SPINE An International Journal for the study of the spine Publish Ahead of Print

DOI : 10.1097/BRS.0000000000002235

Reduced spinal cord movement with the straight leg raise test in patients with lumbar intervertebral disc herniation

MarinkoRade, M.Sc. Orth. Med., Ph.D., Department of Physical and Rehabilitation Medicine, Kuopio University Hospital, Kuopio, Finland. Director of Josip JurajStrossmayer University of Osijek, Faculty of Medicine, Orthopaedic and Rehabilitation Hospital "Prim. dr.MartinHorvat", Rovinj, Croatia. – e-mail: marinko.rade@gmail.com; marinko.rade@kuh.fi

JannePesonen, MD, Department of Physical and Rehabilitation Medicine, Kuopio University Hospital, Kuopio, Finland.– e-mail:janne.pesonen@kuh.fi

MerviKönönen, Ph.D., Department of Radiology, Kuopio University Hospital, Kuopio, Finland – e-mail: mervi.kononen@kuh.fi

JarkkoMarttila, M.D., Department of Radiology, Kuopio University Hospital, Kuopio, Finland – e-mail: Jarkko.Marttila@kuh.fi

Michael Shacklock, F.A.C.P., M.App.Sc, Dip.Physio., Neurodynamic Solutions, Adelaide, Australia – e-mail: michael@neurodynamicsolutions.com

RitvaVanninen, M.D., Ph.D., Clinical Director, Professor, Department of Radiology, Kuopio University Hospital, Kuopio, Finland – e-mail: ritva.vanninen@kuh.fi

Markku Kankaanpää, M.D., Ph.D., Clinical Director, Department of Physical and Rehabilitation Medicine, Tampere University Hospital, Tampere, Finland – e-mail: markku.kankaanpaa@pshp.fi

OlaviAiraksinen, M.D., Ph.D., Clinical Director, Department of Physical and Rehabilitation Medicine, Kuopio University Hospital, Kuopio, Finland – e-mail: olavi.airaksinen@kuh.fi

The manuscript submitted does not contain information about medical device(s)/drug(s).
No funds were received in support of this work.
No relevant financial activities outside the submitted work.

Abstract

STUDY DESIGN: Controlled radiological study.

OBJECTIVE: To explore whether impairment of neural excursion during the straight leg raise test occurs in patients with sciatic symptoms secondary to lumbar intervertebral disc herniation (LIDH).

SUMMARY OF BACKGROUND DATA: Earlier studies have shown that during the SLR test in asymptomatic volunteers tensile forces are consistently transmitted throughout the neural system and the thoracolumbar spinal cord slides distally.

METHODS: Fifteen patients with sciatic symptoms due to subacute LIDH were studied with a 1.5T magnetic resonance (MR) scanner. First a spine specialist diagnosed the LIDH using conventional scanning sequences. Following this subjects were scanned using different scanning sequences for planning and measurement purposes. Displacement of the conus medullaris during the unilateral and bilateral SLR was quantified reliably with a randomized procedure and compared between manoeuvres.

RESULTS: The results showed 66.6% less excursion of conus medullaris with SLR performed on the symptomatic side compared to excursions measured with SLR performed on the asymptomatic side ($p \leq .001$).

CONLUSION: In patients with LIDH, the neural displacement on the symptomatic side is significantly reduced by the compressing IVD herniation. To our knowledge, these are the first data in intact human subjects to support the limitation of neural movements in the vertebral canal with LIDH.

Key Words: Spinal cord, Radiculopathy, Low back pain, Straight leg raise, SLR, Sciatica, Intervertebral disc herniation, Neurodynamics, IVD, LBP

Level of Evidence:3

Introduction

Thestraight leg raise (SLR) is a standard physical test in diagnosis of sciatica due to lumbar intervertebral disc herniation (LIDH) and shows high sensitivity with heterogeneous specificity (1-3). In isolation, the test is insufficient to make a diagnosis of LIDH because many other conditions could cause abnormality in the test. This necessitates that novel in-depth knowledge of the neural biomechanics underpinning the SLR is providedin order to better aid interpretation of the test.

Through elongation of the sciatic nerve bed at the hip, knee and ankle(4), the SLR applies distal tension to the nerve. The forces from this reach the lumbosacral nerve roots whereby they are drawn distally in the foramen (5-10). Theeffects of this are transmitted via the nerve roots to the spinal cord which also follows by moving caudally in the canal (11-13).

Using magnetic resonance imaging (MRI), Rade et al (14) established normal multiplanarspinal cord movement with the SLR(11-13,15,16).It is apparent thatthe conus medullaris consistently moves in a caudal direction (11,13), primarily due to direct transmission of forces through the lumbosacral nerve roots(16), and that conus movement prevails over bony movement(16). The conus displacement is double with a bilateral compared with the unilateral SLR, possibly being a reflection of the number of nerve roots transmitting the force (i.e. unilateral vsbilateral SLRs)(12,13). Furthermore, conus displacement is positively correlated with the angleof hip flexion (15).

Since a full set of consistent and reliable dataon conus medullaris displacement within the vertebral canal with unilateral and bilateral SLRs tests is now available for clinical comparison, it is now possible to extend this line of research. In view of the fact that nerve root excursion has been shown to be impaired in patients with LIDHduring intraoperative investigations (10,17), we studied cord movement with the SLR in such patients to ascertain if any alterations extend to the spinal cord using non-invasive methods in structurally intact subjects.

Having found areduction in excursion of conus medullaris with SLR in patients with LIDH, we here describe the methods of this investigation.

Materials and Methods

Subjects and clinical selection procedure:

Study volunteers were collected from patients referred from primary healthcare centres and occupational doctors' offices to Kuopio University Hospital (KUH) Spine Centre(approximately 2,500 referrals per year) for a specialist's consultation regarding severe low back pain (LBP). Of those, patientswith subacute (3-8 weeks) sciatic symptoms with no known confounding factors (shown in table 1; exclusion criteria) were collected from the preliminary data available at referral and invitedfor clinical evaluation by a spine specialist (JP). A thorough clinical evaluation was performed for exclusion and inclusion criteria (table 1), and to confirm that all patients were on active sick leave due todisabling LBP. As data from symptomatic SLRs were compared with contralateral, asymptomatic, SLR and normal casespreviously published (11-13),the contralateral SLR was assessed to be fully asymptomatic and the LIDH only single-level with strictly posterolateral direction impinging on only one nerve root (figure 1). Moreover, as amount of conus displacement with unilateral and bilateral SLR has been shown to be significantly correlated with amount of hip flexion during SLRs (15), patients selected for the study were required to present with an abnormal SLR between 45-70 degrees of hip flexion. This was in order to allow for comparison of conus medullaris displacement with normal data now available in the literature in which the same methods with the SLR and measurement of conus displacement were used(11-13). An additional reason not to include acute patients was that acute patients would not be able to tolerate an SLR position for the whole duration of the MR 3D spc scanning sequence (4min and14sec for each manoeuvre) without producing pain-mediated movement artefacts, as well as ethical concerns.

Of those, 42 patientswith proven typical clinical findings for unilateral radiculopathy due to LIDHand matching the inclusion criteria were referred for diagnostic MR with standard T1 and T2 sagittal sequences and T2 axial sequences. Upon confirmation of single-level posterolateral L4-5 or L5-S1 LIDH by a medical radiologist (JM,RV), patients were included in the experimental protocol.Importantly, both diagnostic MRI and experimental MRI protocols were conducted within a week of the clinical assessment in order to minimize possible confounding factors including physiologic healing processes that can occur with time.

A flow chart showing the patients selection process is presented in figure2.

Figure 1. MRI T2 sagittal and T2 axial slices showing L5-S1 single-level left posterolateral lumbar intervertebral disc herniation (LIDH).

Figure 2. Flow chart showing the patients selection process.

Finally, fifteen symptomatic volunteers ranged from 23 to 58 years (mean age 36.87±9.26 years, height 178.6± 8.6 cm, BMI 26.09±3.78, VAS 63.93±6.19), and who met all the inclusion criteria (table 1) were included in the study. Characteristics of the tested sample are shown in table 2.

All aspects of work that involved human patients was conducted with the ethical approval of the Research Ethical Committee of Kuopio University Hospital, approval number 79/2012. All tested subjects signed an informed consent form and the study was performed in accordance with the Declaration of Helsinki.

Experimental protocol:

Devices: As in previously published(13), subjects lay in supine in a 1.5T magnetic resonance (MR) scanner (Siemens MagnetomAera, Erlangen, Germany). The imaging area was centred approximately 3cm proximally from the xiphoid process of the sternum and the coronal images centred at the lower part of the imaging area to T12-L2 anatomic region. The volunteers were scanned using a 32-channel spine matrix coil.

As previously suggested (13), different scanning sequences for planning and for measurement were used.

1. Planning: T2 weighted turbo spin echo sequence (TR 3530ms, TE 96ms, 17 slices, slice thickness 3mm, FOV 300mm, in plane resolution 0.8x0.8mm, flip angle 150 degrees). Sagittal slices were aligned with the spinal cord to allow better identification of the conus medullaris.

2. Measurement: T2 weighted spc 3D-sequence (TR 1800ms, TE 128ms, slice thickness 1mm, sagittal scan, FOV 300mm, phase encoding direction proximal to caudal, in plane resolution 0.6x0.6mm, flip angle 160 degrees).

Coronal, axial and sagittal slices (slice thickness 1mm, approximately 70 slices in each plane) were reconstructed from the native T2 weighted spc 3D-sequence sagittal scans using the MPR program available in Sectra PACS workstation (Sectra Workstation IDS7, version 15.1.8.5-2013 – Sectra AB, Sweden).

Subject positioning and test movements

We explored whether any difference in conus medullaris displacement would occur between the unilateral SLR performed on the symptomatic limb, asymptomatic limb and bilateral SLR.

The volunteers were scanned in the following positions in a random order with the level of hip flexion having been determined by pre scan SLR tests on the symptomatic side:

-Neutral: Subject lying supine, aligned symmetrically in the anatomic position, lower limbs extended and relaxed.

- Symptomatic SLR: passive SLR to maximum degree of hip flexion allowed by patients' symptoms.

- Asymptomatic (contralateral) SLR: passive SLR to same degree of hip flexion as in symptomatic SLR (figure 3).

- Bilateral SLR: as with the unilateral SLR. Two investigators were required for this in which subjects' legs were raised to the same degree of hip flexion as in symptomatic SLR, one by one, starting from the right, left or both legs together in a random order (figure 3).

During MRI scanning, 56.6±4.3°(mean±SD) of hip flexion was achievedon the symptomatic SLR.As before (11), hip flexion was measured with an oil-filled precision goniometer placed on the anterior surface of the distal third of the tibia. This method has been shown to have good intra-observer reliability with the SLR (18) and was considered safe to be operated in the MR scanning room, security zone IV.

Each movement was performed twice for evaluation of reliability. Three practitioners performed the manoeuvres in a random sequence in order to avoid possible series effects.

Cervical flexion in the subjects was always avoided so as not to influence spinal cord position or movement.

Figure3. Passive unilateral SLR (A) and bilateral SLR (B) with subject lying supine in the magnetic resonance scanner. Adapted from Rade et al. (2015): Part 3: Developing Methods of In Vivo MRI Measurement of Spinal Cord Displacement in the Thoracolumbar Region of Asymptomatic Subjects with Unilateral and Bilateral Straight Leg Raise Tests. Spine (Phila Pa 1976) 2015;40 (12):935-41. With permission.

Conus medullaris displacement measurement: The displacement of the conus medullaris relative to the upper intervertebral surface of the adjacent vertebra during theunilateral passive SLR performed on the symptomatic side, asymptomatic side and bilateral SLR was quantified and compared with the position of the conus in the neutral (anatomic) position (figure5ABCDEFGH).

Figure 4: Marking process. Two observers independently assessed the conus displacement by first identifying the tip of the conus. The tip was initially identified on the coronal slices and its position concurrently verified on the axial and sagittal slices using the crosshair and localizer tools available in Sectra PACS workstation and MPR extension.

Figure 5. Magnetic resonance scans. Coronal slices of the thoracolumbar region of a sample subject during (A) reference scan, (C) unilateral symptomatic SLR, (E)unilateral asymptomatic SLR, and (G) bilateral SLR are presented. The apex of the conus medullaris is marked. The vertical distances from the upper vertebral endplate of the adjacent vertebral body are marked and presented in B, D, F and H. Original images and different measurements from both observers are presented.

Consistent with earlier investigations (11-13), measurements and reconstructions from native experimental scans were performed twice by the main author without previous knowledge of the manoeuvre being analysed, and once by co-author (JM). Three months periods were allowed between each measurement in order to allow for more reliable evaluation of intra- and inter-observer reliability.

The two observers independently assessed the conus displacement by first identifying the tip of the conus. The tip was initially identified on the coronal slices and its position concurrently verified on the axial and sagittal slices using the crosshair and localizer tools available in Sectra PACS workstation. Particular care was taken to identify the origin of filum terminale so as to confirm the location of the tip of the conus (figure 4).

The mark on the tip of the conus was then precisely projected at the centre of the adjacent vertebral body by using the crosshair and localizer tools available in Sectra PACS program (Sectra Workstation IDS7, version 15.1.8.5-2013 – Sectra AB, Sweden). As in Rade et al. (11-13)the distance between the mark on the vertebral body and the anatomical reference point represented by the upper intervertebral surface of the adjacent vertebrawas measured on the coronal slices and data compared between different manoeuvres. The measurements were made using Sectra PACS program (Sectra Workstation IDS7, version 15.1.8.5-2013 – Sectra AB, Sweden).

All the presented metric*values were truncated* to the next *lowest* decimal value(3.55=3.5) to provide more conservative and reliable data.

Statistical Methods

As in previous investigations (11-13), the purpose of the data analysis was to detect any statistically significant differences in medullar cone position between the reference and test positions for the symptomatic,asymptomatic and bilateral SLRs.

A two-tailed hypothesis that the conus would displace in response to SLRs versus no change was tested.

As in previous investigations (11-13), Pearson correlation between the displacements found in two scans of the same manoeuvres performed on each subject was calculated as well as for inter- and intra-observer reliability.

Having found strong correlation between the measures from different scans of the same manoeuvres performed on each subject, as well as high correlations between different measurements performed by different observers on those scans, it was decided to average all the available measurements when presenting the mean values and their standard deviations, in order to present the results as accurately and conservatively as possible.

Student´s t-test was used to test the significance of medullar displacement during SLR manoeuvres in relation to the position found in the reference scans. The Alpha level was set at $p<.05$.

Owing to the relatively small data sample (N=30) it was postulated that the data distribution is leptokurtic, thus 95% Confidence Intervals (95% CI) were calculated using t distribution.

The Observed Power was calculated on the data using t distribution, while the minimum number of subjects needed to extract statistically significant results was calculated from the collected data. Statistical analysis was performed using R Program (R Foundation for Statistical Computing, Vienna, Austria), Version 2.15.2 (2012).

Results

The conus medullaris displaced caudally with the asymptomatic (contralateral) SLR by 2.28 ± 1 mm (Mean±SD) ($p\leq0.001$) 95% CI (-1.75, -2.81). However, the excursion produced by the symptomatic SLR was only0.76± 0.34mm ($p\leq0.001$) 95% CI (-0.58, -0.95), a reduction of 66.6%. Alternatively, the symptomatic produced only 33.3% of cord excursion produced by the asymptomatic SLR. The bilateral SLR produced 3.40± 1.68 mm of cord excursion ($p\leq0.001$) 95% CI (-2.98, -3.63).

Comparison between symptomatic and asymptomatic(contralateral) SLR showed statistically significant difference ($p\leq0.001$)(figure6). Statistical significance was alsoachieved for comparisons between mean value of conus displacement with 1. symptomatic and asymptomatic (contralateral) SLRand 2. bilateralSLR ($p\leq0.001$) (figure7).

Figure 6. Conus medullaris caudal displacement with unilateral SLR test performed on the asymptomatic (ASYM) and symptomatic (SYM) side**.** Mean value and standard deviations of measurements are presented. Note the significant difference in conus movement with symptomatic and asymptomatic SLRs

indicating limitation of neural adaptive movements with SLR on the symptomatic side. Values are expressed as negative to indicate the caudal direction of the displacement.

Figure 7. Conus medullaris displacement with unilateral and bilateral SLR. Mean value and standard deviations of measurements are presented. Values are expressed as negative to indicate caudal displacement. Note that compared with the unilateral SLR, the magnitude of conus displacement was almost double with the bilateral SLR indicating a linear relationship between magnitude of conus displacement and number of nerve roots involved into the movement (i.e. unilateral and bilateral SLRs).

The number of subjects required to produce statistically significant results($p<0.05$) was only five for symptomatic SLR, asymptomatic SLR and for bilateral SLR.

Pearson correlations proved higher than 0.99 for both inter and intra observer reliability as well as results reproducibility for each tested manoeuvre. Observed power was 1 for each tested manoeuvre (table 3).

Discussion

Here we show non-invasively with sensitive and reliable MRI reduction of movement of the conus medullaris in patients with posterolateral LIDH ($p\leq0.001$). The SLR on the symptomatic side produced less conus movement compared to i) the same SLR on the contralateral asymptomatic side (66% reduced) and ii) our previous studies on asymptomatic subjects with the same methods (11-13).

In relation to mechanisms, our results support the ‘principle of linear dependence’. In this principle, the cord displacement would be proportional to that of the lumbosacral nerve roots and dependent on the number of nerve roots to which tension is applied. The unilateral and bilateral SLRs would therefore apply proportionally different amounts of force to the cord.

An important consideration is the fact that the reductions in cord movement are an ‘effect’ and not a ‘cause’. It is likely that compression, ischaemo- and mechano-sensitivity and reduced nerve root movement from the disc protrusion are the causal mechanisms.

Even though our findings are indirect, they are consistent with earlier work showing reduced lumbar nerve root excursion (10,17) which probably relates to impaired capacity of the nerve roots to transmit forces to the cord. Furthermore, it may be that loss of neural excursion is a factor in some spinal symptomatologies(11-13).

The high correlation values presented in this study show that these sliding movements with unilateral and bilateral SLRs are consistent and reproducible. This indicates that they may also be predictable both in terms of magnitude and direction.

The value of these findings may be that clinical measurement of cord movement could be of benefit in quantification and diagnosis with radiology. Loss of neural excursion may lend support to interventions directed at restoring neural excursion.

Conclusions

In patients with LIDH, spinal cord displacement with SLR on the symptomatic side was significantly reduced by phenomena associated with IVD herniation.

These findings help clarify why the SLR test as a useful tool in assessment of neuromechanical impairment in patients with sciatica from the nerve root.

To our knowledge, these are the first non-invasive data to objectively support the limitation of spinal cord displacement in the vertebral canal with LIDH in in-vivo and structurally intact human subjects.

Acknowledgements

The authors would like to thank the patients who volunteered to take part in the study. We would also like to thank Prof.Kai Kaarniraantaa (Department of Ophthalmology, University of Eastern Finland) and Dr.Frances MK Williams (Department of Twin Research and Genetic Epidemiology, King's College London, London, UK)fortheir invaluable comments on the reporting of this study.

References

(1) van der WindtDaniëlle AWM, Simons E, Riphagen Ingrid I, Ammendolia C, Verhagen Arianne P, Laslett M, et al. Physical examination for lumbar radiculopathy due to disc herniation in patients with low-back pain. Cochrane Database Syst Rev 2010 2010 Feb;17;(2).

(2) Airaksinen O, Brox JI, Cedraschi C, Hildebrandt J, Klaber-Moffett J, Kovacs F, et al. COST B13 Working Group on Guidelines for Chronic Low Back Pain. European guidelines for the management of chronic nonspecific low back pain. Eur Spine J 2006:15 (Suppl 2): S192-S300.

(3) Rebain R, Baxter GD, McDonough S. A systematic review of the passive straight leg raising test as a diagnostic aid for low back pain (1989 to 2000). Spine (Phila Pa 1976) 2002;27:E388-95.

(4) Beith I. An assessment of the adaptive mechanisms with and surrounding the peripheral nervous system during changes in nerve bed length resulting from underlying joint movement. In: Shacklock M, editor. Moving in on Pain Sydney: Butterworth-Heinemann; 1995. p. 194-203.

(5) Goddard MD, Reid JD. Movements induced by straight leg raising in the lumbosacral region. J NeurolNeurosurg Psychiatry 1965;28:12-18.

(6) Breig A. Adverse mechancial tension in the central nervous system. Stockholm: Alqvist and Wiksell; 1978.

(7) Breig A, Troup JDG. Biomechanical considerations in the straight-leg-raising test. Cadaveric and clinical studies of the effects of medial hip rotation. Spine 1979;4(3):242-250.

(8) Gilbert KK, Brismée J-, Collins DL, James CR, Shah RV, Sawyer SF, et al. 2006 Young investigator award winner: Lumbosacral nerve root displacement and strain: Part 1. A novel measurement technique during straight leg raise in unembalmed cadavers. Spine 2007;32(14):1513-1520.

(9) Gilbert KK, Brismée J-, Collins DL, James CR, Shah RV, Sawyer SF, et al. 2006 Young investigator award winner: Lumbosacral nerve root displacement and strain: Part 2. A comparison of 2 straight leg raise conditions in unembalmed cadavers. Spine 2007;32(14):1521-1525.

(10) Kobayashi S, Shizu N, Suzuki Y, Asai T, Yoshizawa H. Changes in nerve root motion and intraradicular blood flow during an intraoperative straight-leg-raising test. Spine 2003;28(13):1427-1434.

(11) Rade M, Könönen M, Vanninen R, Marttila J, Shacklock M, Kankaanpää M, et al. 2014 young investigator award winner: In vivo magnetic resonance imaging measurement of spinal cord displacement in the thoracolumbar region of asymptomatic subjects: Part 1: Straight leg raise test. Spine 2014;39(16):1288-1293.

(12) Rade M, Könönen M, Vanninen R, Marttila J, Shacklock M, Kankaanpää M, et al. 2014 young investigator award winner: In vivo magnetic resonance imaging measurement of spinal cord displacement in the thoracolumbar region of asymptomatic subjects: Part 2: Comparison between unilateral and bilateral straight leg raise tests. Spine 2014;39(16):1294-1300.

(13) Rade M, Shacklock M, Könönen M, Marttila J, Vanninen R, Kankaanpää M, et al. Part 3: Developing Methods of In Vivo MRI Measurement of Spinal Cord Displacement in the Thoracolumbar Region of Asymptomatic Subjects With Unilateral and Bilateral Straight Leg Raise Tests. Spine (Phila Pa 1976) 2015;40 (12):935-41.

(14) Rade M, Shacklock M, Könönen M, Marttila J, Vanninen R, Kankaanpää M, et al. Normal multiplanar movement of the spinal cord during unilateral and bilateral straight leg raise: Quantification, mechanisms and overview. J Orthop Res 2016;Aug 9. doi: 10.1002/jor.23385. [Epub ahead of print].

(15) Rade M, Könönen M, Marttila J, Vanninen R, Shacklock M, Kankaanpää M, et al. Correlation analysis of demographic and anthropometric factors, hip flexion angle and conus medullaris displacement with unilateral and bilateral straight leg raise. Eur Spine J 2016;25(3):724-31.

(16) Rade M, Könönen M, Marttila J, Shacklock M, Vanninen R, Kankaanpää M, et al. In Vivo MRI Measurement of Spinal Cord Displacement in the Thoracolumbar Region of Asymptomatic Subjects with Unilateral and Sham Straight Leg Raise Tests. PLoS ONE 2016;Jun 2;11(6).

(17) Kobayashi S, Takeno K, Yayama T, Awara K, Miyazaki T, Guerrero A, et al. Pathomechanisms of sciatica in lumbar disc herniation: Effect of periradicular adhesive tissue on electrophysiological values by an intraoperative straight leg raising test. Spine 2010;35(22):2004-2014.

(18) Porter RW, Trailescu IF. Diurnal changes in straight leg raising. Spine 1990;15(2):103-106.

FIGURE LEGENDS

Figure 1. MRI T2 sagittal and T2 axial slices showing L5-S1 single-level left posterolateral lumbar intervertebral disc herniation (LIDH).

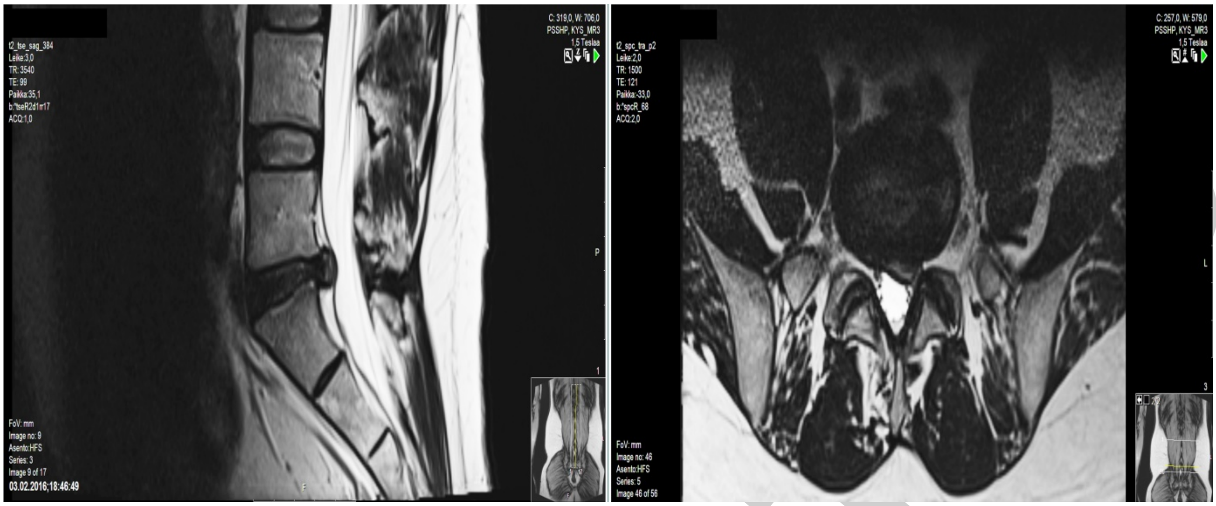

Figure 2. Flow chart showing the patients selection process.

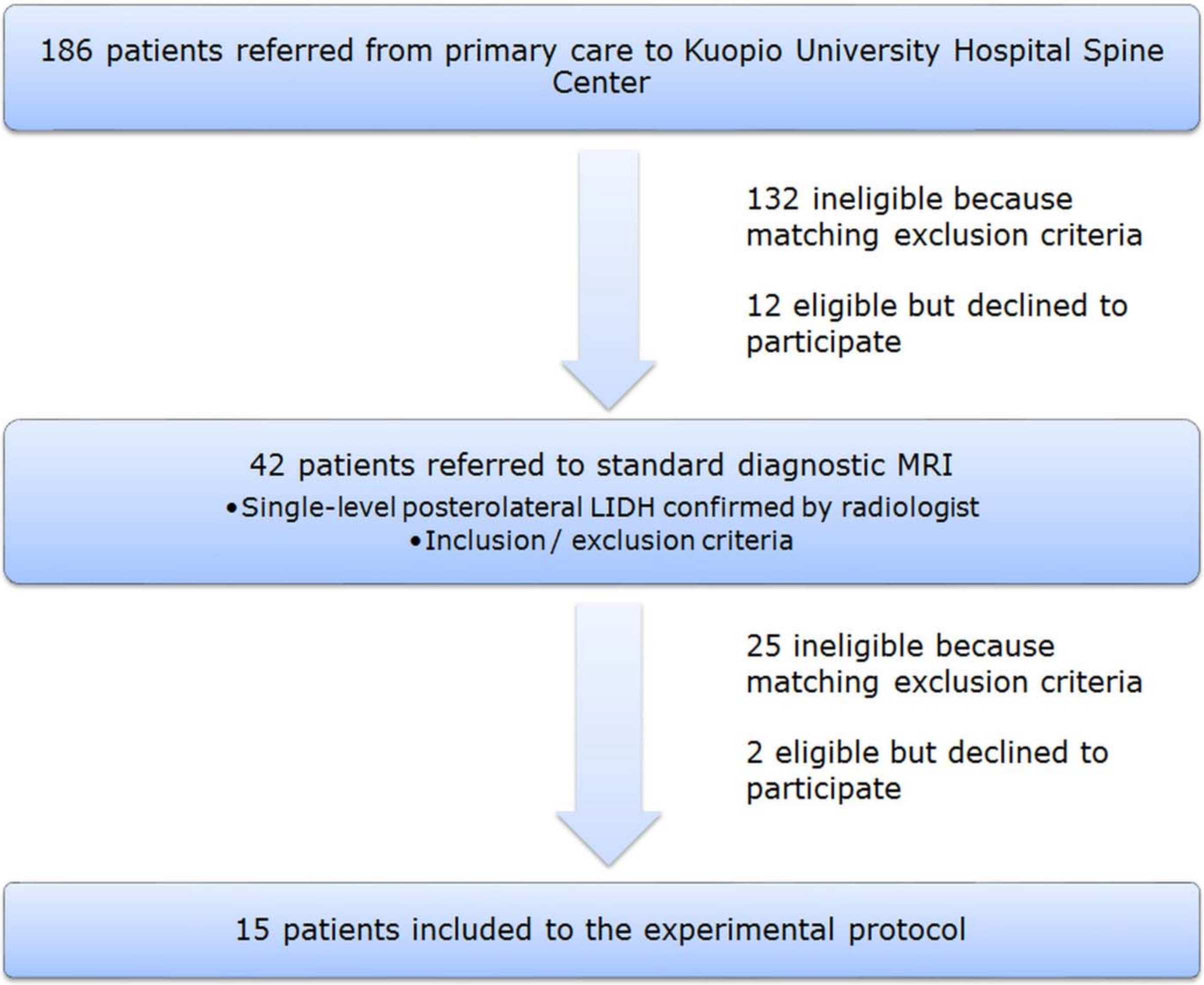

Figure 3. Passive unilateral SLR (A) and bilateral SLR (B) with subject lying supine in the magnetic resonance scanner. Adapted from Rade et al. (2015): Part 3: Developing Methods of In Vivo MRI Measurement of Spinal Cord Displacement in the Thoracolumbar Region of Asymptomatic Subjects with Unilateral and Bilateral Straight Leg Raise Tests. Spine (Phila Pa 1976) 2015;40 (12):935-41. With permission.

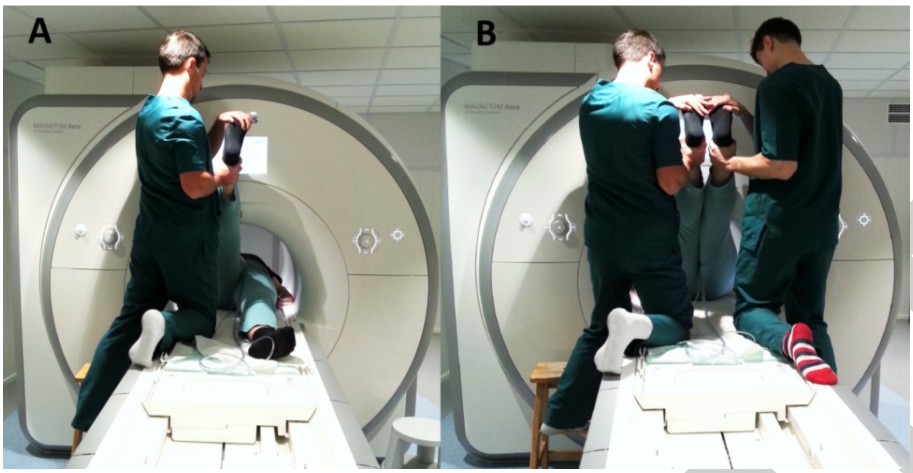

Figure 4: Marking process. Two observers independently assessed the conus displacement by first identifying the tip of the conus. The tip was initially identified on the coronal slices and its position concurrently verified on the axial and sagittal slices using the crosshair and localizer tools available in Sectra PACS workstation and MPR extension.

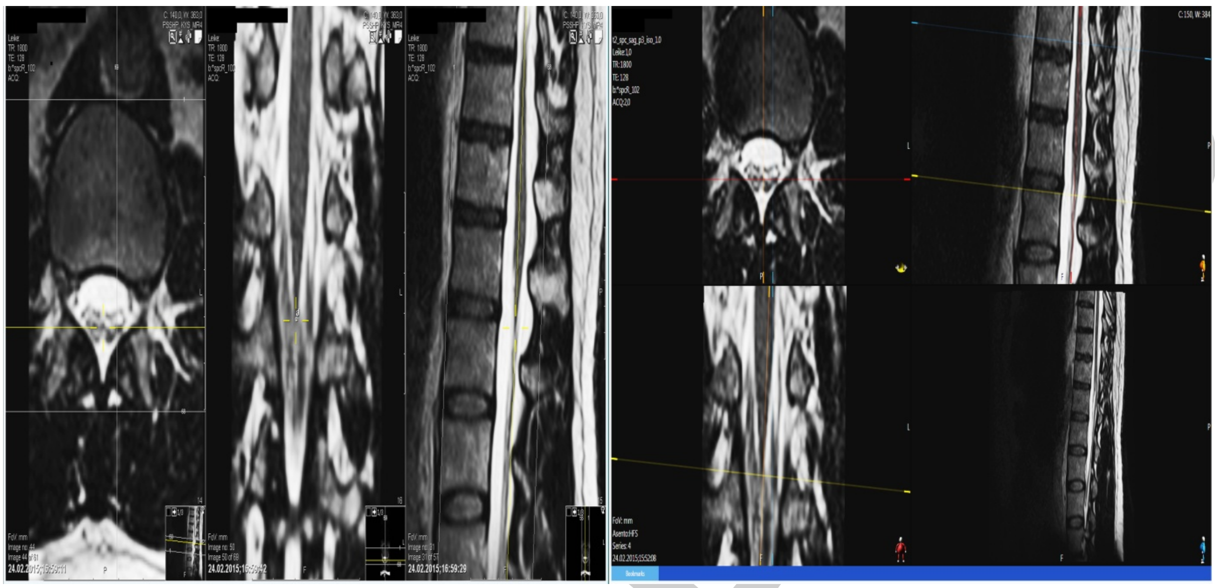

Figure 5. Magnetic resonance scans. Coronal slices of the thoracolumbar region of a sample subject during (A) reference scan, (C) unilateral symptomatic SLR, (E) unilateral asymptomatic SLR, and (G) bilateral SLR are presented. The apex of the conus medullaris is marked. The vertical distances from the upper vertebral endplate of the adjacent vertebral body are marked and presented in B, D, F and H. Original images and different measurements from both observers are presented.

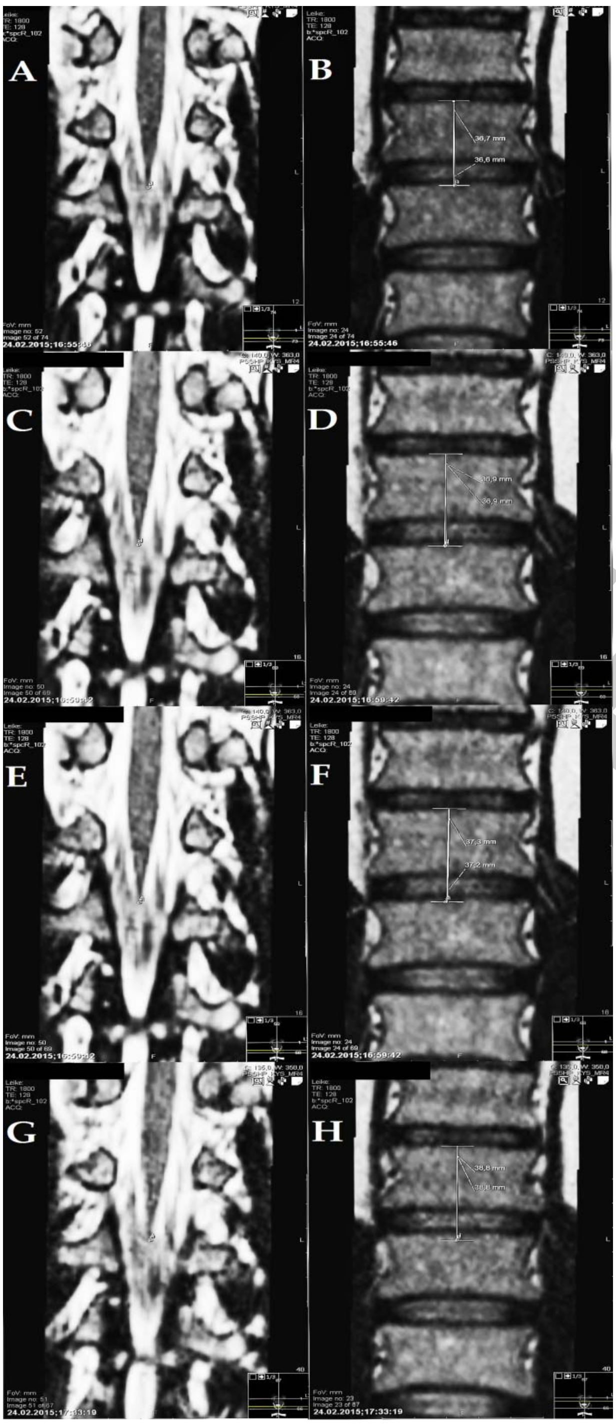

Figure 6. Conus medullaris caudal displacement with unilateral SLR test performed on the asymptomatic (ASYM) and symptomatic (SYM) side**.** Mean value and standard deviations of measurements are presented. Note the significant difference in conus movement with symptomatic and asymptomatic SLRs indicating limitation of neural adaptive movements with SLR on the symptomatic side. Values are expressed as negative to indicate the caudal direction of the displacement.

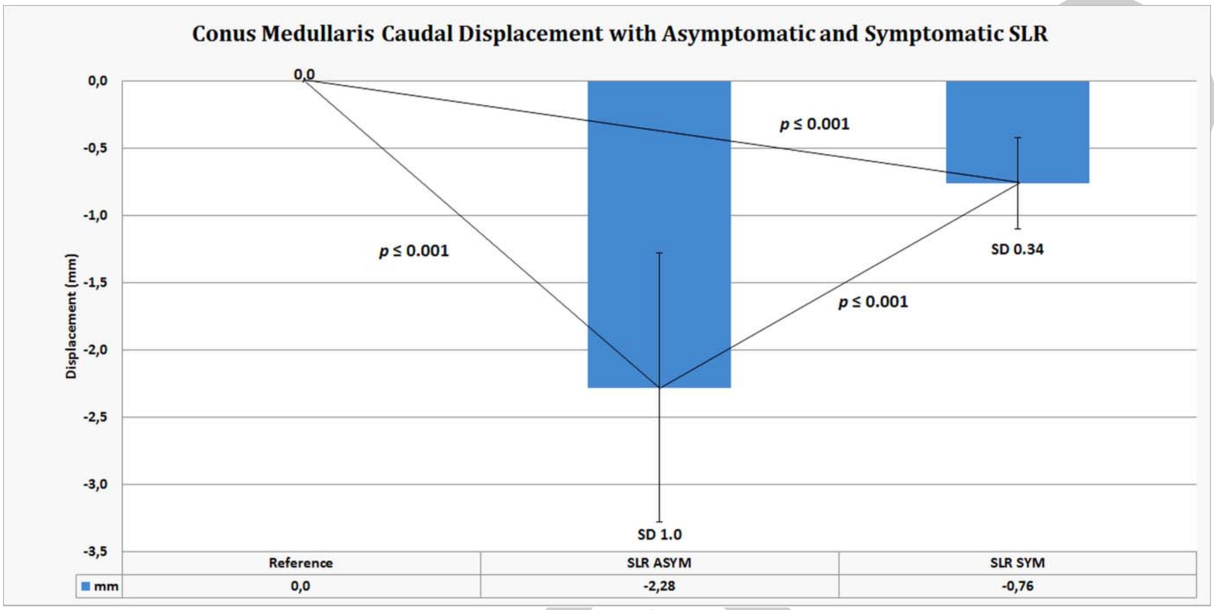

Figure 7. Conus medullaris displacement with unilateral and bilateral SLR. Mean value and standard deviations of measurements are presented. Values are expressed as negative to indicate caudal displacement. Note that compared with the unilateral SLR, the magnitude of conus displacement was almost double with the bilateral SLR indicating a linear relationship between magnitude of conus displacement and number of nerve roots involved into the movement (i.e. unilateral and bilateral SLRs).

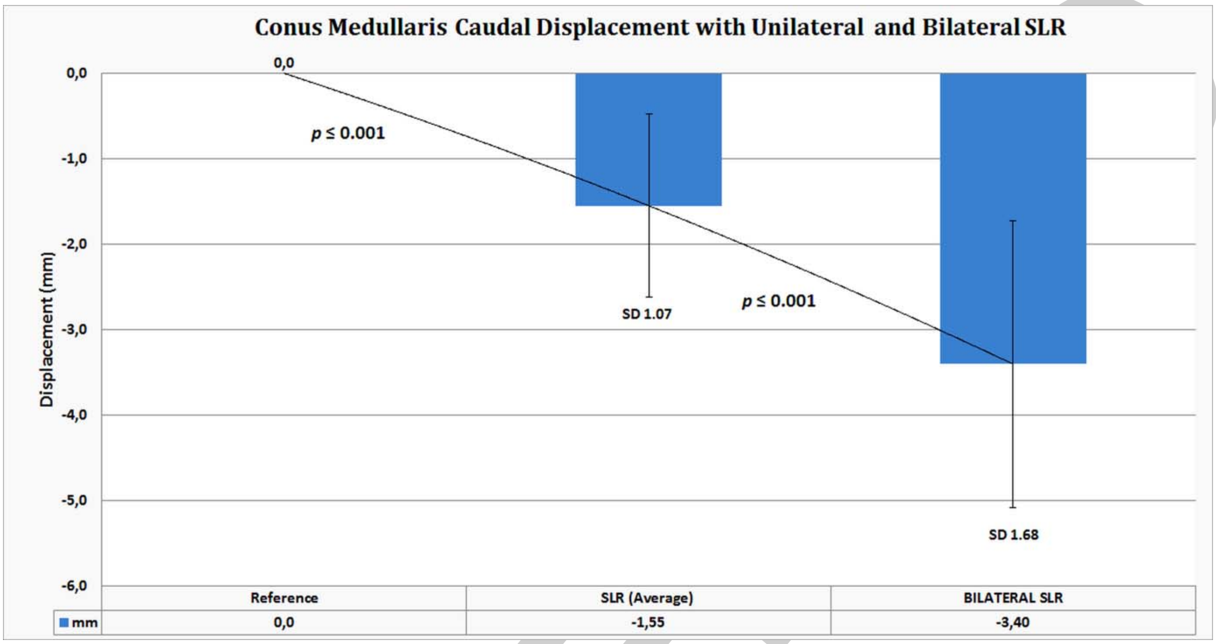

Table 1. Exclusion and inclusion criteria
Exclusion criteria
• Multisegmental or posterocentralLIDH verified to exist at MRI • Incomplete and/or painful knee extension • Incomplete and/or painful hip range of motion • History of previous lumbar surgeries • Other joint involvement, such as arthritis or already recognized metabolic bone disease • No clear signs of sciatic radiculopathy in anamnesis and at clinical examination • Clinical and/or radiological signs of lumbar spinal stenosis • Presence of pacemakers and ferromagnetic implants • Sciatic radiculopathy with SLR abnormal over 70° or under 45° of hip flexion
Inclusion criteria:
• Subjects with sciatica with segmental posterolateral LIDH verified to exist at MRI. • Subjects' consent to participate • No present exclusion criteria at the time of testing • Patient on sick leave due todisabling low back pain with proven radiculopathy • SLR "abnormal" at 45-70° of hip flexion

Table 2. Sample characteristics

Subject	Sex	Age (years)	Height (cm)	Weight (kg)	IVD herniation level	IVD herniation direction	Impinged nerve root	SLR abnormal (degrees of hip flexion)	VAS (BL/mm)	Herniation type
1	F	36	173	73	L4-L5	R	L5	50	68	Extrusion
2	M	40	171	100	L5-S1	L	S1	60	51	Extrusion
3	M	32	180	78	L5-S1	R	S1	60	64	Sequestration
4	M	23	189	88	L4-L5	R	L5	60	61	Extrusion
5	M	40	178	71	L4-L5	L	L5	55	72	Sequestration
6	M	42	188	95	L5-S1	L	S1	70	65	Extrusion
7	M	45	188	118	L4-L5	L	L5	70	63	Extrusion
8	F	35	163	79	L5-S1	L	L5	50	55	Extrusion
9	M	58	185	80	L4-L5	R	L5	70	59	Extrusion
10	M	46	186	90	L5-S1	L	L5	70	71	Extrusion
11	F	24	164	73	L4-L5	R	L5	60	69	Sequestration
12	M	26	182	72	L4-L5	L	L5	45	58	Extrusion
13	F	33	173	69	L4-L5	R	L5	65	64	Sequestration
14	M	41	185	92	L5-S1	L	S1	60	70	Sequestration
15	M	32	174	71	L5-S1	R	S1	60	69	Sequestration

Importantly, all the tested subjects were on sick leave due todisabling low back pain with proven radiculopathy.

VAS: visual analogic scale; BL/mm: baseline/millimetres

Table 3. Reproducibility values and observed power of conus medullaris displacement with SLRs

	RANGES (mm)		PEARSON'S CORRELATIONS			NUMBER OF SUBJECTS TESTED	NUMBER OF SUBJECTS NEEDED FOR SIGNIFICANT RESULTS	OBSERVED POWER
	MIN	MAX	RESULTS REPRODUCIBILITY	INTRA OBSERVER	INTER OBSERVER			
ASYMPTOMATIC SLR	-0.5	-3.7	0.995	0.999	0.999	15	5	1
SYMPTOMATIC SLR	-0.2	-1.4	0.999	0.999	0.999	15	5	1
BILATERAL SLR	-0.8	-6.2	0.999	0.999	0.999	15	5	1
REFERENCE SCAN			0.998	0.999	0.999	15		