Poznań

SUMMARY
Low back pain is a common medical problem. Over 40% of low back pain are discogenic. The standard examination to visualize intervertebral disc pathology is magnetic resonance imaging (MRI) due to lack of patient exposure to ionizing radiation. In this article, the following MRI options are described: dynamic MRI, MRI with contrast, MRI spectroscopy, MRI myelography, functional MRI. There are presented clinical impact of each way of diagnostic. New technique of 3D reconstruction is introduced.

Keywords: magnetic resonance imaging, intervertebral disc, degenerative intervertebral disc, 3D reconstruction of intervertebral disc

Date received: 5th May 2017
Date accepted: 7th July 2017

PRZEGLĄD TECHNIK WYKORZYSTUJĄCYCH MAGNETYCZNY REZONANS JĄDROWY W OBRAZOWANIU ZMIAN DEGENERACYJNYCH KRĄŻKA MIĘDZYKRĘGOWEGO

Paweł Główka[1]
Szymon Rubczak[1]
Dominik Gaweł[2]
Witold Dudziński[3]
Michał Nowak[2]
Tomasz Kotwicki[1]
[1]Klinika Chorób Kręgosłupa i Ortopedii Dziecięcej Uniwersytetu Medycznego w Poznaniu
[2]Katedra Inżynierii Wirtualnej Politechniki Poznańskiej
[3]Rehasport Clinic, Poznań

STRESZCZENIE
Bóle odcinka lędźwiowo-krzyżowego to powszechny i często spotykany problem medyczny. Ponad 40% z nich jest dyskopochodne. Badaniem z wyboru stosowanym do diagnostyki krążka miedzykręgowego jest rezonans magnetyczny. Jest on badaniem bezpiecznym, nieobciążającym z uwagi na brak promieniowania jonizującego. W tym artykule zostały opisane różne rodzaje badań rezonansu magnetycznego: dynamiczny MR, MR z kontrastem, spektroskopia MR, mielografia MR, funkcjonalny MR. Pokazana została przydatność kliniczna każdej metody. Przedstawione zostały również nowe techniki rekonstrukcji 3D na podstawie MR.

Słowa kluczowe: rezonans magnetyczny, krążek miedzykręgowy, dysk, rekonstrukcja 3D krążka międzykręgowego

Data otrzymania: 5 maja 2017
Data zaakceptowania: 7 lipca 2017

Introduction

Pathology of the intervertebral disc is one of the most frequent causes of low back pain. 40% of low back pain syndromes are discogenic (Finch 2006). 80% of general population has already suffered from lower back pain, or will suffer from it in the future (Schoenfeld *et al.* 2010; Yang *et al.* 2015), 5–10% will develop a chronic spine pain syndrome (Lawrence *et al.* 1998; Finch 2006).

Development of methods of medical imaging encourage clinicians to keep track of scientific reports. After entering "MRI intervertebral disc" phrase into the PubMed library, 5061 titles appear (1983–2016). After narrowing the results to the last 5 years, there are 1273 titles left. This number shows the intensiveness of works over imaging with nuclear magnetic resonance method.

Aim

Taking under consideration cause of discogenic pain syndromes and availability of magnetic resonance devices, clinicians will evaluate MRI scan reports more often. In order to better understand the method a review of imaging techniques with the use of MRI has been conducted.

Material and methods

State of knowledge

MRI is a non-invasive examination which uses the nuclear magnetic resonance technique in imaging of anatomic structures. Nucleus of the hydrogen atom – proton, is the resonance nucleus. Hydrogen is a constituent atom of water. Water comprises 73% of fat-free human body mass (Hewitt *et al.* 1993). MRI detects changes in the content of water in the body tissues (Finch 2006). It makes possible to illustrate intervertebral disc structures: annulus fibrosus and nucleus pulposus. It shows the size and direction of disc elements displacements, as well as the degree of degeneration (Kraemer 2013, Mok *et al.* 2016). The basis for evaluation of spine anatomic structures, including intervertebral disc, is constituted by T1 and T2 weighted sequences. Signal intensity of tissues in T1 and T2 weighted images is presented in table 1 (Greenspan 2011).

Table 1. Signal Intensity of tissues in T1 and T2 weighted images.

Tissue	Image – intensity of signal	
	T1-weighted	T2-weighted
Annulus fibrosus	Low	Low
Nucleus pulposus	Intermediate	High
Fat, yellow bone marrow	High	Intermediate
Acute hematoma, subacute	Intermediate to High	High
Chronic hematoma	Low	Low
Compact bone	Low	Low
Ligaments	Low	Low
Fibrous cartilage	Low	Low
muscles	Intermediate	Intermediate
Nerves	Intermediate	Intermediate
Hyaline cartilage	Intermediate	Intermediate
Red bone marrow	Low	Low to intermediate
Tumors (majority)	Low to intermediate	High
Lipoma	High	Intermediate
Angioma	Intermediate	High
Cicatricial tissue	Low	Low
Air	Low	Low
Fluid	Intermediate	High
Proteinaceous fluid	High	High

Results

Pfirrmann scale

Development of degenerative changes is accompanied by the progressive dehydration of intervertebral disc. Dehydration changes are most visible in T2-weighted images. In the T2-weighted image of magnetic resonance, Pfirrmann scale grades the advancement level of intervertebral disc degenerative changes in five degrees (Figure 1, Table 2) (Pfirmann *et al.* 2001; Stelzeneder *et al.* 2012)

I. The disc has homogeneous structure with bright, hyperintense white signal. Height of the disc is preserved;
II. The disc is non-homogeneous, but retains hyperintense white signal. The nucleus and annulus are easy to distinguish. Grey, horizontal strand can be visible. Height of the disc is preserved.
III. The disc is non-homogeneous, with insertions of grey intensity signal. The border between the nucleus and the annulus is less clear. Height of the disc is correct, or slightly reduced.
IV. The disc is non-homogeneous with hypointense signal of dark-grey intensity. It is impossible to distinguish the border between the nucleus and the annulus. Height of the disc is slightly or moderately reduced.
V. The disc is non-homogeneous, hypointense with black/dark intensity signal. It is impossible to distinguish the border between the nucleus and the annulus. The disc is collapsed.

Modic Classification

In order to evaluate bone changes, Modic classification can be used as well (Modic *et al.* 1998). Changes described by Modic correlate with the presence of low back pain (Pfirmann *et al.* 2001). This scale evaluates the occurrence of degenerative changes in vertebral bodies adjacent to intervertebral disc; their development is the result of degeneration of intervertebral disc (Kraemer 2013). Three types can be distinguished depending on changes of signal intensity found in T1 and T2 weighted images (Figure 2, Table 3):

Modic I: T1 – weak signal, T2 – intense signal; corresponds to swelling of bone marrow;

Modic II: T1 – intense signal, T2 – isointense signal or intense signal; corresponds to correct transformation of hematopoietic bone marrow into yellow bone marrow, as a result of bone marrow ischemia;

Modic III: T1 – weak signal, T2 – weak signal; corresponds to subchondral bone sclerosis.

Movement of nucleus pulposus is also evaluated in MRI. The following can be distinguished:

3. disc protrusion
I. in the area of annulus fibrosus,
II. reaching the outer layer of the annulus
4. disc herniation
III. closed, subligamental
IV. transligamentous hernia connected with the disc
V. sequestration – free fragments of the disc in the vertebral canal (Kraemer 2013).

Table 2. Morphology of intervertebral disc in T2 weighted images – Pfirrmann grading system.

	Structure of the disc	The border between the nucleus and the ring	Height of the disc
I	homogeneous with bright, hyperintense white signal	clear	preserved
II	non-homogeneous, but retains hyperintense white signal; grey, horizontal strip can be visible	the nucleus and rings are easy to distinguish	preserved
III	non-homogeneous, with insertions of grey intensity signal	less clear	correct, or slightly reduced
IV	non-homogeneous with hypointense signal of dark-grey intensity	it is impossible to distinguish the border between the nucleus and the ring	slightly or moderately reduced
V	non-homogeneous, hypointense with black/dark intensity signal	it is impossible to distinguish the border between the nucleus and the ring	the disc is collapsed

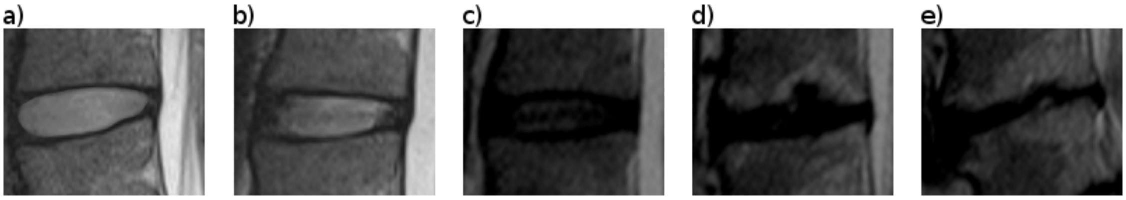

Figure 1. The figure shows the morphology of intervertebral disc in T2 weighted images in Pfirrmann grading system: a) I degree, b) II degree, c) III degree, d) IV degree, e) V degree.

Table 3. Signal intensity of bone marrow of perilaminal area in T1 and T2 weighted images of magnetic resonance found in Modic type changes.

	T1	T2
I	weak	intense
II	intense	isointense/intense
III	weak	weak

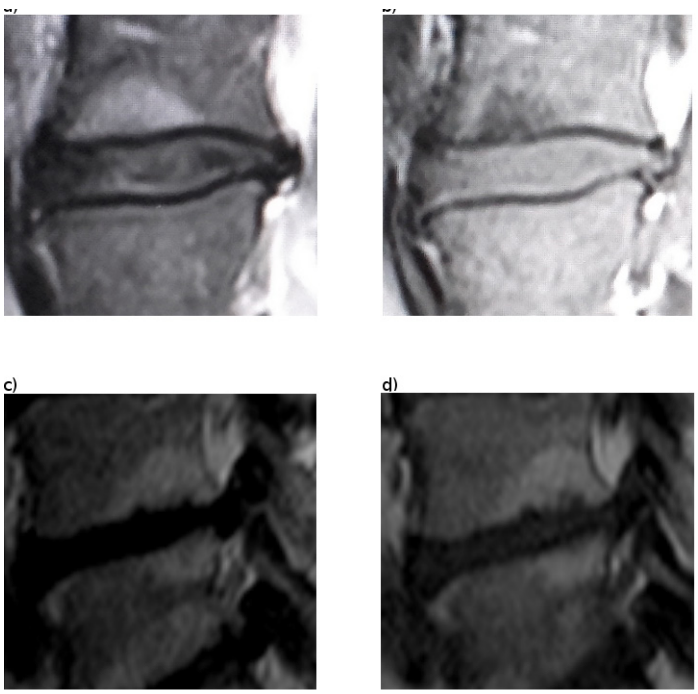

Figure 2. The figure shows degenerative changes in vertebral bodies adjacent to intervertebral disc; their development is the result of degeneration of intervertebral disc: a) T2 weighted image Modic I; b) T1 weighted image Modic I; c) T2 weighted image Modic II; d)T1 weighted image Modic II.

Aforementioned scales are based on single-dimensional cross-section of the disc and vertebral bodies.

Dynamic MRI

Standard protocol of spine imaging with MRI method has one flaw – supine position. Examination can be performed only when the person is laying on the back. Movement of intervertebral disc or nucleus pulposus occurring in the upright position can be absent in this position, which can be the cause of omitting herniation of the intervertebral disc (Zou *et al.* 2008). Dynamic MRI uses cameras, which make it possible to perform the test in sitting position. It can be used to image a “hidden” herniation of the intervertebral disc, absent in supine position; to perform measurements of intervertebral foramen or vertebral canal in the upright position with applied axial bearing, in flexion position or hyperextension (Haughton V. 2004). Performing the examination in the flexion position or hyperextension of lumbosacral spine makes it possible to evaluate the size of angular and translational displacement in the area of the motor unit of the spine (Hu *et al.* 2011) It also allows to evaluate the displacement of nucleus pulposus and the size of herniation of the intervertebral disc in relation to the spine position.

MRI with contrast

Intravenous application of contrast agent in order to increase the contrast of tissue is commonly used in imaging with TK and MRI methods. After the intravenous application of contrast, the image of correct intervertebral disc is not amplified significantly because the disc does not have vascularization (Haughton 2004). Contrast agent is slowly diffusing into the inside, increasing the intensity of its signal (Nguyen-minh *et al.* 1998). In the discs with low content of glycosaminoglycans, faster and more clear amplification of the image is observed after the application of contrast agent (Ibrahim *et al.* 1995). Amplification with contrast, shortly after application of contrast agent, can appear in the area of intervertebral discs with radiate ruptures (Haughton 2004). Vascularized granulation tissue penetrates the area of radiate ruptures (Finch 2006). Vessels start to appear together with nerve terminals, which can be the cause of the pain experienced by the patient. Amplification of intervertebral disc structures with contrast can be the symptom indicating intervertebral discs causing the pain. Radiate ruptures can be also visible in T2 weighted MRI images as the areas of high intensity near the annulus fibrosus, which in T2 weighted images is hipointense.

MRI spectroscopy

In medical diagnostics, the nucleus of the hydrogen atom is the nucleus of resonance. On the basis of MRI it is possible to evaluate the hydration of tissues. In MRI spectroscopy, the resonance answer of chemical compounds is used. It makes possible to determine their placement in tissues. The basic task in which spectroscopy can be utilized in diagnostics of discopathic changes is defining process of chemical compounds which concentration changes with the progression of degeneration changes. Together with the development of intervertebral discs degenerative changes, the change of concentration of lactic acid and proteoglycans has been found (Keshari *et al.* 2008). Content of lactic acid, glycine, alanine, choline, glutamic acid, n-acetyl group has undergone the spectroscopic evaluation. Utilization of in-vivo spectroscopy reduces the low correlation between the signal of the aforementioned chemical compounds and noises (low signal-to-noise ratio).

MRI myelography

MRI allows tridimensional imaging of blood vessels and dural sac. In MRI angiography and myelography, in order to visualization blood vessels or dural sac, the technique utilizing the phase displacement of protons in motion is used. Proper choice of measuring sequence and times of relaxation allows amplification of the signal coming from the flowing blood, at the same time the signal intensity of motionless tissues is dampened. In this way a tridimensional image of blood vessels or dural sac is produced.

Functional magnetic resonance (*fMRI*)

fMRI allows to test the functional organization of central nervous system. It is utilized to map brain areas in patients planned for neurosurgeries. This potential can be used in patients with spine problems (Haughton 2004). fMRI demonstrates the activity of spinal cord neurons, as a response to the specific activity of nervous system: motor, sensor, or nociceptive (Stroman *et al.* 2002; Wilmink *et al.* 2003).

Works is underway over the utilization of fMRI for ways of conduction in spinal cord. In one work a changing activity of the signal in patient performing isometric exercises has been discovered. Activation has been distributed through the spinal cord, concentrating in anatomic localization corresponding to the motor innervation (Madi *et al.* 2001). fMRI makes it possible to evaluate the neuron activity as a response to touch (Stroman *et al.* 2002; Wilmink *et al.* 2003).

3D model of intervertebral disc
As a part of the VIRDIAMED project, the Department of Spinal Disorders and Paediatric Orthopedics of Poznan University of Medical Sciences, together with the Department of Virtual Engineering Poznan University of Technology, developed a method of obtaining tridimensional geometric models of intervertebral discs and adjacent vertebral bodies (Figure 3). It is a new method which has not been described yet. Tridimensional geometric model has the information about size and shape of the intervertebral disc. Additionally, nucleus pulposus, which is a part of intervertebral disc, has been imaged. Thanks to that, it is possible to evaluate correlation between annulus fibrosus and nucleus pulposus; evaluation of size, volume, and displacement of nucleus pulposus in the area of intervertebral disc and beyond its borders. Preliminary results are optimistic, on this level it is manually work to segment disc from MR imaging. Now works is underway on increase automation of segmentation process.

Conclusions
Imaging with the utilization of MRI method is one of the best developing methods in the last years. Its advantage is the lack of exposure of the patient to the ionizing radiation during the examination and the possibility of obtaining the images of soft tissues. Popularization of non-invasive methods of imaging such magnetic resonance imaging and the variety of it techniques decreased the number of invasive diagnostic tests such as: discography, myelography, epidurography (Haughton 2004).

Authors see better chances of imaging in three dimensional reconstruction of intervertebral disc. Techniques utilizing tridimensional imaging of anatomic structures based on the MRI data are particularly appealing. Their development may help to better understand the pathology of intervertebral disc.

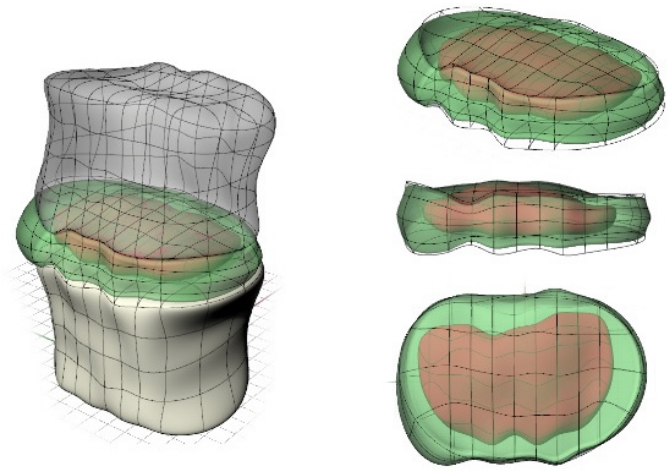

Figure 3. Figure presents tridimensional geometric model of intervertebral disc (green color) with bodies of adjacent vertebraes (grey color). It was obtained from T2 weighted cross-sections and side views of the spine. Marked with red is the nucleus pulposus of intervertebral disc.

REFERENCES

Finch, P. (2006) *'Technology Insight: Imaging of low back pain.'* Nature Clinical Practice Rheumatology, 2 (10), pp. 554–561.

Greenspan, A. *„Diagnostyka obrazowa w ortopedii dla lekarza praktyka."* 2nd Ed. Warszawa: MediPage; 2011, str. 35–43.

Haughton, V. (2004) *'Medical Imaging of Intervertebral Disc Degeneration.'* Spine, 29 (23), pp. 2751–2756.

Hewitt, Mi., Going, SB., Williams, DP., Lohman, TG. (1993) *'Hydration of the fat free body mass in children and adults: Implications for body composition assessment.'* Am J Physio. 265 (1), pp. 88–95.

Hu, JK., Morishita, Y., Montgomery, SR., Hymanson, H., Taghavi, CE., Do, D., Wang, JC. (2011) *'Kinematic Evaluation of Association between Disc Bulge Migration, Lumbar Segmental Mobility, and Disc Degeneration in The Lumbar Spine Using Positional Magnetic Resonance Imaging.'* Global Spine J. 1 (1), pp. 43–48.

Ibrahim, MA., Haughton, VM., Hyde, JS. (1995) *'Effect of disc maturation on diffusion of low-molecular-weight gadolinium complexes: an experimental study in rabbits.'* Am J Neuroradiol 16 (6), pp. 1307–1311.

Keshari, KR., Lotz, JC., Link, TM. Hu, S., Majumdar, S., Kurhanewicz, J. (2008) *'Lactic acid and proteoglycans as metabolic markers for discogenic back pain.'* Spine, 33 (3), pp. 312–317.

Kraemer, J. „*Choroby krążka międzykręgowego***."** 1st Ed. Wrocław: Elsevier Urban&Partner; 2013, str. 158–178.

Lawrence, RC., Helmick, CG., Arnett, FC., Deyo, RA., Felson, DT., Giannini, EH., Heyse, SP., Hirsch, R., Hochberg, MC., Hunder, GG., Liang, MH., Pillemer, SR., Steen, VD., Wolfe, F. (1998) *'Estimates of the prevalence of arthritis and selected musculoskeletal disorders in the United States.'* Arthritis Rheum, 41 (5), pp. 778–799.

Madi, S., Flanders, AE., Vinitski, S., Herbison, GJ., Nissanov, J. (2001) *'Functional MR imaging of the human cervical spinal cord.'* Am J Neuroradiol, 22 (9), pp.1768–74.

Modic, MT., Steinberg, PM., Ross, JS., Masaryk, TJ., Carter, JR. (1998) *'Degenerative disk disease: assessment of changes in vertebral body marrow with MR imaging.'* Radiology, 166 (1), pp. 195–199.

Mok, F., Samartzis, D., Karppinen, J., Fong, D., Luk, K., Cheung, K. (2016) *'Modic changes of the lumbar spine: prevalence, risk factors, and association with disc degeneration and low back pain in a large-scale population-based cohort.'* Spine, 16(1), pp. 32–41.

Nguyen-minh, C., Haughton, VM., Papke, RA., An, H., Censky, SC. (1998) *'Measuring diffusion of solutes into intervertebral disks with MR imaging and paramagnetic contrast medium.'* Am J Neuroradiol., 19 (9), pp. 1781–1784.

Pfirrmann, CW., Metzdorf, A., Zanetti, M., Hodler, J., Boos, N. (2001) *'Magnetic resonance classification of lumbar intervertebral disc degeneration.'* Spine, 26 (17), pp. 1873–1878.

Schoenfeld, AJ., Weiner, BK. (2010) *'Treatment of lumbar disc herniation: Evidence-based practice.'* International Journal of General Medicine, 21 (3), pp. 209–214.

Stelzeneder, D., Welsch, GH., Kovács, BK., Goed, S., Paternostro-Sluga, T., Vlychou, M., Friedrich, K., Mamisch, TC., Trattnig, S. (2012) *'Quantitative T2 evaluation at 3.0 T compared to morphological grading of the lumbar intervertebral disc: A standardized evaluation approach in patients with low back pain.'* European Journal of Radiology, 81 (2), pp. 324–330.

Stroman, PW., Krause, V., Malisza, KL., Frankenstein, UN., Tomanek, B. (2002)**.** *'Functional magnetic resonance imaging of the human cervical spinal cord with stimulation of different sensory dermatomes.'* Magn Reson Imaging., 20

(1), pp. 1–6.
Wilmink, JT., Backes, WH., Mess, WH. (2003) *'Functional MRI of the spinal cord: will it solve the puzzle of pain?'* JBR-BTR., 86 (5), pp. 293–294.
Yang, H., Liu, H., Li, Z., Zhang, K., Wang, J., Wang, H., Zheng, Z. (2015) *'Low back pain associated with lumbar disc herniation: role of moderately degenerative disc and annulus fibrous tears.'* Int J Clin Exp Med., 8(2) pp. 1634–44.
Zou, J., Yang, H., Miyazaki, M., Wei, F., Hong, SW., Yoon, SH., Morishita, Y., Wang, JC. (2008) *'Missed lumbar disc herniations diagnosed with kinetic magnetic resonance imaging.'* Spine, 33 (5), pp. 140–144.

This article was written during the work in research grant Virdiamed funded by National Centre for Research and Development. PBS3/B9/34/2015

Praca została zrealizowana w ramach projektu Virdiamed finansowanego przez Narodowe Centrum Badań i Rozwoju. PBS3/B9/34/2015

Authors declared no conflict of interests.
Author responsible for correspondence:
Szymon Rubczak
Os. Przyjaźni 7/164
61-684 Poznań, Poland
tel. 790313405
szymon.rubczak@wp.pl

Autorzy nie deklarowali konfliktu interesów.
Autor odpowiedzialny za korespondencję:
Szymon Rubczak
Os. Przyjaźni 7/164
61-684 Poznań, Poland
tel. 790313405
szymon.rubczak@wp.pl