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Low risk of underestimating dural sac cross-sectional area with conventional MRI: Insights from Axial-loaded MRI after decompression for lumbar spinal stenosis

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Abstract

Purpose

To evaluate the effect of axial-loaded MRI (AL-MRI) on dimensions of central canal or foramina in patients with lumbar spinal stenosis (LSS) following decompression surgery.

Methods

This study included patients with LSS from the spinal stenosis trial of the NORwegian Degenerative spondylolisthesis and Spinal STENosis (NORDSTEN-SST) study, five years after decompression surgery with one out of three minimally invasive techniques. MRI was performed without and with axial loading (AL-MRI). MRI measurement of dural sac cross-sectional area (DSCA), Schizas grading of central canal stenosis and Lee grading of foraminal stenosis (L2 – L5) were independently performed by two experienced radiologists.

Results

AL-MRI was performed on 64 patients, mean age at baseline was 65.6 (SD 7.1) years, 30 (46.9%) men. Mean DSCA showed small (between 6.7 and10.8 mm^2) but significant reduction comparing MRI without and with load at all lumbar levels($p < 0.001–0.018$), except at decompressed L2/L3 ($p = 0.435$). AL-MRI induced absolute DSCA reductions of similar magnitude at decompressed and non-decompressed levels, with percentage reductions slightly greater at non-decompressed segments (6.7–8.7% versus 4.6–6.0%). DSCA changes were not significantly different between the three decompression techniques. Changes of Schizas grades were only significant at non-decompressed L2/L3 and L3/L4 ($p = 0.003$ and 0.008, respectively), no significant changes for Lee grades were detected.

Conclusion

Compared to conventional MRI, AL-MRI induced significant but small reductions in DCSA at both decompressed and non-compressed levels, changes of Schizas grade were limited to non-decompressed levels. These findings suggest that the risk of underestimating restenosis after decompression using standard supine MRI is low.

Introduction

Magnetic resonance imaging (MRI) is the method of choice for assessment of degenerative changes and the severity of narrowing of the spinal canal in patients with lumbar spinal stenosis (LSS) (1). Due to its high tissue resolution, MRI can delineate the causes of stenosis and their effects on neural structures within the spinal canal and neural foramina. Quantitative assessment of spinal canal stenosis by

measuring the dural sac cross-sectional area (DSCA), or semiquantitative gradings (i.e. classification systems) are among the most common MRI methods used to grade the severity of spinal canal stenosis or foraminal stenosis in LSS. However, a consistent association between MRI findings and symptoms of LSS has not been established (2, 3). This inconsistency persists when evaluating patients after decompression surgery for LSS as well (4–6). Despite adequate decompression and MRI-confirmed widening of the spinal canal, up to 20–33% of patients may not achieve anticipated pain relief or improvement in functional outcomes after surgery (7, 8).

Routine MRI examinations of the lumbar spine are usually performed in supine position, which may not accurately reflect the impact of physiological weight-bearing on the narrowing of the spinal canal or neural foramina. Weight-bearing conditions can decrease the volume of the spinal canal and neural foramina, causing aggravation of the symptoms of the disease (1, 9, 10). Lumbar MRI may be performed in an upright (standing) position. Studies have demonstrated a higher correlation between MRI findings of upright MRI and measures of pain in patients with low back pain and LSS, compared to non-weight-bearing supine MRI (11). However, due to limited availability of open MRI systems needed for upright MRI, generally lower field strength leading to an inferior image quality, and other practical challenges (e.g. patients´ inability to remain still during the examinations), axial-loaded MRI (AL-MRI) performed in supine position can be used as an alternative (10, 12). A strong correlation between preoperative MRI parameters of LSS has been demonstrated when comparing supine AL-MRI with upright MRI (12).

Studies suggest that AL-MRI can reveal induced reductions of the central spinal canal and the foraminal area, and have the potential to demonstrate nerve root compromise more clearly than conventional supine imaging (10, 13). In addition to impact on preoperative MRI parameters in LSS, AL-MRI have demonstrated a stronger correlation with patient-reported pain and disability than conventional non-loaded MRI (10, 14, 15). The impact of axial loading on spinal canal and foraminal dimensions in LSS patients treated with decompression surgery remains unknown. Further, with different decompression techniques used in patients with LSS, the amount of tissue removal to reach the spinal canal somewhat vary. This could potentially affect the operated segment’s ability to withstand axial compression postoperatively. Understanding and evaluating the effects of loading on the spine can provide valuable insights into the postoperative diagnostic utility of AL-MRI.

The aim of the current study was to evaluate the influence of axial loading on central spinal canal and neural foramina at non-decompressed levels, as well as decompressed levels operated with three different minimally invasive surgical techniques.

Material and methods

Patients in the current study were enrolled from the spinal stenosis trial of the NORwegian Degenerative spondylolisthesis and Spinal STENosis (NORDSTEN-SST) study, a prospective, multicentre, randomised controlled trial that was designed to compare three minimally invasive surgical techniques used in treatment of LSS without degenerative spondylolisthesis. The techniques were unilateral laminotomy

with cross-over (UL), bilateral laminotomy (BL) and spinous process osteotomy (SPO). Two years post-surgery, no significant differences were observed between the methods in terms of achieved DCSA enlargement or patient-reported pain and disability (16, 17). In total, 437 patients from 16 Norwegian hospitals are included in the NORDSTEN-SST and the current prospective comparative imaging study was set to perform AL-MRI at five-year follow-up after surgery on a subgroup of patients from this cohort with geographical vicinity to an MRI unit with possibility to perform AL-MRI (three of 16 hospitals). Based on prior AL-MRI studies, a sample size of 16 patients per surgical group (UL, BL, SPO) was calculated to detect a 10 mm² difference in the DSCA with 80% power and a significance level of 0.05, assuming a standard deviation (SD) of 10 mm^2. To account for possible inability of some patients to endure axial loading, 24 patients in each surgical technique group were deemed reasonable (72 patients in total). Inclusion and exclusion criteria for the NORDSTEN-SST are detailed in Table 1.

In addition to the initial written informed consent necessary to be included in the NORDSTEN study, all patients included in the current study provided specific written informed consent, and the study was approved by the regional ethics committee (REK Vest ref. number 12076). The study was performed in accordance with the declaration of Helsinki and adhered to the ICMJE recommendations for the protection of research participants.

MR imaging

MRI examinations were performed in 1.5 Tesla field strength MRI with sagittal T1- and T2-weighted and axial T2-weighted images without and with axial loading (with the same imaging parameters without and with loading). Field of view and matrix size were 160 – 180 x 300 – 350 mm and 160 – 320 x 276 – 320 for sagittal and 200 - 220 x 200 – 220 mm and 320- 332 x 245 – 320 for axial images, respectively. Repetition time for T1- and T2-weighted sequences was 400 – 600 and 3000 – 4200 ms, echo time was 8 – 10 and 90 – 120 ms, respectively. Slice thickness was 4 mm for all images.

Axial loading was applied using DynaWell® L-Spine (Dynawell diagnostics Inc.,

Henderson, NY, USA). This portable compression device is placed on the MRI table before patient positioning. It was secured to the patients using a harness around shoulders, and two side-straps connected to foot plates (Fig. 1 a). The patients were informed in detail about the procedure and axial loading before examination. In the first step, the patients were scanned without axial loading. In the next step, without changing the patient's position, axial loading was applied by about 50% of the body weight of each individual patient. This amount of force was applied to both feet equally (approximately a quarter of body weight on each foot) and monitored by the in-built measurement devices (Fig. 1 b). The patients were asked for their body weight; scales were available to weigh in the case of doubt. The performing MRI technicians recorded the amount of axial load at the start and end of the load MRI. If the amount of axial load at the end was less than 40% of body weight, the patient was offered a repeat MRI examination in a separate session. Patients who could not endure a minimum of 40% of their body weight during axial loading were excluded. To simulate weight-bearing in standing position, the patients were instructed not to bend their knees during axial loading.

MRI evaluations

Two board-certified radiologists with 19 and 18 years of experience in musculoskeletal and spine imaging (HB and HH, respectively) performed measurements on MRI examinations at the L2-L5 levels, without and with axial loading. All MRI examinations were anonymised, and the two radiologists were blinded to each other's measurements. Inbuilt measurement tools of a picture archiving and communication system (ID7 Sectra PACS, Sweden) were used for the measurements. Measurements on MRI examinations without and with axial loading were performed in separate sessions, at least two weeks apart.

Severity of spinal canal stenosis was assessed on axial T2-weighted images both quantitatively by the DSCA, and semiquantitatively by the Schizas classification (18).

The DSCA was measured by manual segmentation of the dura, calculating the actual area of the dural sac (excluding the epidural fat) (Fig. 3). The Schizas classification system has four grades; grade A indicates no stenosis with abundance of cerebrospinal fluid (CSF) around rootlets inside the spinal canal, grade B indicates grey signal from CSF with recognisable rootlets, grade C indicates grey-black signal from CSF with no clearly recognisable rootlets and grade D indicates findings of grade C and absence of epidural fat.

Semiquantitative grading of foraminal stenosis was assessed on sagittal T1-weighted images, using a classification proposed by Lee et al. (19). This classification has four grades; grade 0 indicates no obliteration of the perineural fat, grade 1 indicates obliteration of the perineural fat either horizontally or vertically, grade 2 indicates obliteration of the perineural fat both horizontally and vertically and grade 3 indicates complete obliteration of the perineural fat and structural changes in the nerve. All the MRI parameters were registered for the surgically treated, as well as for the non-operated levels (L2-L5).

Statistical analyses

Continuous variables were reported as means and SDs, categorical variables as absolute and relative frequencies. Two-sided Wilcoxon signed-rank test and McNemar tests were used to compare continuous (DSCA) and categorical (Schizas and Lee grades) values without and with axial loading, respectively. The values for non-decompressed and decompressed levels, without and with axial loading were compared separately. For the DSCA, the mean value of measurements from the two raters were used. For the categorical variables measurements from one of the raters (the primary investigator HB) were used in the statistical analyses. This choice was made based on the high interobserver reliability of these parameters. Delta values for the DSCA changes were calculated and a linear regression model with a corresponding F-test was used to compare means across the three decompression techniques. For better clinical relevance, the categorical parameters (Schizas and Lee grades) were dichotomised; Schizas grades A and B were categorised into category 0, and grades C and D into category 1; Lee grades 0 and 1 were categorised into category 0 and grades 2 and 3 into category 1 (6, 20). Intraclass correlation coefficient (ICC) was used to assess the interobserver reliability of the DSCA measurements

and Gwet's agreement coefficient (AC1) to assess the interobserver reliability of the categorical measurements. ICC values were interpreted to indicate poor (< 0.50), moderate (0.51 – 0.75), good (0.76 – 90) and excellent agreement (> 91) (21). AC1 values were interpreted using a scale for κ defined by Landis and Koch (22), indicating poor (≤ 0.0), slight (0.01– 0.20), fair (0.21– 0.40), moderate (0.41– 0.60), substantial (0.61– 0.80) or almost perfect (0.81– 1.00) agreement. Significance level was set to ≤ 0.05.

All statistical calculations were performed using Stata software (StataCorp. LLC. Release 18. College Station, TX, USA).

Results

Out of 72 patients initially enrolled in the current study, eight patients were excluded. The causes of the exclusions are presented in the flowchart (Fig. 2). In total, AL-MRI of 64 patients performed between May 2021, and March 2024 were included in the statistical calculations. Among the included patients, 48 (75%) were able to perform axial loading with 50% body weight, the remaining performed loading with values between 40% and 50%. Mean age of the patients at baseline (inclusion in the NORDSTEN-SST) was 65.6 years (SD 7.1 years), mean body mass index was 27.8 (SD 3.6) and 30 (46.9%) were men. Distribution of the patients with regard to the surgical techniques was even; 22 patients (34.4%) were operated with UL, 22 (34.4%) with BL and 20 (31.3%) with SPO. In total, 177 levels (L2-L5) were examined, of which, 83 (46.9%) levels were surgically decompressed.

DSCA changes without and with axial loading

There were statistically significant changes of DSCA with axial loading both for non-treated and surgically treated levels (Table 2). Mean DSCA for all non-treated levels (L2/L3, L3/L4 and L4/L5) was 113 (SD 39) mm^2 without and 104 (SD 39) mm^2 with axial loading ($p < 0.001$). For surgically treated levels, mean DSCA was 145 (SD 51) mm^2 without and 137 (SD 49) mm^2 with axial loading ($p < 0.001$).

Axial loading induced comparable absolute reductions in DSCA at decompressed and non-decompressed levels; however, statistically significant changes were more consistent at non-decompressed segments (Table 2). Given the larger baseline DSCA at decompressed levels, the relative (percentage) reduction in area was smaller in this group (Table 2). At individual lumbar levels, significant loading-induced DCSA reductions were observed at all non-decompressed levels ($p < 0.001$), and at all decompressed levels ($p = 0.009–0.018$), except at the surgically decompressed L2/L3 level ($p=0.437$). The percent changes with corresponding p values and 95% CIs are presented in Table 2.

Comparison of DSCA changes between decompression techniques

Baseline DSCA measurements for the three decompression techniques did not show statistically significant differences. Comparisons of the adjusted means (margins) showed no significant load-induced differences between the three techniques ($p > 0.05$). Mean changes of the DSCA for each level

and decompression technique, together with 95% CIs and p values for F test probability are presented in Table 3. It should be noted that there were few observations at the L2/L3 levels (no observation for UL at this level), and the 95% CIs were generally wide. The mean load induced DSCA change for all levels was highest for BL (10.6 mm^2) and lowest for SPO (4.2 mm^2) (table 3).

Changes of the Schizas and the Lee grades

Dichotomised Schizas grades changed from category 0 (A and B) to category 1 (C and D) at several levels which were statistically significant only for the non-decompressed levels of L2/L3 and L3/L4 (p = 0.003 and p = 0.008, respectively). Generally, the effect sizes varied and were larger for the non-decompressed levels; the 95% CIs were wide (table 4). Changes of dichotomised Lee grades were not consistent; there were several changes from category 0 (grades 0 and 1) to category 1 (grades 2 and 3) but for some levels and sides the categories changed from 1 to 0. However, none of these changes were statistically significant (Table 4).

Interobserver reliability

Interobserver reliability of DSCA measurements without and with axial loading for surgically decompressed and non-decompressed levels were good or excellent (ICC range 0.84 – 0.99). For the Schizas classification, interobserver reliability was substantial or almost perfect (AC1 range 0.70 – 0.90). For foraminal stenosis (Lee classification), interobserver reliability was almost perfect for all lumbar levels (AC1 range 0.80 – 0.98), except for decompressed L4/L5 levels without and with axial loading where the reliability was substantial (AC1 without and with loading 0.77 and 0.74, respectively).

Discussion

In this study, we evaluated the effect of axial loading on central spinal canal and foraminal stenosis for both surgically decompressed and non-decompressed levels, five years after surgery for LSS. The main finding was that axial loading induced a small reduction of the DSCA, both at surgically treated and non-treated levels. The induced DSCA reduction was statistically significant, except for surgically treated L2/L3 level. The DSCA differences without and with axial loading for the surgically treated levels did not show significant differences between the three decompression techniques (UL, BL and PSO). Patients in the current study were enrolled from a larger cohort of patients who were surgically treated for LSS (the NORDSTEN-SST); baseline demographics were similar between the current study and the NORDSTEN-SST (age, male sex and BMI 65.6, 46.9% 27.8 in the current and 66.8, 52,7% and 27.8 in the NORDSTEN-SST, respectively) (6). Thus, the results of the current study may be generalised to other patients with symptomatic LSS without degenerative listhesis, who are treated by minimally invasive techniques.

Similar to present findings, Kanno et al. (15) reported that axial loading induced significant reductions in DCSA, with more pronounced effects at levels with severe stenosis. In the current study, decompressed levels exhibited larger DCSA than non-decompressed levels without axial loading; consequently, the relative (percentage) reduction under axial loading was smaller at decompressed segments compared

with non-decompressed segments (approximately 5.6% versus 8%, Table 2). However, although no formal statistical comparison between surgically treated and untreated levels was performed, the absolute magnitude of the load-induced DCSA changes were small in both groups, indicating overall limited dynamic variation by axial loading.

Small dynamic changes at decompressed levels five years after surgery are likely to be caused by the known high degree of degeneration at these segments but may also be considered as a confirmation that no destabilisation was caused by any of the surgical techniques used. A considerable proportion of the non-operated levels in the present patient cohort would likewise be expected to exhibit significant degenerative changes, which could explain small dynamic changes also non-decompressed levels These findings support the rational for not routine usage of Al-MRI for assessing decompressed levels in patients with suboptimal postoperative outcomes, as the risk of overestimating central or foraminal canal area dimensions appear to be minimal.

Using an alternative compression device, Fang et al. reported significant DCSA reductions during axial loading in asymptomatic individuals (23). These authors reported improvement of the diagnostic yield using AL-MRI in patients with suspected LSS by unmasking functionally relevant stenosis not evident on standard supine MRI (23). Although the magnitude of induced changes in the current study is not likely to be clinically relevant in the majority of cases (i.e. unlikely to alter clinical management), the findings on non-operated patients underscore the potential value of axial loaded imaging in selected cases, such as radiologically borderline stenotic cases or when symptoms do not align with conventional imaging findings.

Schizas and Lee grades showed predominantly non-significant changes and small effect sizes under axial loading. In contrast to our findings, Hebelka et al. (13) reported significant neural foraminal changes under axial loading, assessed both quantitatively and by Lee classification, showing a modest mean reduction of 2%, but with individual variability up to ± 50%. However, this study was performed on younger patients with nonspecific low back pain who were not surgically treated, why these results are not comparable to the current study. Despite significant changes with axial loading at some levels in the current study, the lack of global changes of the semiquantitative gradings supports that the risk of underestimating foraminal nerve compromise and central canal packing of the spinal rootlets with conventional (unloaded) MRI remains minimal.

Previous publications from the NORDSTEN group reported comparable postoperative increase of the DSCA following decompression using the three surgical techniques evaluated in the current study (24). The findings of the current study support our prior assumptions that none of these techniques induce instability at the treated segments. Nevertheless, a small difference between surgical groups was observed with the BL showing a greater change in the DSCA under axial loading. This may suggest that removing more of the lamina, and posterior parts of the facet joints with the BL technique might have the potential to reduce resistance to axial loading. Although the SPO technique is generally considered the most invasive of the three methods, the lamina and posterior parts of the facet joints are less affected

despite greater influence on posterior structures. Overall, the differences between the surgical techniques in the current study were small and unlikely to be clinically significant. This observation requires further investigation with a larger sample size and cannot, based on the current results, be used to favour any specific surgical technique.

Comparative studies evaluating axial load–induced changes on the spinal canal and neural foramina in patients with LSS using minimally invasive techniques are lacking. In a study evaluating LSS patients with AL-MRI preoperatively and three months after decompressive surgery, Hjaltadottir et al. (25) demonstrated significant increase of the spinal canal area as well as improved Schizas classification postoperatively compared to baseline. However, they did solely investigate patients with axial loading pre- and postoperatively and did not evaluate load induced differences.

The interobserver reliability in this study was good, both for non-decompressed and surgically decompressed levels, consistent with previous reports on preoperative axial loading of the lumbar spine (12, 25). Reliability for Lee classification was slightly lower at decompressed levels compared to the non-decompressed levels (both without and with axial loading) but still indicated substantial or good agreement. Notably, our reliability values for foraminal stenosis exceeded those previously reported (10), possibly reflecting greater observer experience in the present study.

Strengths and limitations

The main strength of the current study was prospective inclusion of patients from a well-organised cohort of patients with LSS who were treated with one of the three minimally invasive decompression techniques. Distribution of the included patients was even in these three groups, making the effects of axial loading comparable. Limitations included the explorative design of the study and inclusion of patients only from three of the 16 sites of the NORDSTEN study, primarily due to geographic constraints. Most of the surgical decompressions were performed at the L4/L5 and L3/L4 levels meaning the AL-MRI at the L2/L3 level was mostly performed at non-decompressed levels. Particularly for the categorical parameters, there were few measurements after decompression at the L2/L3 level. The statistical calculations included multiple testing for several levels. However, we did not adjust the p values for multiple testing since this method is not broadly accepted.

Conclusion

In this cohort of LSS patients treated with minimally invasive decompressive surgery evaluated at five-year follow-up, AL-MRI induced significant but small reductions in DSCA compared to conventional MRI in both surgically treated and untreated levels. Also changes of Schizas grading to a more stenotic category were more common at the non-treated levels. Changes of the DSCA did not differ significantly between the three minimally invasive decompression techniques used. These findings suggest that conventional supine MRI carries low risk of underestimating restenosis at surgically treated levels utilising modern decompression techniques.

Declarations

Ethics approval and consent to participate

This study was approved by the Norwegian regional committees for medical research ethics (Central and western regions ref. numbers 12076 and 2011/2034, respectively). All patients provided written informed consent.

Conflict of interest

The authors declare that they have no conflicting interests.

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Author Contribution

All the listed authors have been involved in the design of the study and made substantial contributions to the concept of the study. The initial design of the study was made by He.B, EH and the corresponding author (HB), who also together with HH performed the radiological measurements. HB performed the statistical calculation under the supervision of senior statistician TÅM and drafted the manuscript. All the listed authors have critically reviewed the manuscript, made substantial contributions to the manuscript, and approved the final version.

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Data Availability

The datasets used and/or analysed during the current study are available from the corresponding author on a reasonable request.

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Tables

Table 1. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
• Age between 18 and 80 years • Clinical symptoms of LSS • Not responding to at least 3 months of non-surgical treatment • Radiological findings of LSS corresponding to the clinical symptoms such as back pain, leg pain or neurologic claudication • Understanding the Norwegian language (spoken and written) • Ability to perform AL- MRI	• Previous surgery at the level of stenosis • Previous fracture or fusion of the thoraco-lumbar spine • Cauda equina syndrome (bowel or bladder dysfunction) or fixed complete motor deficit • ASA grade 4 or 5 • More than 20° lumbosacral scoliosis • Distinct symptoms in lower limbs due to other diseases or inflammation in the muscles • Stenosis in more than three lumbar levels • Being unable to comply fully with the study protocol • Isthmic defect in pars interarticularis at the level of stenosis • Participation in another clinical study that could interfere with the present trial • Alcohol or substance abuse • ≥ 3 mm spondylolisthesis verified on upright lateral view X-ray. Axial T2-weighted MR images not covering the paraspinal and the psoas muscles at both sides of the spine or angled more than 5 degrees to the upper endplate of the vertebra at level of measurement

AL-MRI: *Axial load MRI****, ASA*** American Society of Anesthesiologists score, ***LSS*** Lumbar spinal stenosis.

Table 2. DSCA changes without and with axial loading

	No loading	Loading				
	Mean (SD)	*Mean (SD)*	*Delta (SD)*	*Change(%)*	*95% CI*	*P value*
Non-decompressed L2/L3 (n=46)	123.7 (42.7)	112.8 (40.1)	10.8 (14.7)	8.7	6.5 – 15.2	< 0.001
Decompressed L2/L3 (n=6)	142.6 (50.3)	135.9 (45.0)	6.7 (13.2)	4.6	-7.1 – 5.4	0.435
Non-decompressed L3/L4 (n=29)	104.6 (33.8)	97.6 (36.1)	7.1 (25.1)	6.8	-2.5 – 16.6	< 0.001
Decompressed L3/L4 (n=35)	130.0 (43.7)	122.1 (41.6)	7.9 (15.7)	6.0	2.5 – 13.2	0.009
Non-decompressed L4/L5 (n=22)	108.9 (58.7)	101.7 (58.9)	7.3 (9.8)	6.7	2.9 – 11.6	< 0.001
Decompressed L4/L5 (n=42)	149.0 (57.4)	141.4 (58.2)	7.6 (19.9)	5.0	1.4 – 13.8	0.018
Non-decompressed L2-L5 (n=58)	113.1 (39.3)	104.1 (38.7)	9.1 (10.8)	8.0	6.2 – 11.9	< 0.001
Decompressed L2-L5 (n=61)	144.9 (50.7)	136.8 (49.2)	8.2 (14.8)	5.6	4.4 - 12	< 0.001

CI: Confidence interval, DSCA: Dural Sac Cross-sectional Area (mm^2), SD: Standard deviation

Table 3. Mean delta values for DSCA changes without and with axial loading by three surgical decompression techniques

Change (mm^2)	BL* (95% CI)	SPO (95% CI)	UL (95% CI)	P value
L2/L3, n=6	9.8 (-9.3 – 28.8)	0.5 (-26.5 – 27.5)	**	0.479
L3/L4, n=35	10.4 (1.0 – 19.8)	5.2 (-4.7 – 14.9)	7.8 (-1.56 – 17.2)	0.733
L4/L5, n=42	7.5 (-2.4 – 17.4)	3.3 (-9.7 – 16.2)	10.7 (0.16 – 21.2)	0.667
L2-L5, n=61	10.6 (4.3 – 16.9)	4.2 (-2.6 – 11.0)	9.2 (2.6 – 15.9)	0.370

*BL: Bilateral laminotomy, CI: Confidence interval, DSCA: Dural sac cross-sectional area, SPO: Spinous process osteotomy, UL: Unilateral laminotomy with cross-over. * Reference category, **No observations.*

Table 4. Changes of Schizas and Lee grades from category 0 to 1 without and with axial loading

Schizas grading					
	No loading *Cat.1 (%)*	**Loading *Cat.1(%)***	***Cat. Change (%)***	***95% CI***	***P value***
Non-decompressed L2/L3 (n=46)	15(33)	27(57)	12(26)	0.0 – 0.6	0.003
Decompressed L2/L3 (n=6)	2(33)	2(33)	0(0)	0 – 1.9	1.000
Non-decompressed L3/L4 (n=29)	11(38)	19(66)	8(28)	0. – 0.6	0.008
Decompressed L3/L4 (n=35)	10(29)	14(40)	4(11)	0 – 1.9	0.290
Non-decompressed L4/L5 (n=20)	5(25)	4(20)	1(5)	1 - 118	1.000
Decompressed L4/L5 (n=41)	3(7)	7(17)	4(10)	0 – 1.5	0.125
Lee grading right side					
Non-decompressed L2/L3 (n=58)	3(5)	*3(5)*	*0(0)*	*0 – 78.5*	*1.000*
Decompressed L2/L3 (n=6)	2(33)	1(16)	-1(16)	-0.2 – 0.6	1.000
Non-decompressed L3/L4 (n=29)	5(17)	5(17)	0(0)	0 – 78.5	1.000
Decompressed L3/L4 (n=35)	10(29)	9(26)	-1(3)	0.2 - 18	1.000
Non-decompressed L4/L5 (n=22)	3(14)	3(14)	0(0)	0 – 78.5	1.000
Decompressed L4/L5 (n=42)	14(33)	15(36)	1(2)	0.2 - 18	1.000
Lee grading left side					
Non-decompressed L2/L3 (n=58)	2(33)	0(0)	-2(33)	-0.1 – 0.1	0.500
Decompressed L2/L3 (n=6)	2(33)	2(33)	0(0)	-0.2 – 0.2	1.000
Non-decompressed L3/L4 (n=29)	3(10)	1(3)	-2(7)	-0.1 – 0.2	0.500

Decompressed L3/L4 (n=35)	10(29)	11(31)	1(3)	-0.2 – 0.1	1.000
Non-decompressed L4/L5 (n=22)	4(18)	4(18)	0(0)	-0.1 – 0.1	1.000
Decompressed L4/L5 (n=42)	13(31)	12(29)	-1(2)	-01 – 0.2	1.000

Cat. : Category, Schizas categories: 0 (A and B) and 1(C and D), Lee categories: 0 (0 and 1) and 1 (2 and 3), CI: Confidence interval.

Figures

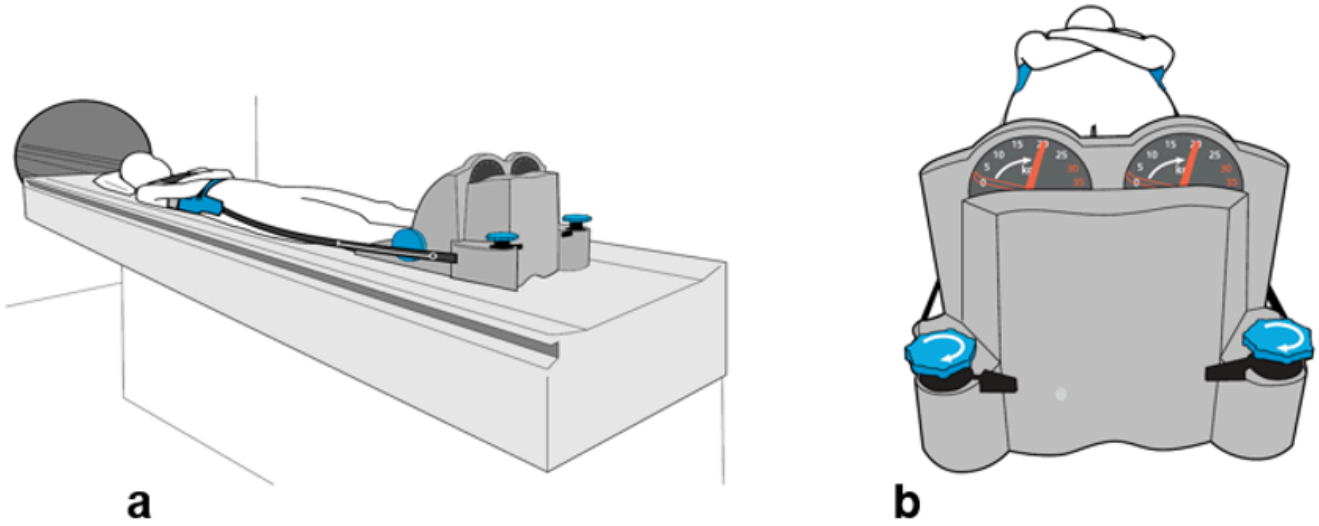


Figure 1

The DynaWell axial load device, a) demonstration of the device, the harness and the side-straps, b) the in-build monitor system for applying desired force to the feet.

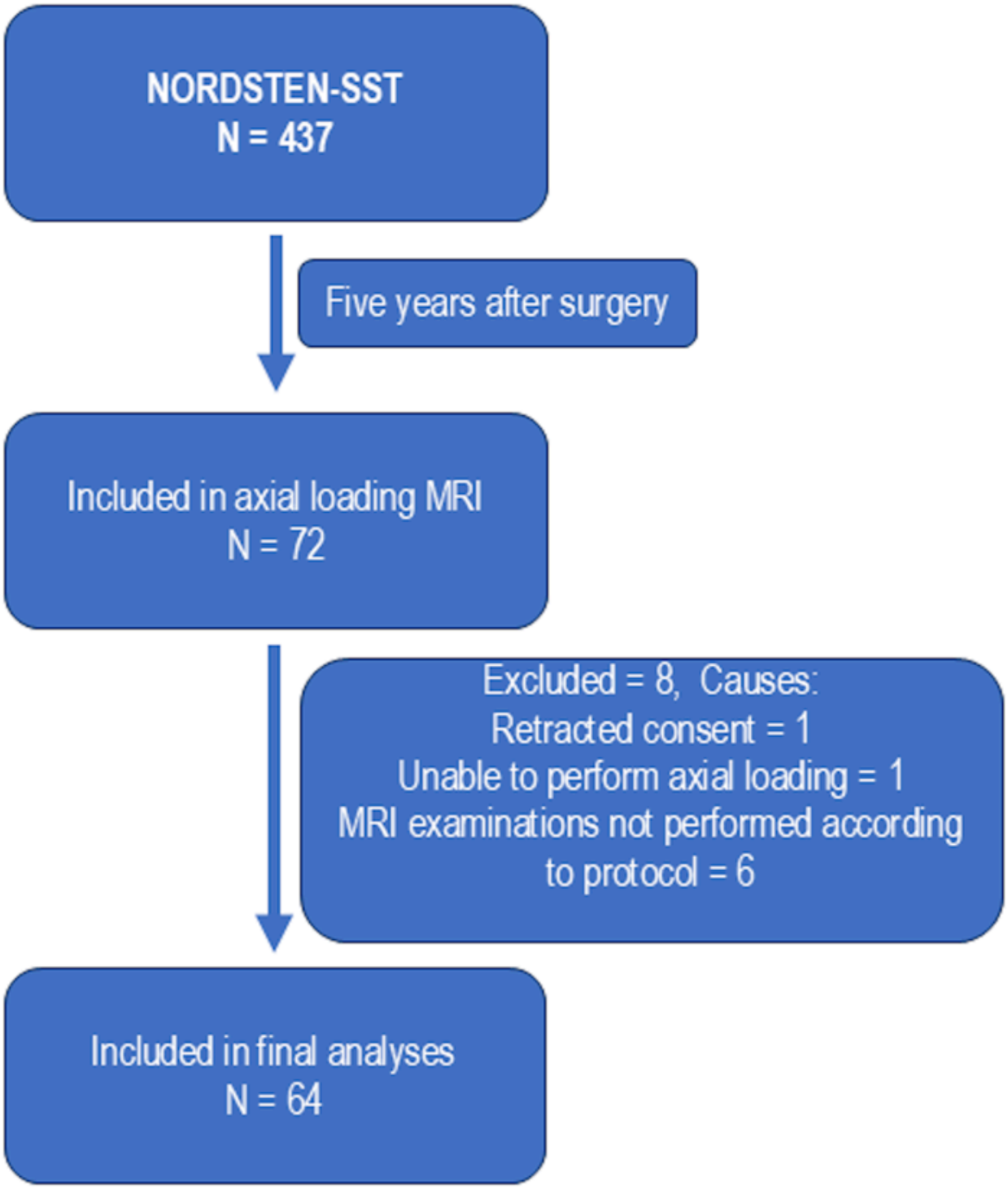


Figure 2

Flowchart of the included patients in the current study.

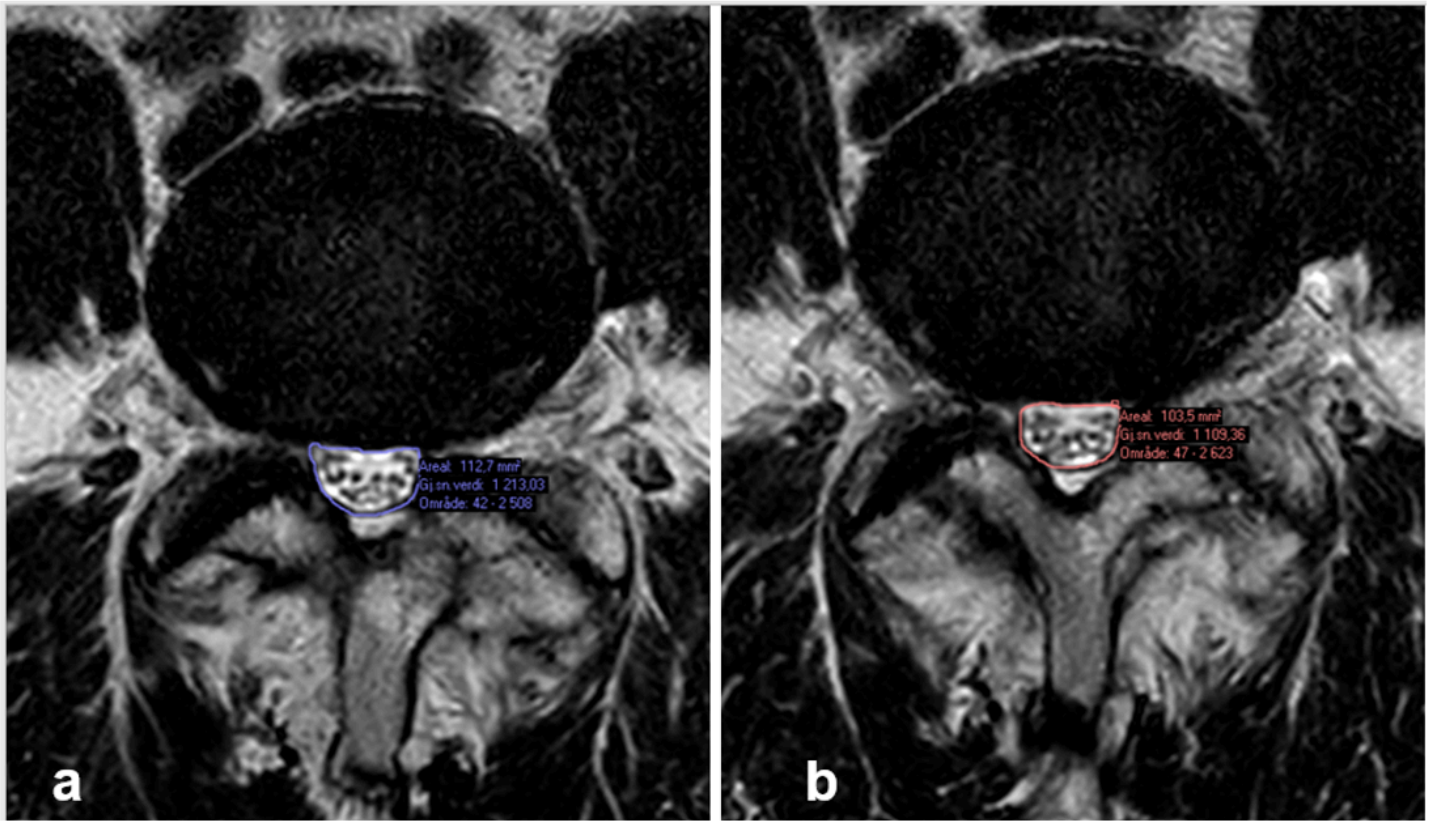


Figure 3

Axial T2-weighted MRI at the L3/L4 level before (a) and during (b) axial load. Dural sac cross-sectional area at the level of decompression is measured to 112.2 mm^2 before and 103.5 mm^2 during axial loading.