Magnetic resonance imaging (MRI) of the lumbar spine with dedicated machine G-Scan in the upright position: a retrospective study and our experience in 10 years

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Authors: V. Di Tunno, G. Grattacaso, M. Perri, C. Marsecano, G. Michelini, A. Gennarelli, A. Splendiani, C. Masciocchi, M. Gallucci; L'Aquila/IT
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Aims and objectives

Low back pain with or without sciatica is one of the most common medical problems in the Western World [1-2-3]. It is an extremely frequent disease that most people suddenly experience in their lives; estimates of the 1-year incidence of a first-ever episode of low back pain range between 1.5% and 36% [4]. The imaging techniques using traditional magnetic resonance imaging (MRI) have the major limitation of studying the spine in a position of relative functional rest, as images are acquired with the patient in the supine position while the pain exacerbates in the upright position as well as the insability of the lumbar spine. False negatives in MRI of the spine performed in the supine position are often due to patient position, with knees and hips bent and spinal variation with increasing breadth of the foramen and vertebral canal. Pathological conditions underlying clinical symptoms, often prompted by standing or sitting, are therefore not seen[5-6]. Magnetic resonance imaging (MRI) enables the visualization of all structures that could be causing pain, but in patients with pain originating from nerve root compromise, disc herniations, or protrusions, might be invisible on traditionally positioned supine images[7]. An approach to evaluate the spine under the loading condition was the axial load technique, which simulates the physiological loading of the spine. Although results were certainly interesting, this technique did not allow evaluation of the influence that weight of the head, body and by muscle activation have on the lumbar spine, simulating a load with caudate-cranial direction [8-9-10]. The technological advancement of open MRI-scanner as G-scan(ESAOTE) characterized by 0.25T permanent magnetic field, greater gradient homogeneity, and faster sequences resulted in a significant improvement in SNR(Signal-to-noise-ratio), spatial and contrast resolution and therefore image quality. This equipment is characterized by being open, also it has the advantage of eliminating the patient's feeling of claustrophobia, which sometimes limits diagnostic evaluation of the spine [11-12-13]. The purpose of this study is to evaluate the MRI-GScan diagnostic performance in evaluating the instability of the spine taking into account the variations of some pathological conditions from recumbent to upright position.
Methods and materials

Patients

Between June 2004 and May 2014, 4305 patients aged between 21 and 80 years (including 1875 males and 2430 females, mean age 45 years), previous informed consent, were selected for retrospective double-blind reviewing approved by the Medical Ethical Committee of our institution. These patients underwent MRI examinations of the lumbosacral column in our institute of Radiology first in upright position and then in the supine position. All patients had an history of low back pain with or without sciatica. Were excluded from our study all patients presenting with a history of trauma, malformations, infectious-inflammatory diseases, spinal cord injury, primary and secondary tumors of the spine. Patients undergoing MRI exams G-scan, after selective retrospecting, were divided into 3 age groups (Tab.1): (Group A) of 1200 patients (27.8% of the total) aged 21 to 40 years (615 males and 585 females); second group (group B) of 2055 patients (47.7% of the total) aged between 41 and 60 years (780 males and 1275 females); third group (group C) of 1050 patients (24.5%) aged between 61 and 80 years (465 males and 585 females).

MR Protocol

The MRI exams were performed using open MRI scanner G-scan (ESAOTE, Genova, Italy) characterized by 0.25T permanent magnetic field. This MRI scanner allows the acquisition of images of the lumbosacral spine in both the supine and upright (standing position) carried out using a system gantry / patient rotated approximately 82°. This grade of rotation has been chosen to allow to carry out evaluations to gravitational load almost complete (90°), without creating a feeling of instability in the patient and moreover without repositioning the patient[14]. For the acquisition of the images have used dedicated surface coils of various sizes for the lumbar spine, in relation to the morphotype of the patient. In our study we performed the examinations first under physiological load and then, with the same sequences, in the supine position; this MRI protocol was performed in order to minimize the discomfort of the patients and to avoid possible hypotensive crisis that may arise when the patient moves from the supine to orthostatic resulting in motion artifacts[15]. The standing and supine position MRI protocol provided the use of sagittal FSE T2-weighted sequences (TR / TE 2860/90 ms; 4 mm), sagittal SE T1-weighted (TR / TE 560/26 ms; 4mm) and axial 3D HYCE (TR / TE 4420/130 ms; 3.4mm). For sagittal sequences was used a matrix of 224 x 208, a field of view (FOV) of 320 x 320 mm and a slice thickness of 4 mm with an interval of 0.5 mm. For axial 3D HYCE sequence was used a matrix of 224 X 192, a field of view (FOV) of 300 x 300 mm and a slice thickness of 4 mm with an interval of 0.5 mm. The acquisition time was about 20 minutes for each position + 5min for the preparation / positioning. The images were sent via local network to the RIS / PACS (Polaris, Kodak Carestream PACS) of the Institute for the possibility
of a direct comparison between images obtained in supine and standing positions on workstations with dual monitors.

**Image Analysis**

Two neuroradiologists, respectively 25 and 6 years experience, blinded to the history and clinical objectivity of the subjects, independently reviewed lumbar MR images separately for supine and standing position. A consensus readout was performed after all the data were collected. For this study, six MRI parameters including lumbar disc pathologies, discovertebral alterations (DVA), facet joint osteoarthritis (FJO), ligament flavum hypertrophy (LFH), lumbar segmental translational movements and postural abnormalities of the lumbar spine were used. According to the recommendations of the combined task forces of the North American Spine Society, the American Society of Spine Radiology and the ASNR[16], on FSE-T2, SE-T1-weighted images and axial 3D HYCE, the type of herniated disk was classified as presence or absence of protrusions and / or herniated discs, evaluated on both the sagittal and axial plane. The discovertebral alterations (DVA) was classified into one of five grades using Pfirrmann's criteria[17]; Grade I indicated the presence of a homogeneously hyperintense nucleus pulposus that is clearly distinct from the hypointense outer annular fibers. In grade II degeneration, the nucleus pulposus is inhomogeneous, and horizontal hypointense bands might be present in a sandwichlike configuration. In grade III degeneration, the inner parts of the disk are inhomogeneous and had intermediate signal intensity. In grade IV degeneration, the distinction between the inner and outer parts of the disk is lost, and the inner parts of the disk had intermediate or low signal intensity. In grade V degeneration, the disc was collapsed. Facet joint osteoarthritis (FJO) was classified into 4 grades according to Fujiwara et al.’s method[18]. Grade I corresponded to normal facet joints; grade II, III, IV, to mild, moderate, severe facet joints degeneration, respectively. The spinal canal stenosis was assessed based on the presence or absence of ligament flavum hypertrophy (LFH). The presence or absence of lumbar segmental instability was evaluated according to a cut-off translational movement (greater than 3 mm)[19]. Postural abnormalities of the lumbar spine were evaluated by assessing the increase in the Cobb angle with a cut-off of 6.3° from sitting to standing position[20]. Therefore the pathological changes highlighted in the MR exams from the supine to upper position were divided into 3 groups; diseases of the disc (accentuation of hernias and protrusions, appearance of new hernias or protrusions); diseases of the lumbar segmental instability (listhesis); Postural abnormalities of the lumbar spine (reduction or accentuation of the lumbar lordosis).
### Table 1. Demographic data.

<table>
<thead>
<tr>
<th>Age Groups</th>
<th>Age</th>
<th>Total patients(%)</th>
<th>Men</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>21-40</td>
<td>1200(27.8%)</td>
<td>615</td>
<td>585</td>
</tr>
<tr>
<td>B</td>
<td>41-60</td>
<td>2055(47.7%)</td>
<td>780</td>
<td>1275</td>
</tr>
<tr>
<td>C</td>
<td>61-80</td>
<td>1050(24.5%)</td>
<td>465</td>
<td>585</td>
</tr>
</tbody>
</table>

Note. In parentheses there are percentage values.

Table 1

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Results

After a consensus readout of image analysis, the total number of patients was divided into two groups: those with orthostatic test "negative" with MR images unchanged in the two positions (sitting and standing), and "positive" with MR images changed in the upright position. Having identified the "positive", we have analyzed the individual findings. The MRI examination in the standing position has documented changes in the lumbosacral spine in 1435 patients out of 4305 (33.3%), of which 608 were males and 827 females. Positive were a number of 421 patients aged between 21 and 40 years (Age Group A 29.3% of which 231 males and 190 females); 563 patients aged between 41 and 60 years (Age Group B 39.2% of which 203 males and 360 females) and 451 patients between 61 and 80 years (Age Group C 31.5% of which 174 males and 277 females)(Tab. 2).

Comparing supine and standing positions we founded modifications inherent biomechanics (mobility of the spine, lordosis modifications), and modifications so-called "pathological" both in terms of onset of disease, both in terms of modifications of vertebral pathologies already present in the supine position.

Pathological changes were:

- Diseases of the disc (744) as accentuation of hernias and protrusions, appearance of new hernias or protrusions), divided into unifocal (177) if the changes were for a single discal level and multifocal (567) if there were involved more levels;

- Diseases of the vertebrae (556) such as listhesis, modifications of spinal mobility and redistribution of fluid of the facet joints);

- Functional spinal unit disorders (135), an association between diseases of vertebrae, intervertebral disc, facet joints, ligaments and segmental muscles.

In particular we found discal pathologies in 744 patients (51.8%); purely vertebral pathologies in 556 patients (38.8%); vertebral-disc disease in 135 patients (9.4%). Of the total of the tested patients these diseases account for 17.2%, 12.9% and 3.2% = 33.3%.

Dividing the 744 patients by age, we have got: in group I (between 21 and 40 years) there were 193 patients (25.9%); in group II (between 41 and 60 years) there were 418 patients (56.2%), in group III (between 61 and 80 years) there were 133 patients (17.9%). Group I, 49% were male and 51% female; Group II 43.5% males and 67.5% females; Group III 62% males and 38% females.

We further divided the patients with disc disease in two groups: the first group was involved a single disc layer (unifocal) and the second group with more disc layered together (multifocal).
Patients with disc disease unifocal were 177 (including 73 pcs. Of between 21 and 40 years; 91 pcs. Between 41 and 60 years and 13 pcs. Between 61 and 80 years).

Patients with multifocal disc disease were 567 (of which 132 pcs. Between 21 and 40; 327 pcs. Between 41 and 60 years; 108 pcs. Between 61 and 80 years).

In 556 patients there were found vertebral pathologies typically, equal to 38.8% of total positive transition between supine and standing positions. We observed the appearance or modification of listhesis in 230 patients (onset of listhesis in 56 pcs., Modification of listhesis in 174 patients). In 223 patients we noticed changes in the mobility of the lumbar spine (in particular there has been an increase in the curvature of scoliosis in 9 pcs.; stiffness of the lumbar spine in 19 pcs; hypomobility of the lumbar spine in 81 pcs; hyperlordosis in 56 pcs and reduction lordosis in 58 pcs) (Fig.).

The third group of patients with spinal pathologies had 103 patients, who are the ones in which we noted a redistribution of facet joint fluid (3 pcs in L1-L2, L2-L3 in 3 pcs, 6 pcs in L3-L4; 49 pcs in L4-L5, L5-S1 in 36 pcs) and in 6 cases has formed a pseudo synovial cyst. (Fig.).

We found 133-vertebral disc disease (9.7%). Among these diseases were part of the unit that is functional spinal disorders of vertebrae, intervertebral disc, facet joints and capsules, ligaments and muscles segmental (Fig.).
Table 2. Positive Patients after MRI examination in the standing position.

<table>
<thead>
<tr>
<th>Age Groups</th>
<th>Age</th>
<th>Total patients(%)</th>
<th>Men</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>21-40</td>
<td>421(29.3%)</td>
<td>231</td>
<td>190</td>
</tr>
<tr>
<td>B</td>
<td>41-60</td>
<td>563(39.2%)</td>
<td>203</td>
<td>360</td>
</tr>
<tr>
<td>C</td>
<td>61-80</td>
<td>451(31.5%)</td>
<td>174</td>
<td>277</td>
</tr>
</tbody>
</table>

Note. In parentheses there are percentage values.

Table 2

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Fig. 1

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Conclusion

MRI of the lumbar spine is one of the most requested tests in clinical practice, and the excellent quality of the images obtained with modern scanners allows an overall assessment of the compression of the dural sac and nerve roots from various diseases. However, it was noted that many patients have no visible abnormality on common MRI, although they have a very disabling symptom.

Posture plays an important role in the exacerbation of pain, and it is seen that the orthostatic position is avoided as much as possible, because it worsens symptoms.

This is the reason why the "G-Scan" has generated considerable interest in the scientific world as it is able to better understand the role of dynamic structures of the spine because it allows the study of the lumbosacral spine in orthostatic position.

In this study, out of a total of 4305 patients underwent MRI examination in both supine and standing position, the 47.7% belong to an age between 41 and 60 years and there is a predominance of women (2445 F vs. 1860 M). This data confirms what has already been described in other studies showing that the incidence of low back pain is higher in the third decade of life and it increases with age up to 60-65 years and then slowly decreases.[17]

In our experience we have noticed that in the transition from supine to orthostatic position there has been a change in MRI findings in 1435 patients, representing 33.3% of the total, so in one third of cases "standing" MRI allowed us to find pathological changes that otherwise would have remained "hidden".

In the transition from supine to orthostatic position there was no prevalence by age group, while there is a minimum prevalence in females than males (females 837F vs 608m).

The most surprising data that emerged in this study was that in more than half of the "positive" cases (744 patients), we found pure discal diseases (51.9%), and, among these, in 76% of cases (567 patients), there were changes that involved more discal layers, while in 24% (177 patients) was involved in a single discal layer.

With regard to patients with single discal layer involved, there was an increase of the protrusion / herniation in 124 patients (19 in the L3-L4, L4-L5 in 69 and 36 in L5-S1), while in others 53 patients the orthostatic position showed a hernia or a disc protrusion that was not visible in the supine position (35 in L4-L5 and 18 in L5-S1): so in the unifocal pathology of the column the more involved disc by the transition from supine orthostatic was L4-L5.

In multifocal disease the most significant changes have been in the tract L4-S1 (193 patients); among these 157 patients in the increase occurred in both levels (L4-L5 and
L5-S1), while in 36 cases it was changed only the stretch L5-S1. In absolute terms, the multifocal disc disease, the level that mostly has been changed was L4-L5 (308 cases), followed by L5-S1 (304 cases) and L3- L4 (228 cases).

In just under 40% of the cases (38.8%) changes in the transition from supine to orthostatic we found purely vertebral pathologies (listhesis, impaired mobility and redistribution of fluid of facet joint).

In particular, in 56 cases we found "hidden" listesis, not visible to the supine position, and among these the most common sites involved were L5-S1 (37 cases) and L4-L5 (19 cases).

The study dynamic angle of lumbar lordosis and lumbosacral angle is altered in patients with disc disease. This figure makes reason of the reduced elasticity of the column in the presence of even a single degenerated disc.

In our study in a small percentage of cases (only 9.7%), we found changes related diseases spinal functional unit in the transition from supine to orthostatic. These changes concern contiguous vertebrae, intervertebral disc, facet joints and capsules, ligaments and muscles which together resulted segmental modifications of the amplitude of the spinal canal.

Despite the significant improvement in the diagnostic, the rate of incidence of false-negative results in the evaluation of spinal stenosis is still be high, as reported in literature.

In our experience, the involvement of the spinal root compression was associated to the simultaneous presence of disc and facet joint pathology. This association is in agreement with previous work about biomechanical and pathological anatomy that demonstrate that loss of elasticity of the disc is one of many causes of yellow ligament fibrosis, in response to an increased mechanical stress.

MRI in supine and orthostatic position performed with G-Scan reproduces more faithfully than other technical conditions the anatomical relationships existing in the patient in daylife. It is particulary useful in cases in which the patient feels pain exclusively in orthostatic position and in all cases in which the traditional MRI examination is negative, and it is indicated for each patient with sciatica.

Our research has led to better clarify the role of the evaluation of the spine in physiological load, as evidenced by the 33% of positive cases that were not detected in the supine position.

These results seem to validate the importance of imaging of the lumbar spine in an upright position, as it can detect hidden hernias or width greater than a width greater or protrusion of a protrusion or herniated disc already demonstrated by examination in place supine or in the presence of a spondylolisthesis condition of physiological load, or an accentuation occult or stenosis of the spinal canal.
This study of last 10 years on the spinal pathology under physiological loading by RM "G-Scan" reveals that there is no prevalence of “positives” diseases in terms of age in the general population: this shows that the MRI of the spine under physiological load is important at any age and can display pathologies that could remain hidden in about one third of patients.

In view of the many benefits that come from the execution of the MR of lumbosacral spine in the upright position (physiological and dynamic studies), the main limitations of this technique are represented by the use of medium-low magnetic fields compared to those used in conventional studies, and the necessary cooperation of the patient to maintain the immobility during standing.

Nonetheless, the experience to date confirms that even if the image quality is not excellent and it is subject to possible motion artifacts, the information obtained in the upright position may provide more useful diagnostic information for the resolution of the clinical question about patients suffering from low back than those obtained by MRI performed in the supine position. A more complete diagnosis is necessary in patient management in terms of the correct therapeutic procedure (as a conservative therapy, rehabilitation or surgery).
References