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Axial-loaded Magnetic Resonance Imaging in the Diagnosis of Static Disorders of the Lumbar Spine

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Introduction The diagnosis of spinal statics disorders requires a study conducted both with and without axial load. Standard multislice computed tomography (MSCT) and magnetic resonance imaging (MRI) are limited to the examination of the patient in the supine position. Axial loading techniques have expanded the indications for the use of high-tech methods of radiological diagnosis in assessing the statics of the lumbar spine. **Methods** 124 patients underwent conventional radiographic examination of the lumbar spine in the frontal and lateral projections in a standing position and an MRI study before and during axial load. Radiography with functional tests was used for cases with displaced vertebras. The Pearson correlation coefficient was used to compare the data; the significance of the methods was evaluated using calculations of diagnostic performance indicators. **Results** An increase of the angle of lordosis was noted in tests with axial load (r = 0.93). Indicators of scoliotic deformity obtained with MRI with axial load corresponded to X-ray data (r = 0.89). The diagnostic efficiency of MRI with a dosed axial load was the following: Se = 91.7 %, Sp = 89.2 %, Ac = 90.6 %; the results of MRI in the upright position were slightly lower: Se = 89.2 %, Sp = 73.9 %, Ac = 83.3%. Spondylolisthesis was found in 11 patients. The instability data obtained by comparing MR studies before and during the axial load with radiography with functional tests revealed their almost complete correspondence (r = 0.88). **Discussion** Axial-loaded MRI can provide additional information on statics, which is necessary to assess the nature of pathological changes. MR techniques based on low-field tomographic systems are limited in the diagnosis of extended deformations. MRI with axial load is a method of choice, especially when dynamic monitoring is necessary, due to the absence of ionizing radiation. Axial loading of the spine in MSCT study seems promising.

Keywords: magnetic resonance imaging, static disorders, axial loading techniques

INTRODUCTION

Spinal deformities, both acquired and congenital in nature, present a complex problem from the point of view of diagnosis. When planning treatment, various modalities are required to assess the extent, stage and nature of the disorders in the mutual arrangement of functional elements of the spine, its motor segments. This information is useful for treatment planning and, if necessary, for assessing the possibilities of surgical correction. The most objective data may be obtained using radiological diagnostic methods [1].

Traditionally, the method of choice in defining the character of static disorders was radiography and all its possible techniques, including functional ones, that is, studies in a standing position and the tests of bending, extension, and inclinations [2]. The disadvantages of this method, or rather its physical features, are projection distortions and a summary effect. In a number of cases, they hinder a reliable assessment of the changes and may lead to significant measurement errors.

Current diagnostic techniques that use the principles of classical radiography have clearly expanded the possibilities to study the spine. They enable to obtain a three-dimensional image of the skeleton, which is constructed in the form of a computer model based on reference points calculated from biplanar radiographs [3, 4].

The most detailed and reliable images of the spine structures are obtained with MSCT and MRI. However, these methods are limited in assessing the skeleton structures under functional load, which is due to the design features of the equipment [5, 6, 7, 8, 9, 10].

One of the ways to solve this problem was the development of low-floor MRI scanners with the possibility of patient´s verticalization during the study, as well as the emergence in clinical practice of specialized platforms that simulate the upright position of a lying person [11, 12, 13].

MATERIAL AND METHODS

To study the possibilities of functional MRI techniques, 124 patients with chronic pain in the lumbar spine were examined. The age of patients ranged from 20 to 55 years (56 % females, 44 % males).

Before the MRI studies under axial load, the patients underwent clinical and instrumental examination, which consisted of an examination by a clinical specialist (neurologist, neurosurgeon,

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orthopaedist), standard radiography of the lumbar spine in frontal and lateral projections. If displaced vertebras were detected during the examination, radiography with functional tests was performed (maximum flexion and extension).

The study in an upright position (n = 60, 48.4 %) was carried out on a low-floor (0.25 T) open-type MRI scanner G-Scan Brio (Esaote, Italy) (Fig. 1 a). The methodology included 2 steps. First, the patient was examined in a horizontal position according to the standard protocol. Next, verticalization was performed to obtain T2-weighted images (WI) in 3 planes. To obtain the most objective data on the position of the MS structures, an angle > 84º with respect to the horizontal line was obtained. This angle enabled to transfer the weight of the body to the spine and at the same time maintain minimal support, which is necessary to retain immobility.

To simulate an upright position (n = 64; 51.6 %), a DynaWell L-Spine apparatus with the possibility of dosed axial load (DynaWell Int. AB, Sweden), compatible with MRI and CT systems, was used. This unit consisted of two elements: a hard base and soft vests, which are interconnected by belts located on the side surfaces. The vests had various sizes and were chosen in accordance with the physical features of the subjects, since their tight fit enables to optimally distribute the load on the body, thereby reducing unpleasant sensations. Scales are built into the rigid base of the dosed axial load apparatus (separately for each lower limb), which allow obtaining information about the load exerted and assessing its symmetry). MRI study was conducted on a high-field (1.5 T) MRI-scanner VANTAGE Atlas (Toshiba, Japan) (Fig. 1 b).

The research methodology included two stages. Initially, the patient was examined without load and images were obtained according to the standard protocol. Then, during exposure to a dosed axial load, T2-WI was obtained in the frontal, sagittal and axial planes. According to the manufacturer's recommendations and the results of numerous works, the dosed axial load should be 40–50 % of the patient's body weight for adequate imitation of the vertical position. Moreover, the exposure of the load to obtain images with reliable geometric characteristics should be at least 5 minutes [7, 14, 15, 16].

According to the findings, the axis of the spine (its deviation in the sagittal and frontal planes) was evaluated according to the Cobb – Lippmann method (1974); the relative position of the vertebral bodies in accordance with the modified Lambl – Meyerding classification (1932). The criterion for listhesis stability was 3 mm. So, the displacement of the vertebrae during the functional load of more than 3 mm was considered unstablity. Radiography in the direct and lateral projections was chosen as the reference method in assessing the statics of the spine; in listhesis, using functional tests in the positions of maximum flexion and extension [16].

To compare the data obtained with radiography and functional MRI, the Pearson correlation coefficient and diagnostic efficiency indicators (sensitivity, specificity and accuracy) were calculated.

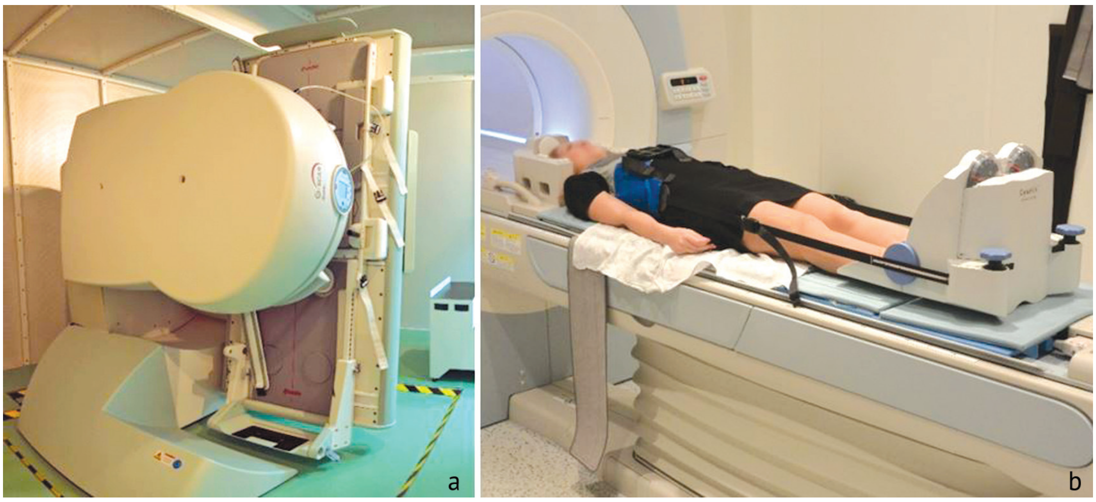

Fig. 1 MRI system with the possibility of verticalization (*a*); position of a patient during the study with a dosed axial load (*b*)

RESULTS

The physiological reaction of the spine to axial load is an increase in the angle of the cervical and lumbar lordosis and thoracic kyphosis. This reaction was expectedly observed in most patients (n = 109; 87.9 %) with functional MRI studies of the lumbar spine both in an upright position and in its imitation. Due to degenerative changes, the nature of the response of the lumbar spine to the functional load could be abnormal.

In 8.9 % of cases (n = 11), there was a decrease in lumbar lordosis, including its flattening and even pathological kyphosis in 3.2 % (n = 4) (Fig. 2 a–c). The changes correlated with the radiography findings in those patients in an upright position (r = 0.93).

In evaluating vertebral displacements, the capabilities of MRI techniques with axial load were compared with the standard radiography of the lumbar spine in functional tests (maximum flexion and extension). Listhesis was detected in 19 patients (15.3 %). One patient (0.8 %) had a stair-like listhesis at the level of two vertebral bodies; it was seen only under functional load.

Stable listhesis or displacement with signs of hypermobility were determined in 57.9 % of cases (n = 11). When X-ray data were compared with functional tests, the findings corresponded to each other in 90 % (n = 9), r = 0.88. The discrepancy was revealed in one case (0.8 %), when the MRI displacement was within 2.5 mm (hypermobility) and reached 3 mm in the radiographic view (unstable listhesis).

The number of unstable displacements by comparing X-ray and functional MRI techniques findings corresponded to each other in all cases (n = 9) (Fig. 3 a–d). At the same time, the magnitude of the displacement of the vertebrae in functional radiographs was more significant in six out of 9 cases.

MRI with axial load has the advantage in evaluating spinal statics due to high soft tissue contrast. It is possible, in contrast to radiography, to evaluate not only the presence of deformation, but also the features of the relative position of the vertebral bodies and neural structures of the spinal canal.

However, in a number of cases (n = 10, 8.0 %), the absence of a summary effect, on the contrary, made image interpretation difficult due to complexity in assessing the degree of torsion of vertebral bodies and the need to take into account the magnitude of lordosis. The latter required additional processing of images to obtain multiplanar reconstructions for a more reliable assessment of the axial deformity of the spine.

Scoliotic deformity of more than 5º was detected in 59.7 % (n = 74) cases. The data obtained with radiography taken in an upright position were comparable with the results of functional MRI techniques, r = 0.89 (Table 1).

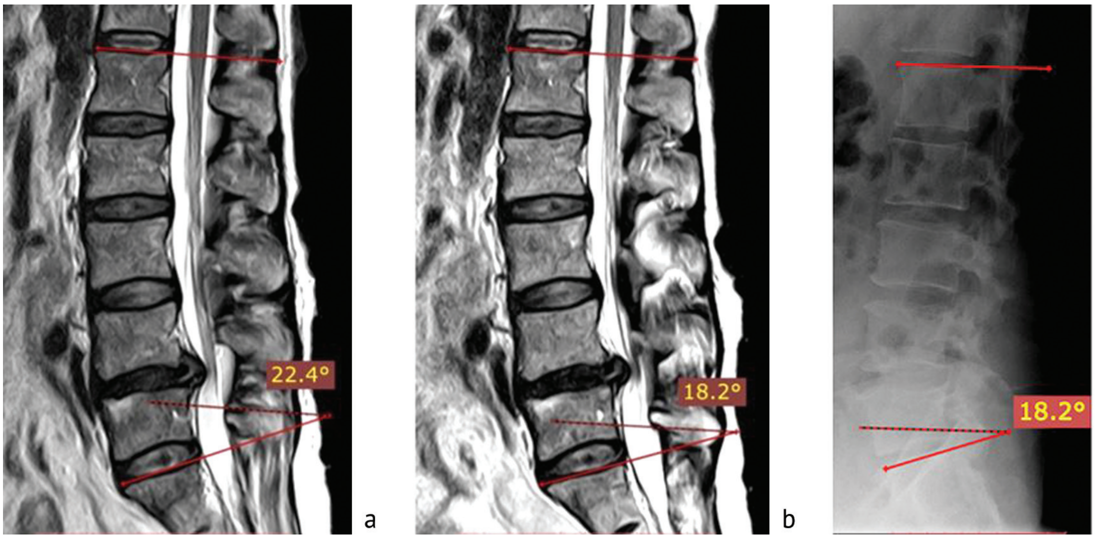

Fig. 2 MRI scans (T2-WI) of the lumbar spine in the sagittal plane: *a* – in the supine position, *b* – in dosed axial load; *c* – lateral radiograph of the lumbar spine . The magnitude of lordosis detected by MRI with functional load and radiography is comparable

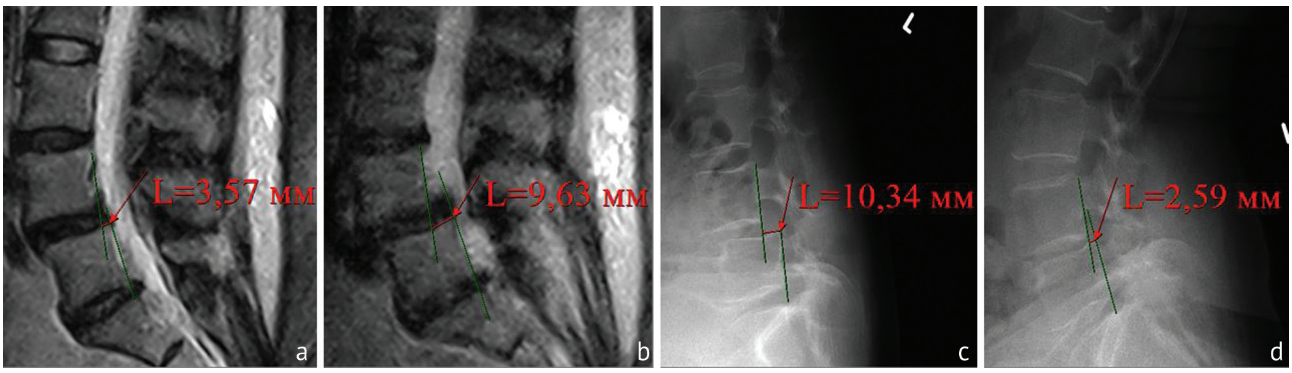

Fig. 3 MRI scans (T2-WI) of the lumbar spine in the sagittal plane: *a* – supine position; *b* – upright position. Radiographs of the lumbar spine in the lateral projection: *c* – flexion; *d* – extension position. The magnitude of the displacement of the vertebrae in functional load test, obtained by X-ray and MRI, is comparable

Table 1

Magnitude of the angle of scoliotic deformity in standard X-rays performed in an upright position and in MRI scans with a functional load

Method	Angle of scoliosis, degrees	Level of significance
Standard radiography	6.1 ± 1.5	p < 0.001
Functional MRI	6.5 ± 1.8	p < 0.001

Difficulties in the assessment and significant discrepancies in the obtained data arose by comparing the pronounced deformations of the spine (n = 6, 4.8 %) which were accompanied by significant torsion of the vertebral bodies and laterolisthesis (Fig. 4 a, b).

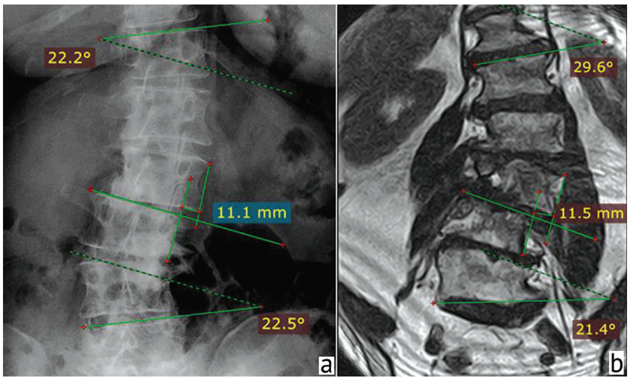

Fig. 4 X-ray of the lumbar spine in the direct projection (a); MRI scan (T2-WI) of the lumbar spine in the frontal plane (b) in an upright position. There is a difference in the values of the angles of scoliotic deformity

To compare the diagnostic effectiveness of functional MRI techniques with standard radiography in assessing spinal statics, specificity (Sp), sensitivity (Se), and accuracy (Ac) were calculated (Fig. 5).

A separate problem with both functional techniques in this study was the appearance or intensification of pain (n = 37). This problem led to dynamic artifacts (n = 15), which minimized the diagnostic significance of the images. Moreover, in simulating an upright position, the patient could independently reduce the load by bending the lower extremities to relieve pain. This fact required proper instructions before the start of the test, as well as careful monitoring of load sensors by the medical staff during the test.

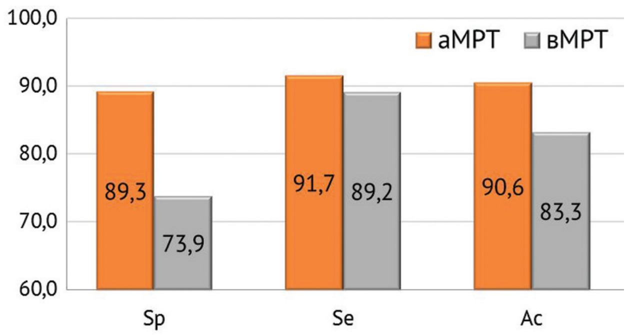

Fig. 5 Indicators of diagnostic effectiveness of MRI with axial load (aMRI) and in an upright position (вMRI) in assessing scoliotic deformity of the lumbar spine (%, relative to standard radiography)

Load correction to reduce pain was a need in 17 patients. Thus, by examining the upright position, it was possible to reduce the angle of verticalization and thereby reduce the axial load. When simulating an upright position, the problem was more complicated. It was difficult to decrease the tension of the belts in a measured manner due to the design features. However, a decrease in the load in most cases still led to a significant decrease in the severity of pain with the possibility of continuing the test.

DISCUSSION

The problem of assessing statics in spinal deformities remains relevant in view of the emergence of new methods for their correction and the need for a more accurate and detailed evaluation of geometric characteristics. The importance of using tomographic techniques is undeniable in preoperative diagnosis, as it allows more accurate planning of an intervention [17].

Well-known limitations of radiography are pronounced summation and projection effects, which decrease the diagnostic effectiveness of the data obtained. The use of new radiological techniques also does not completely solve all the problems.

The way out of this situation is the introduction of radiation diagnostics techniques into the arsenal of spinal deformity research that do not feature significant summation and projection distortion effects; at the moment they are MSCT and MRI. When used in conjunction with functional load, they allow not only a more accurately assessment of the geometry of bone and soft tissue structures but also provide information about their position under functional load.

In our work, the possibilities of MRI technologies using axial load were demonstrated. These methods have proved to be quite effective in determining all the characteristics of the statics of the spine, including pronounced ones, with significant curvature angles and vertebral displacements due to degenerative changes.

At the same time, discrepancies were noted in the assessment of vertebral displacements with classical radiography and functional MRI techniques with a significant correlation of the obtained indices. In functional MRI studies, the reaction of the displaced vertebrae was expected: with stable displacements, it was absent, with unstable one it progressed. These characteristic changes were also noted in a number of other works [14, 18, 19, 20, 21]. It is not possible to judge upon the diagnostic effectiveness of the data obtained due to the limited sample of patients with this pathology.

Despite the efficiency and physiology of the axial-load MRI techniques, there were discrepancies in determining the stability of listheses. It was partly due to the features of functional radiological techniques. In the latter case, when assessing stability, radiography is used with functional tests in flexion and extension of the body trunk, i.e. at maximum load on the spinal motor segments. In performing functional MR techniques, we are limited to comparing the examination before and during exercise. Radiography is a projection method, and, therefore, the obtained indicators have distortion tendency to upward.

Another important diagnostic problem is scoliotic spinal deformity. To determine its angle, X-ray is still used in direct projection in a standing position. MRI with functional tests of axial loading may provide similar information. The method is not associated with radiation exposure, which is especially important in young patients who need dynamic observation. According to P. Wessberg et al. [22] and P. Knott et al. [23], the error in measuring the scoliosis angle according to the Cobb–Lippmann method (1974) in classical radiography and functional MRI is comparable to the error in repeated expert evaluation of radiographs of one patient by another specialist. The same is confirmed in our work, where the calculated diagnostic efficiency indicators approach the reference method

However, the assessment of complex spinal deformities accompanied by pronounced torsion of the vertebral bodies might be difficult according to flat MRI images. In part, this problem may be solved by using multi-planar reconstructions.

MRI in vertical position was less effective. It was associated with equipment design features. The MRI scanner has a small area of a uniform magnetic field, which led to distortions of the normal geometry along the margins of the image and the impossibility of estimating the true curvature. In an axial load MRI, the only limitation was pronounced rotation of the vertebrae and increased lordosis, which could not be eliminated by multi-planar reconstructions [16].

The use of MRI in assessing scoliotic deformity may be advantageous due to reduced exposure to radiation for patients due to exclusion from the algorithm of a standard X-ray examination, which is especially important for dynamic control in children. It is possible to obtain only T2-WI in the frontal plane, which will significantly reduce the time of re-examination.

Imitation of an upright position using dosed axial load devices for MSCT seems promising. This method has a higher spatial resolution, and is also practically not limited by the length of the scanning zone. Moreover, having initially obtained images with an isotropic voxel with MSCT, we are able to perform three-dimensional and multiplanar reconstruction, which is very important in assessing complex and pronounced spinal deformities.

CONCLUSIONS

Axial load MRI techniques have comparable diagnostic efficiency for assessment of spinal deformities and vertebral displacements. The techniques have several advantages: high soft tissue contrast, absence of summation effects and exposure to radiation. All this allows us to recommend MRI techniques with axial load to clarify the nature of static disorders and spinal deformities when dynamic monitoring is necessary, especially in children and treatment planning.

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