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Dynamic MR in patients affected by neurogenical claudication: technique and results from a single-center experience

Mario Muto[1] · Francesco Giurazza[2] · Gianluigi Guarnieri[1] · Rossana Senese[3] · Emiliano Schena[4] · Fabio Zeccolini[1] · Alvaro Diano[1]

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Abstract
Introduction This study aimed to determine changes in size of lumbar spinal canal and related articular structures, during dynamic MR scans acquired in symptomatic patients standing upright using a new open MR system.
Methods Forty patients (mean age 58.4 years) affected by lumbar back pain associated with claudication, referring symptoms since more than 6 months. No one underwent to previous spine surgery. MR scans were performed with a novel open 0.5-T scanner, patient supine and upright (90°). Lumbar lordotic angle, flavum ligament thickness, herniated discs, spinal canal area, spinal canal and dural sac antero-posterior diameters, and spinal alignment were measured and compared in both supine and upright positions. Mean scanning time was 43 min.
Results All the considered parameters showed a statistically significant difference, except for lumbar lordotic angle. Mean percentage differences moving from supine to upright were +3.9 % for lumbar lordotic angle, +15 % for flavum ligament thickness, +16.2 % for sagittal disc bulge, −10.8 % for dural sac diameter, −13.1 % for spinal canal diameter, and −15.8 % for spinal canal area. In supine position, no patient presented with spondylolisthesis; moving to upright position, four patients showed spondylolisthesis (grade I).
Conclusion Dynamic MR is a valuable diagnostic exam to analyze the structures involved in lumbar back pain due to spinal canal stenosis and spondylolisthesis; in supine position, relevant factors can be underestimated or hidden, becoming appreciable only patient standing upright. In this series, flavum ligament thickening presented a role comparable to disc bulge for narrowing of lumbar spinal canal.

Keywords Neurogenical claudication · Dynamic MR · Spinal canal stenosis · Flavum ligaments · Disc bulge

✉ Francesco Giurazza
francescogiurazza@hotmail.it

[1] Neuroradiology Department, Cardarelli Hospital, Naples, Italy

[2] Radiology Department, Università Campus Bio-Medico di Roma, Via Alvaro del Portillo 200, 00100 Rome, Italy

[3] Emicenter European Medical Imaging, Casavatore, Naples, Italy

[4] Measurement and Biomedical Instrumentation Laboratory, Università Campus Bio-Medico di Roma, Rome, Italy

Introduction

Low back pain with or without sciatica is one of the most common medical problems in the Western world [1]. Magnetic resonance (MR) is widely employed to evaluate various diseases of the lumbar spine, responsible for neurological claudication. Since the conventional MR examinations of the spine usually are performed in supine position and so in functional rest, the loading conditions differ from those known to elicit symptoms in patients affected by lumbar canal stenosis; indeed, this is frequently exacerbated by upright standing and hidden in the supine position [1, 2].

For this reason, different techniques [1, 3–9] have been developed to overcome this issue in order to study the column under loading conditions; thanks to its peculiarity in recognizing soft tissue pathologies entailing articular structures and nerve roots, great interest emerged in the last two decades on new MR scanners able to perform dynamic acquisitions in upright position.

The technological progress of dynamic MR scanner has allowed to obtain a new open magnet, as MR open from

Paramed® (Genova, Italy); this is the first commercially available scanner completely open thanks to its parallel upright magnet design.

The aim of this study was to evaluate the changes in size of the lumbar spinal canal and related articular structures, during dynamic MR scans acquired in supine and upright position, in a sample of symptomatic patients affected by chronic neurogenical claudication using the new MR open 0.5-T scanner.

Materials and methods

Population data

From July to December 2015, we collected prospectively a sample of 40 patients (20 males; 20 females) with a mean age of 58.4 years (SD 8.1; range 38–66 years).

All were affected by lumbar back pain associated with claudication, referring symptoms since more than 6 months. No one had undergone to previous spine surgery. The study protocol was approved by the institutional review board.

MR protocol

The MRs of the lumbar spine were performed using the novel MR open 0.5-T scanner (Paramed®, Genova, Italy) with a dedicated receive-only spine coil (Fig. 1); this system allows the patient to stand both supine and naturally upright without external fixation.

The standard imaging protocol included the following sequences:

- Supine: sagittal T1-weighted turbo spin echo (TSE) (repetition time [TR] 342 ms/echo time [TE] 16 ms), sagittal T2-weighted TSE (TR 1550 ms/TE 126 ms), sagittal short tau inversion recovery (STIR) (TR 2711 ms/TE 30 ms/inversion time 90 ms), axial T2-weighted TSE (TR 4408 ms/TE 117 ms).

Fig. 1 MR open 0.5-T scanner (Paramed®, Genova, Italy) with parallel magnet design

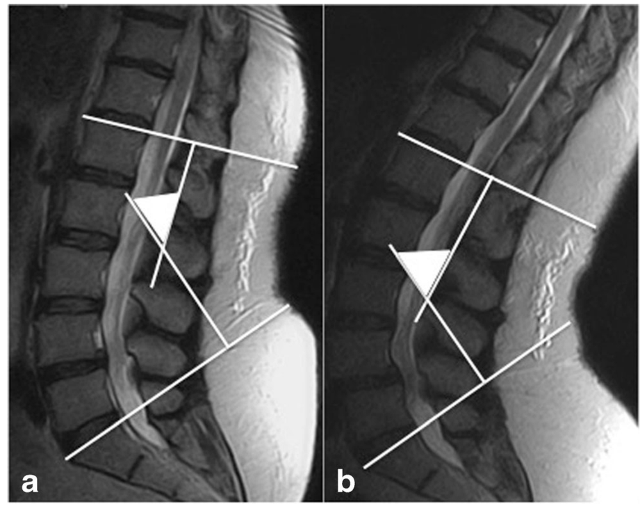

Fig. 2 Sagittal T2-weighted TSE in supine (**a**) and upright (**b**) standing. Lordotic angle is measured according to Cobb's method, increased in **b**

- Upright: sagittal TSE T2-weighted (TR 1550 ms/TE 126 ms), axial TSE T2-weighted (TR 4408 ms/TE 117 ms).

Slice thickness was 4 mm for each sequence.

MR evaluation

In correspondence to the main disc bulge level appreciable on imaging and presenting clinical relevance, we measured the following parameters in supine and upright positions and compared their variations: lumbar lordotic angle, flavum ligament thickness, herniated disc, spinal canal area, spinal canal antero-posterior diameter, and dural sac antero-posterior diameter.

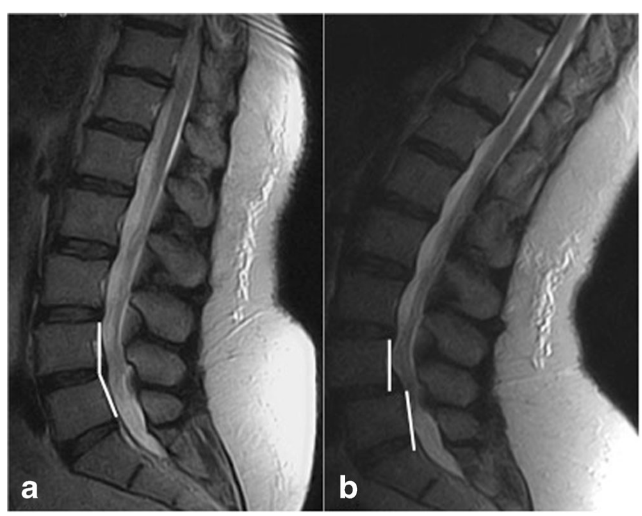

Fig. 3 Sagittal T2-weighted TSE in supine (**a**) and upright (**b**) standing. Anterolisthesis of L4-L5 is evident in **b** (*white lines*)

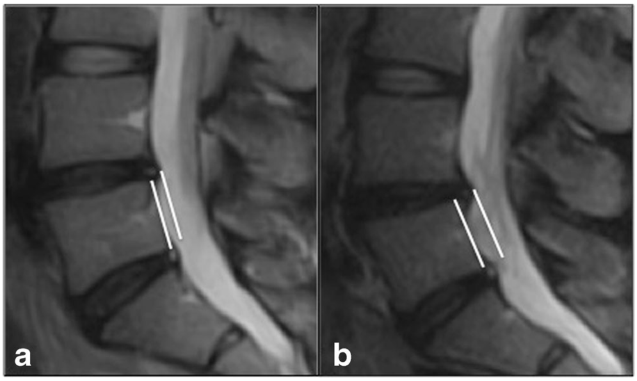

Fig. 4 Sagittal T2-weighted TSE in supine (**a**) and upright (**b**) standing. Disc bulge of L4-L5 is increased in **b** (*white lines*)

All the mentioned parameters have been calculated on T2-weighted TSE sequences, according to already established techniques published in previous studies [10, 11].

Measurements of lumbar lordotic angle were acquired from the mid-sagittal slice of lumbar spine using Cobb's method (Fig. 2).

The flavum ligament thickness was measured drawing a line along the laminar side of the ligament curve and along the side of the ligament facing the spinal canal, considering the thickest point on axial images (Fig. 3).

The disc bulge was assessed on sagittal projections, calculating the distance from the line connecting the cranial and caudal posterior edges of two adjoining vertebral bodies to the most bulging point of the disc (Fig. 4).

Spinal canal and dural sac antero-posterior diameters were evaluated on axial slices, considering the maximum distance from the posterior wall of the vertebral body to the posterior margin of the dural sac and to the confluence of the laminae, respectively (Fig. 5).

The spinal canal area was measured manually on axial slices considering the surface delineated by the posterior wall of the vertebral body anteriorly and the flavum ligaments postero-laterally on the slice where the flavum ligaments showed the maximum thickness (Fig. 6).

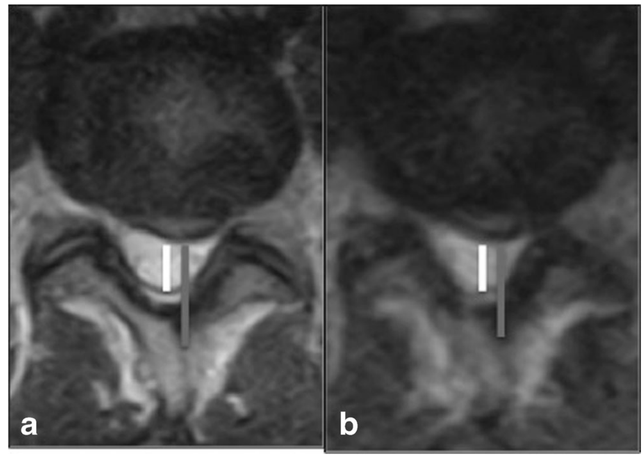

Fig. 6 Axial T2-weighted TSE in supine (**a**) and upright (**b**) standing. Sagittal midline dural sac (*white lines*) and spinal canal diameters (*gray lines*) at L4-L5 level are reduced in **b**

Spinal canal stenosis was also investigated in order to detect spondylolisthesis on T2-weighted sagittal sequences (Fig. 7); the glide of the superior vertebral body on the inferior was rated in quartiles according to the Meyerding classification, 0–25 % of the superior plate length grade I, 26–50 % grade II, 51–75 % grade III, and 76–99 % grade IV [12].

Statistical analysis

The differences between each parameter measured in the two different positions (i.e., standing and upright) were examined by two-tailed Student's test; the differences were considered significant for $p < 0.05$.

All the statistics were developed in Matlab® environment.

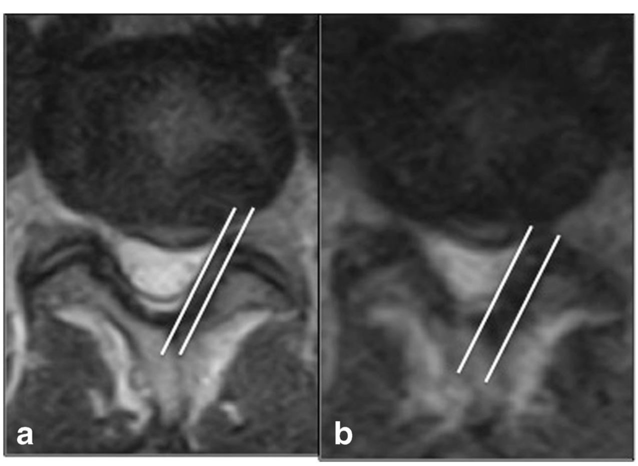

Fig. 5 Axial T2-weighted TSE in supine (**a**) and upright (**b**) standing. Flavum ligament thickening at L4-L5 level is increased in **b**, especially at left (*white lines*)

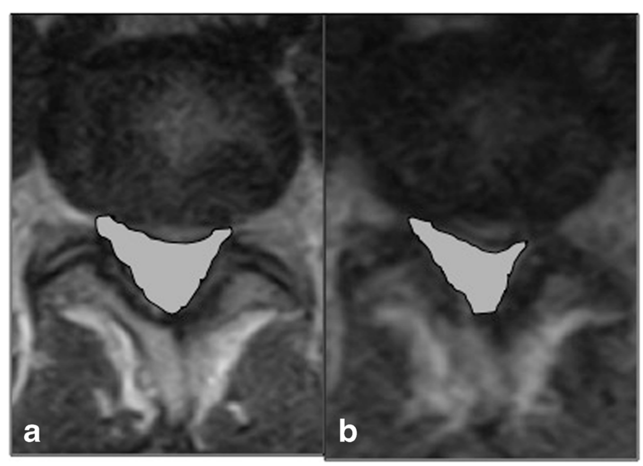

Fig. 7 Axial T2-weighted TSE in supine (**a**) and upright (**b**) standing. Manual computation of dural sac area (in *white*) at L4-L5 level is reduced in **b**

Table 1 Supine and upright values for lumbar lordotic angle, flavum ligament thickness, sagittal disc bulge, dural sac diameter, spinal canal diameter, and spinal canal area

	Supine	Upright	p
Lumbar lordotic angle (°)	51.3 (8.1)	53.3 (9.7)	Not significant
Flavum ligament thickness (mm)	6.38 (1.2)	7.34 (1.7)	$p < 0.05$
Sagittal disc bulge (mm)	4.57 (1.0)	5.31 (1.2)	$p < 0.05$
Dural sac diameter (mm)	11.1 (3.5)	9.9 (3.7)	$p < 0.05$
Spinal canal diameter (mm)	16.8 (4.1)	14.6 (4.5)	$p < 0.05$
Spinal canal area (cm^2)	1.9 (0.8)	1.6 (0.7)	$p < 0.05$

The statistical difference in terms of p value is also reported

Results

The mean scanning time was 43 min; all patients completed the examination and do not refer any suffering from claustrophobia.

All the six considered parameters have shown a significant change (p value < 0.05) moving from supine to upright, except the lumbar lordotic angle (p value > 0.05) (Table 1).

The mean values of lordotic angle, flavum ligament thickness, and sagittal disc bulge were higher in upright than supine, while the mean values of dural sac diameter, spinal canal diameter, and spinal canal area were lower in upright than supine.

In details, the measured percentage differences moving from supine to upright positions were assessed by following two steps: (i) we calculated the difference between upright and supine values, and (ii) we evaluated the ratio between these differences and the corresponding values in supine position, finally multiplied per 100. These values were an increment of 3.90, 15.0, and 16.2 % for lumbar lordotic angle, flavum ligament thickness, and sagittal disc bulge, respectively, while there was a decrease of 10.8, 13.1, and 15.8 % for dural sac diameter, spinal canal diameter, and spinal canal area, respectively. All these differences are reported in Fig. 8.

In supine position, no patient showed signs of spondylolisthesis; however, moving to upright, we appreciated 10 % of slippage (four patients with grade I spondylolisthesis).

Discussion

Supine MR has an established role in the assessment of spinal disorders; however, its findings, as stenosis and disc herniation, have both high false-positive and false-negative rates [4, 13].

In supine position, various pathologic features, including deformation of the dural sac, nerve root compression, disc bulging, thickening of ligamentum flavum, and/or narrowing of the intervertebral foramen, can remain undetected compared with that observed in the upright position [2].

Clinical symptoms can develop with sitting, standing, or dynamic maneuvers (including flexion and extension) and may not be adequately assessed by supine MR. Development of these symptoms reflects morphological changes in normal or degenerated disco-ligamentous structures due to the effects of gravity, changes in size of the intervertebral foramen, and relative motion between adjacent vertebrae on assumption of the upright posture and with dynamic maneuvers [13]. Therefore, upright and dynamic imaging together offer relevant diagnostic information and a number of techniques are already available for this assessment.

Radiographs are acquired in dynamic modality with upright anterior–posterior and true lateral neutral-flexion-extension projections [14], but these fail to visualize soft tissues.

Dedicated compression devices have been developed to expose lumbar spine to an axial force similar to that in the spine in the standing position, corresponding approximately to the 50 % of body weight [5, 15, 16]. These devices have been applied during supine MR to simulate a physiological normal weight-bearing condition in the upright position.

Although results were certainly interesting and cost-effective [2, 6, 7], allowing better assessment in relation to

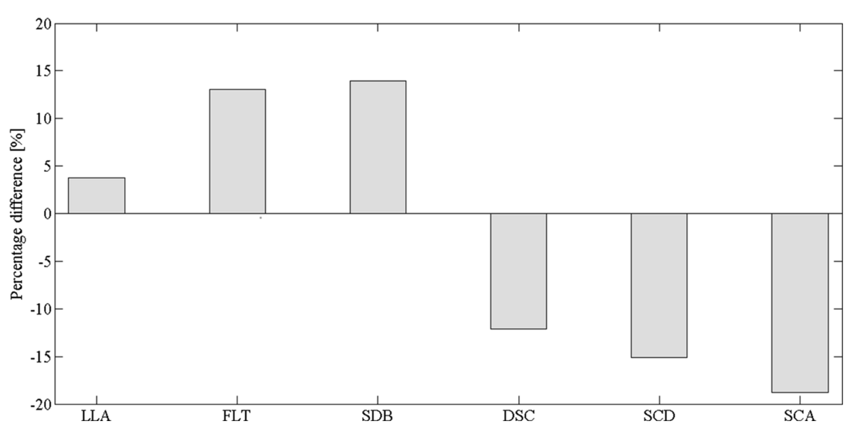

Fig. 8 Diagram reporting the variations observed, in terms of difference percentage, for each measured parameter moving from supine to upright; on y-axis are expressed the percentage values and on x-axis the parameters. *LLA* lumbar lordotic angle, *FLT* flavum ligament thickness, *SDB* sagittal disc bulge, *DSC* dural sac diameter, *SCD* spinal canal diameter, *SCA* spinal canal area

the higher signal-to-noise ratio afforded by the high-field equipment, the technique has not achieved a general consensus.

Studies [10, 15] have demonstrated that the degree of axial loading to the lumbar spine in the standing position does not correctly replicate the patient in the supine position: indeed, this approach does not consider the influence that head/body weight and muscle activation have on the lumbar spine stability [17–19].

At the end of 1990s, the first studies about dynamic MRI have been published [8, 19]; nowadays, the technological advancement of open MRI scanners allows better performances in terms of assessment of spinal canal stenosis and variations of some pathological conditions from recumbent to upright position. These devices also have the advantage of eliminating the patient's feeling of claustrophobia, which sometimes limits diagnostic evaluation of the spine [20–23].

Usually, the magnetic fields are 0.25, 0.5, and 0.6 T; images can be obtained with patient both supine and upright in the flexed, extended, rotated, standing, and bending positions [13].

In many cases, dynamic MR has proven [1, 9, 13, 24, 25] to reveal disc-radicular conflicts not depictable on conventional MR studies.

Splendiani et al. [1] found in a large sample of patients significant differences in the evaluation of degenerative aspects analyzed with dynamic MR in the transition from standing to supine position; in particular, the appearance of disc protrusions was significantly detected in 11 % of the cases, as well as the increase or appearance of spinal canal stenosis in 9.2 % of the cases; these data are in agreement with other previous published studies [9, 24, 25] performed with open dynamic MR magnets.

In another study on a sample of 57 symptomatic subjects with low back pain, Tarantino et al. [26] reported that 70 % of them had an increment of disc protrusions and/or spondylolisthesis found in the upright position.

In the present study, a new open 0.5-T MR scanner has been employed; we observed statistical significant differences ($p < 0.05$) in the transition from standing to supine position with regard to variations in the midsagittal diameters and area of the lumbar spinal canal, especially related to disc bulge and flavum ligament thickness. Indeed, we found that these two variables increased 16.2 and 15 %, respectively, in upright position. These results are in accordance with previous literature studies performed with open MR system, showing pain differences related to position [1, 19, 24, 25]. The diagnostic value of dynamic MR is represented also by the rate of spondylolisthesis, detected in this series in 10 % of the cases only in upright; the hypermobility of some spinal segments detectable with upright MR can lead to a higher degree of spinal canal stenosis, which may correlate with increased symptomatology. These measurements are of considerable importance in the presence of suspected stenosis not detectable by conventional supine MR, with the necessary considerations resulting from the therapeutic point of view [1].

It seemed that dynamic MR offered an optimal linkage of the patient's syndrome with the imaging abnormalities responsible for the clinical presentation, thereby allowing an improvement at once in both imaging sensitivity and specificity.

This technique entails however some limitations [1, 4, 5, 9, 13, 26]: first of all, the low-field magnet results in a low signal to noise ratio and so a lower image quality compared to the common high-field magnet. Another important limit is the long scanning time because of the additional acquisitions in upright standing; this issue can result even in pain problems and motion artifacts because symptomatic patients may find it difficult to maintain the immobility necessary for the whole duration of the imaging acquisition in the upright position [26]. Finally, some authors reported also an occasional difficulty encountered in evaluating the most lateral areas of the spine, as exit foramen and lateral recesses [18, 26], due to section thickness and degree of patient rotation and lateral flexion.

In conclusion, in this series, dynamic MR appeared a valuable diagnostic exam to evaluate the structures involved in lumbar back pain associated with neurogenical claudication, displaying a more realistic upright pain condition. Flavum ligament thickening presented a role comparable to disc bulge in terms of lumbar spinal canal narrowing; this may influence or worsen neurogenic claudication symptoms; however, this is an assumption not studied in this series requiring further investigations.

Compliance with ethical standards We declare that all human and animal studies have been approved by the institutional review board of Cardarelli Hospital, Naples, Italy, and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. We declare that all patients gave informed consent prior to inclusion in this study.

Conflict of interest We declare that we have no conflict of interest.

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