OPEN

Change in Lumbar Lordosis After Decompressive Surgery in Lumbar Spinal Stenosis Patients and Associations With Patient-Related Outcomes Two Years After Surgery: Radiologic and Clinical Results From the NORDSTEN Spinal Stenosis Trial

Josefin Åkerstedt, MD, PhD,[a] Johan Wänman, MD, PhD,[a] Hasan Banitalebi, MD, PhD,[b,c] Tor Åge Myklebust, PhD,[d,e] Clemens Weber, MD, PhD,[f,g] Kjersti Storheim, PhD,[h] Christian Hellum, MD, PhD,[i] Kari Indrekvam, MD, PhD,[j,k] Erland Hermansen, MD, PhD,[d,j,l] and Helena Brisby, MD, PhD[m,n]

Study design. A prospective cohort study.

Objective. The aim was to investigate changes in lumbar lordosis (LL) and its association to changes in patient-reported outcome measures (PROMs) after decompressive surgery for lumbar spinal stenosis (LSS).

Summary of background. Few studies have addressed change in LL after decompression surgery for LSS in relation to outcomes.

Materials and Methods. Preoperative and postoperative data from 310 patients having standing x-ray both before and two years after surgery were included. The patients were grouped based on the change in LL preoperatively to two years after surgery; group 1: $< 5°$ (n = 196), group 2: ≥ 5 $< 10°$ (n = 55), or group 3: $\geq 10°$ (n = 59) of change in LL. The changes in function, disability and pain were assessed by the Oswestry disability index (ODI), numeric rating scale (NRS), and the Zurich claudication questionnaire (ZCQ). The three groups were compared regarding baseline variables using the ANOVA test for continuous variables and the χ^2 test for categorical variables. The groups were further compared with a likelihood ratio test in relation to changes in PROMs two years after surgery and outcomes were adjusted for respective baseline PROMs, age, sex, smoking, BMI, Schizas, and Pfirrmann scores.

Results. LL was significantly changed at group level two years after surgery with a mean difference of 2.2° (SD: 9.4°) ($P = 0.001$). The three LL change groups did not show any significant differences in patient characteristics, function, disability, and pain at baseline. The two groups with a change of more than 5° in LL two years after surgery (group 2 and 3) had significantly greater improvements in ODI ($P = 0.022$) and ZCQ function ($P = 0.016$) in the adjusted analyses, but was not significant for back and leg pain

Conclusion. Changed LL after decompressive surgery for LSS was associated with improved ODI and physical function.

Level of Evidence. Level III.

Key words: lumbar lordosis, lumbar spinal stenosis, lumbar spine surgery, patient-reported outcome measures

(*Spine* 2025;50:40–45)

The natural curvature in the sagittal plane of the lower back, lumbar lordosis (LL), is individual and correlates with the overall alignment of the spine.[1] Over a

Received for publication January 25, 2024; accepted April 26, 2024.

From the [a]Department of Surgical and Perioperative Sciences (Orthopedics), Umeå University, Umeå, Sweden; [b]Department of Diagnostic Imaging, Akershus University Hospital, Akershus, Norway; [c]Institute of Clinical Medicine, University of Oslo, Oslo, Norway; [d]Department of Research and Innovation, Møre and Romsdal Hospital Trust, Ålesund, Norway; [e]Department of Registration, Cancer Registry Norway, Oslo, Norway; [f]Department of Neurosurgery, Stavanger University Hospital, Stavanger, Norway; [g]Department of Quality and Health Technology, University of Stavanger, Stavanger, Norway; [h]Communication and Research Unit for Musculoskeletal Health (FORMI), Oslo University Hospital, Oslo, Norway; [i]Division of Orthopedic Surgery, Oslo University Hospital Ullevål, Oslo, Norway; [j]Kysthospitalet in Hagevik, Orthopedic Clinic, Haukeland University Hospital, Bergen, Norway; [k]Department of Clinical Medicine, University of Bergen, Bergen, Norway; [l]Institute of Health Science, Norwegian Uniiversity for Technology and Science, Trondheim, Norway; [m]Department of Orthopaedics, Sahlgrenska University Hospital, Gothenburg, Sweden; and [n]Department of Orthopaedics, Institute for Clinical Sciences, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden.

The authors report no conflicts of interest.

Address correspondence and reprint requests to Josefin Åkerstedt, MD, PhD, Umeå University Hospital, Daniel Naezéns vag, Umeå 907 37, Sweden; E-mail: josefin.akerstedt@regionvasterbotten.se

DOI: 10.1097/BRS.0000000000005037

lifetime LL tends to decrease, and patient related factors such as sex and range of motion have also been shown to influence LL.[2] The presence of degenerative conditions of the lumbar spine increases with age and recent data show that a total of 102 million (1.4%) Europeans are diagnosed with lumbar spinal stenosis (LSS) yearly.[3] In the Norwegian population the number of LSS surgeries have more than tripled between 1999 and 2013 and the rates of decompressive surgeries over fusion surgery have drastically increased.[4] This trend of increased rate of LSS surgeries is also seen in other countries.[4,5] Degenerative changes of the lumbar spine may per se influence the LL but LL may also influence patients adapting to postural changes such as forward leaning, alleviating pain as the cross-sectional area of the spinal canal is increased.[6] Patients with symptomatic LSS have been shown to have lower LL compared with a control group without symptoms.[7]

Previous studies on changes in LL after decompressive surgery for LSS have found a small but significant increment and change in LL after decompression without fusion for LSS.[8–11] Few studies have addressed the associations between changes in LL and PROMs, and to our knowledge no other study has adjusted the results for other variables that may have an impact on the outcomes after surgery. Thus, this study aims to investigate the association between change in LL and change in PROMs preoperatively to two years after decompressive surgery for LSS.

MATERIALS AND METHODS

Study Population

This cohort study is a secondary analysis of data from the multicenter randomized Spinal Stenosis Trial (SST) from the NORwegian Degenerative spondylolisthesis and spinal STENosis (NORDSTEN) study.[12–14] The inclusion and exclusion criteria for the NORDSTEEN-SST with the addition of the specific radiologic requirements, standing x-ray before and two years after surgery, for this study are presented in Table 1. A corresponding flow chart of the study cohort is presented in Figure 1. At baseline, information about age, gender, body mass index (BMI), smoking and Oswestry disability index score (ODI), Zurich Claudication Questionnaire score (ZCQ), and numeric rating scale score (NRS) for leg and back pain and the minimally invasive surgical procedures (unilateral laminotomy with crossover, bilateral laminotomy, and spinous process osteotomy) were registered. The surgical procedures were unilateral laminotomy with crossover (n = 104), bilateral laminotomy (n = 101), and spinous process osteotomy (n = 105). The three randomized surgical groups showed no clinical differences,[12] and consequently, the patients were treated as one cohort in the present analyses. All surgical techniques involved some degree of detachment of the multifidus muscle along with flavectomy, laminotomy, and medical facetectomy. The surgical techniques have previously been described in more detail.[12]

Radiologic Imaging Preoperative and Postoperative

LL was measured on standing lateral x-rays of the lumbar spine in neutral position, between the upper endplate of L1 and the upper endplate of S1 (Fig. 2). The patients were categorized into three groups based on the change of LL between the preoperative and the two-year postoperative x-rays: change in LL of $< 5°$ (group 1), ≥ 5 and $< 10°$ (group 2) or $\geq 10°$ (group 3). The intervals of change as represented by group 1, 2, and 3 were selected based on the established 5° measurement error[15] found in literature and the $> 10°$ change found to lead to a significant change in physical scores after decompressive surgery for LSS.[16] All radiologic images were imported and stored in a Picture and Archiving Communicating System (PACS), Sectra IDS7, Sweden, where the integrated software tools for angle measurements were used. Measurements of LL on a set of 50 postoperative lateral standing x-rays were performed on two occasions by two spine surgeons to establish the interobserver and intraobserver reliability of the LL measurements.

Outcome Assessment and Patient-Reported Outcomes Measures (PROMs)

The PROMs used in this study were self-administered at the admission for surgery (baseline) and at two years after surgery. The outcomes investigated was changes in pain-related physical function assessed by the ODI (0–100), NRS (an 11-point scale from 0, none to 10, worst possible) for back and leg pain and the ZCQ, a self-administered measures for evaluation of symptom severity and physical function (symptom severity range of scores 1–5, physical function scale range of scores 1–4, and patient satisfaction scale range 1–4), in lumbar spinal stenosis in relation to the three different group of changes in LL after surgery.[17,18]

Statistical Analysis

Descriptive statistics for continuous variables are presented as means with standard deviation and categorical data are presented as numbers and percentages. Intraclass correlation coefficient (ICC) was used for calculation of interobserver and intraobserver reliability of the LL measurements. The mean changes in PROMs; ODI, ZCQ, and NRS (for back and leg pain) are presented with means with a 95% CI. Groups at baseline were compared using the ANOVA test for continuous variables and the χ^2 test for categorical variables. The three groups were compared with a likelihood ratio test in relation to changes in PROMs two years after surgery. The changes in PROMS two years after surgery in relation to the three groups of different change of LL were adjusted for respective baseline PROMs and for age, sex, smoking, BMI, Schizas, and Pfirrmann scores. A $P < 0.05$ was considered to be significant. We used SPSS (IBM SPSS Statistics for Mac, Version 26.0; IBM Corp., Armonk, NY) for statistical analyses.

TABLE 1. Inclusion and Exclusion Criteria for the NORDSTEN-SST Trial With the Addition of the Specific Radiologic Requirements for This Study*

Inclusion criteria
Presence of clinical symptoms of spinal stenosis, such as neurogenic claudication or pain radiating bilaterally to the lower limbs
Nonresponse of at least three months of nonsurgical treatment
Radiological findings corresponding to the clinical symptoms of LSS. Central-stenosis or lateral recess stenosis.
Able to give informed consent and to answer the questionnaires
Over 18 years of age
Able to understand Norwegian, both spoken and written
*Preoperative and two years postoperative standing lateral x-rays of the lumbar spine
Exclusion criteria
Degenerative lumbar spondylolisthesis, with a slip ≥ 3 mm verified on standing plain x-rays in lateral view
Not willing to give written consent
Previous surgery at the level of stenosis
Fracture or former fusion in the thoracolumbar region
Cauda equina syndrome (bowel or bladder dysfunction) or fixed complete motor deficit
ASA classified 4 or 5
Over 80 years of age
Presence of lumbosacral scoliosis of more than 20°, verified on AP view
Presence of distinct symptoms in one or both legs, due to other diseases, for example, polyneuropathy, vascular claudication, or osteoarthritis
LSS at 4 or more levels
Unable to comply fully with the protocol, including treatment, follow-up, or study procedures (psychosocially, mentally, or physically)
The patient is participating in another clinical trial that may interfere with this trial

Ethics and Trial Registration

The Committee for Medical and Health Research Ethics of Central Norway approved the study (study identifier: 2011/2034). The study was registered at ClinicalTrials.gov on November 22, 2013, under the identifier NCT02007083. All patients provided written informed consent.

RESULTS

Demographic Characteristics

The patient characteristics are presented in Table 2. A total of 437 patients were included in the NORDSTEN-SST study, and 310 of these had complete radiology examinations before and two years after surgery and were included in the present study. The mean patient age was 67 years (SD: 8.2) and the study included 165 male and 145 female patients. The mean BMI was 27.8 (SD: 4.1) before surgery. In all, 248 patients (80%) were nonsmokers, 61 patients (20%) were smokers, and 1 patient had missing information about smoking. There were no significant differences regarding baseline parameters between the three groups of changes in LL (Table 2).

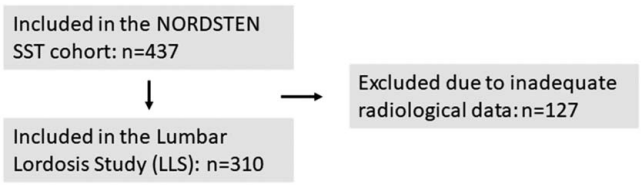

Figure 1. Flowchart of the NORDSTEN study, SST, and LLS cohort according to STROBE statement.

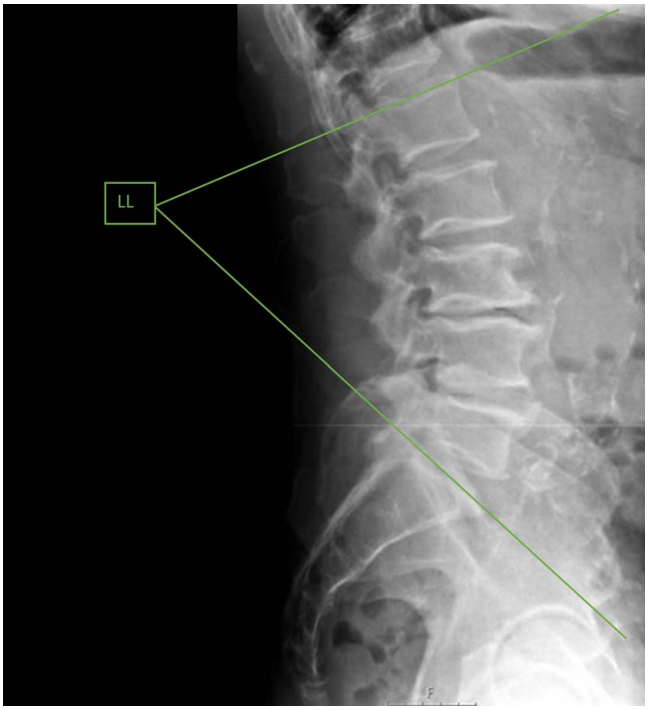

Figure 2. The lumbar lordosis (LL) was measured on lateral x-rays as the angle between the upper endplates of L1 and S1.

Radiologic Findings

The interobserver reliability was 0.98 (95% CI: 0.95–0.98) and the intraobserver reliability was 0.99 (95% CI: 0.98–0.99) for LL measurements. The mean LL was 48.9° (SD: 12.9°) before surgery and 51.1° (SD: 13.5°) two years after surgery, resulting in an increase of 2.2° (SD: 9.4°) ($P = 0.0001$). Most patients (n = 196, 63%) had a small change in LL when comparing the preoperative and postoperative images $< 5°$ (group 1), 55 patients had a change between 5° and 10° (group 2) and 59 patients had a change over 10° (group 3). Figure 3 shows the preoperative and two years postoperative standing x-ray of a patient with a change in LL of $> 10°$ and a patient with a change of $< 5°$. There were no significant differences between the surgical techniques and changes in LL ($P = 0.41$).

Association Between Changes in LL and Changes in PROMS Preoperatively to Two Years Postoperatively

In the unadjusted analyze, a change in LL were associated with improved outcomes in ODI ($P = 0.0040$), ZCQ function ($P = 0.0058$), and NRS back pain ($P = 0.021$), with higher change scores in the group 2 and 3. However, no

TABLE 2. Baseline Parameters of the Cohort of LLS Patients Selected for Surgical Treatment and having Radiologic Investigations With Standing X-Rays Before and at Two Years (N = 310)

	Change in lumbar lordosis, Δ LL (°)				
	Group 1 (< 5°)	Group 2 (≥ 5° < 10°)	Group 3 (≥ 10°)	Total	*P*
Age					
Mean	66.4	68.5	67.5	67.5	0.21
SD	8.5	8.0	8.0	8.2	
N	196	55	59	310	
BMI					
Mean	27.9	27.5	28.0	27.8	0.76
SD	4.0	4.0	4.3	4.1	
N	190	53	59	302	
ODI*					
Mean	37.0	41.3	39.9	38.3	0.10
SD	14.3	16.3	13.5	14.6	
N	195	55	59	309	
ZCQ† symptom					
Mean	3.4	3.4	3.3	3.4	0.89
SD	0.6	0.5	0.5	0.6	
N	194	55	58	307	
ZCQ† physical					
Mean	3.4	3.4	3.3	2.5	0.13
SD	0.6	0.5	0.5	0.5	
N	194	55	58	308	
Leg pain‡					
Mean	6.5	6.0	6.5	6.4	0.28
SD	2.0	2.1	2.3	2.1	
N	187	53	57	297	
Back pain‡					
Mean	6.2	6.1	6.6	6.2	0.40
SD	2.3	2.1	2.2	2.2	
N	189	53	57	299	
Sex, n (%)					
Men	103 (52.5)	34 (62)	28 (47)	165 (53)	0.29
Women	93 (47.5)	21 (38)	31 (53)	145 (47)	
Smoking, n (%)					
Yes	46 (24)	8 (15)	7 (12)	61 (20)	0.079
No	149 (76)	47 (85)	52 (88)	248 (80)	

Descriptive statistics of continuous variables are expressed as mean with SD in brackets while categorical data are expressed as numbers of patients.

*Oswestry disability index (ODI), total score range 0 to 100.

†Zurich claudication questionnaire (ZCQ) for symptom and function (ZCQ), symptom severity range of scores 1 to 5, physical function scale range of scores 1 to 4, patient satisfaction scale range 1 to 4.

‡Numeric pain rating scale (NRS) for back pain or leg pain at baseline, each with a range 0 to 10.

association between LL change and improvements in NRS leg pain ($P = 0.14$) or ZCQ symptoms ($P = 0.084$) were seen. After adjustment for baseline PROMs, age, sex, smoking, BMI, Schizas, and Pfirrmann scores, improvements in ODI ($P = 0.022$) and ZCQ function ($P = 0.016$) were significant between groups 1, 2, and 3 with higher improvements for group 2 and 3 (Table 3).

DISCUSSION

An overall small change of LL was seen on group level in patients with LSS operated with decompressive surgery after two years follow-up. However, a larger change of LL was found to be associated with greater improvements in ODI and ZCQ function.

Figure 3. Preoperative (left) and two years postoperative (right) standing x-ray of a patient with a change in LL of > 10° (top) and a patient with a change of < 5° (bottom).

Radiographic parameters such as low LL has previously been found to be associated with back pain in patients with spinal deformities and LSS.[19] However, a limited number of studies have investigated LL in relation to outcomes after decompressive surgery in patients with LSS.[8–10] A Cochrane review published by Hatakka *et al.* in 2021[20] concluded that decompressive surgery may have a small statistically significant, but probably clinically insignificant, effect on LL. Chang[21] divided their patients into groups with a poor and a good postoperative physical score (SF-36) and VAS. They found LL after surgery to be correlated to improved outcome in SF-36 and VAS with a lower mean LL in the group with poor outcomes compared with the group with good outcomes.[21] Fujii *et al.*[9] on the other hand, found no correlation between LL before surgery and PROMs (ZCQ and VAS) after surgery. None of these studies address changes in LL occurring after surgery in relation to PROMs. To our knowledge, changes in LL in relation to outcomes after LSS surgery without fusion has previously only been studied by Chang[16] where, in a cohort of 85 patients, a 10° change in

TABLE 3. Comparison of Unadjusted and Adjusted Changes in PROMs for the Three LL Changing Groups (Changes Measured Preoperatively to Two Years After Surgery)

	Change in lumbar lordosis, Δ LL (°)			
Change PROMS	**Group 1 (< 5°)**	**Group 2 (≤ 5° < 10°)**	**Group 3 (≥ 10°)**	***P***
Unadjust ODI (n = 305)	−17.6 (−19 to −15)	−24 (−29 to −20)	−22 (−27 to −18)	0.0040*
Adjust ODI (n = 294)	−17.6 (−20 to −15)	−24 (−29 to −20)	−22 (−26 to −18)	0.022*
Unadjust ZCQs (n = 304)	−0.9 (−1.1 to −0.8)	−1.1 (−1.3 to −0.9)	−1.2 (−1.4 to −0.9)	0.084
Adjust ZCQs (n = 293)	−1.0 (−1.1 to −0.8)	−1.1 (−1.3 to −0.8)	−1.2 (−1.4 to −0.9)	0.26
Unadjust ZCQSp (n = 304)	−0.7 (−0.9 to −0.7)	−1.0 (−1.2 to −0.8)	−1.0 (−1.2 to −0.8)	0.0058*
Adjust ZCQp (n = 293)	−0.7 (−0.8 to −0.6)	−1.0 (−1.2 to −0.8)	−1.0 (−1.2 to −0.8)	0.016*
Unadjust back pain (n = 296)	−2.3 (−2.7 to −1.8)	−2.8 (−3.6 to −2.0)	−3.5 (−4.3 to −2.8)	0.021*
Adjust back pain (n = 285)	−2.4 (−2.8 to −2.0)	−2.8 (−3.6 to −2.0)	−3.4 (−4.2 to −2.7)	0.065
Unadjust leg pain (n = 294)	−3.2 (−3.6 to −2.8)	−2.5 (−4.3 to −2.7)	−4.1 (−4.9 to −3.3)	0.14
Adjust leg pain (n = 284)	−3.3 (−3.7 to −2.8)	−3.5 (−4.3 to −2.6)	−4.0 (−4.8 to −3.2)	0.31

The variables are expressed as mean with a 95% CI.

ODI indicates Oswestry disability index (ODI), total score range 0 to 50; ZCQ, Zurich claudication questionnaire (ZCQ) for symptom and function (ZCQ), symptom severity range of scores 1 to 5, physical function scale range of scores 1 to 4, patient satisfaction scale range 1 to 4. Numeric pain rating scale (NRS) for back pain or leg, range 0 to 10.

LL was demonstrated to be associated with improvements in average physical score (SF-36 questionnaire; physical functioning, role physical, bodily pain, and general health). However, no adjustments for confounding variables known to influence the outcomes after surgery were performed.

Similar to the findings by Chang[16] increasing LL after surgery was found to be associated with improvements in several PROMS measuring physical function (ODI, ZCQ, and NRS back) in the unadjusted analysis in the present study. Furthermore, a considerably larger number of patients compared with previous studies allowed for adjusted analysis to be performed. In the adjusted analyze associations between change in LL (preoperative to 2 yr postoperatively) and changes in both ODI and ZCQ scores were found.

On group level an overall small, but statistically significant increase in LL between preoperative and two years postoperative measurements was detected with most of the individual patients demonstrating no or small changes in LL. Comparing the present study cohort to other studies showed that the mean LL preoperatively was comparable to what has been reported in previous studies on LSS patients.[22,23] Even though in most patients the LL did not change markedly after surgery, we found that a change in LL of more than 5° two years after surgery was associated with higher improvements in ODI and ZCQ than for patients with a change of LL of 5° or less. These results highlight the importance of identifying and understand factors that may change and to some extent restore the lumbar lordosis after decompressive surgery.

Overall factors affecting sagittal balance are important in the understanding of pathogenesis and the biomechanical changes occurring in LSS. The changes in LL after decompressive surgery may have several causes. For example, successful decompressive surgery may reduce the need to increase the cross-section area of the spinal canal by forward leaning and thus lead to postural improvements and consequential change in LL. Imagama *et al.*[24] reported that impaired sagittal alignment was related to back muscle strengths in elderly patients, which indicates that postoperative rehabilitation and muscle activation may influence the postoperative changes in LL. The degenerative process with large or bridging osteophytes may result in a more rigid spinal column and reduce the possibility to restore sagittal balance after surgery. On the other hand, decompression may enable mobility of the lumbar level in patients with posterior rigidity such as kissing spinous processes if removed or reduced, and thereby change LL after surgery. The effect of surgery on the paravertebral muscles following the dissection may contribute to changes in LL. The three different decompression techniques in this cohort did not show any difference in change in LL after surgery. A larger change in LL was associated with better outcome in this cohort, but the association between changes in LL and outcomes after surgery may also be explained the other way around, that is that better outcomes and less neurogenic pain after surgery may allow changes in posture and thereby a change in LL. Lower LL has previously been reported to be associated with low back pain.[25] Costa *et al.*[26] have reported the association between lower LL and worse outcomes in ODI one year after lumbar decompressive surgeries. Previous studies on this material did not find any association between LL before and outcomes two years after surgery.[27] The authors of this study concludes that LL before surgery should not be considered a determinant factor for predicting patient outcome after decompressive surgery for lumbar spinal stenosis. Studies as such provides general insights to the correlations between changes in LL after decompressive surgery in LSS patients and PROMs. However, the underlying key factors responsible for changes in LL and their relation to improvements in PROMs after decompressive surgery in LSS patients remains to be better understood. If such factors could be identified, they could provide information of clinical value for the outcomes of LSS patients undergoing decompressive surgery.

Strengths and Limitations

The main strengths of this study are the large sample size that enabled adjusted analyses and the structured study protocol used for including patients and collecting data. In the NORDSTEN-SST standing lumbar spine x-rays was performed preoperatively and postoperatively, however, full spine standing x-rays were not performed why full analysis regarding sagittal balance parameters could not be performed.

CONCLUSION

Changed LL after decompressive surgery for LSS was associated with improved physical function measured with ODI and ZCQ.

➢ Key Points

- ❑ This represents one of a few studies addressing changes in lumbar lordosis after decompressive surgery for lumbar spinal stenosis.
- ❑ Most patients experienced small changes in lumbar lordosis after decompressive surgery.
- ❑ Changes in lumbar lordosis of $>5°$ was associated with improved physical function measured with ODI and ZCQ.

References

1. Abelin-Genevois K. Sagittal balance of the spine. *Orthop Traumatol*. 2021;107(1S):102769.
2. Dreischarf M, Albiol L, Rohlmann A, et al. Age-related loss of lumbar spinal lordosis and mobility-a study of 323 asymptomatic volunteers. *PLoS One*. 2014;9:e116186.
3. Ravindra VM, Senglaub SS, Rattani A, et al. Degenerative Lumbar Spine Disease: Estimating Global Incidence and Worldwide Volume. *Glob Spine J*. 2018;8:784–794.
4. Grøvle L, Fjeld OR, Haugen AJ, et al. The rates of LSS surgery in Norwegian public hospitals: a threefold increase from 1999 to 2013. *Spine (Phila Pa 1976)*. 2019;44:E372–E378.
5. Jensen RK, Schiøttz-Christensen B, Skovsgaard CV, et al. Surgery rates for lumbar spinal stenosis in Denmark between 2002 and 2018: a registry-based study of 43,454 patients. *Acta Orthop*. 2022;93:488–494.
6. Pourtaheri S, Sharma A, Savage J, et al. Pelvic retroversion: a compensatory mechanism for lumbar stenosis. *J Neurosurg*. 2017;27:137–144.
7. Abbas J, Hamoud K, May H, et al. Degenerative lumbar spinal stenosis and lumbar spine configuration. *Eur Spine J*. 2010;19:1865–1873.
8. Jeon CH, Lee HD, Lee YS, Seo HS, Chung NS. Change in sagittal profiles after decompressive laminectomy in patients with lumbar spinal canal stenosis: a 2-year preliminary report. *Spine (Phila Pa 1976)*. 2015;40:E279–E285.
9. Fujii K, Kawamura N, Ikegami M, Niitsuma G, Kunogi J. Radiological improvements in global sagittal alignment after lumbar decompression without fusion. *Spine (Phila Pa 1976)*. 2015;40:703–709.
10. Bouknaitir JB, Carreon LY, Brorson S, Andersen MØ. Change in sagittal alignment after decompression alone in patients with lumbar spinal stenosis without significant deformity: a prospective cohort study. *J Neurosurg Spine*. 2022;37:1–7.
11. Shin EK, Kim CH, Chung CK, et al. Sagittal imbalance in patients with lumbar spinal stenosis and outcomes after simple decompression surgery. *Spine J*. 2017;17:175–182.
12. Hermansen E, Austevoll IM, Hellum C, et al. Comparison of 3 different minimally invasive surgical techniques for lumbar spinal stenosis: a randomized clinical trial. *JAMA Netw Open*. 2022;5:e224291.
13. Hermansen E, Austevoll IM, Romild UK, et al. Study-protocol for a randomized controlled trial comparing clinical and radiological results after three different posterior decompression techniques for lumbar spinal stenosis: the Spinal Stenosis Trial (SST) (part of the NORDSTEN Study). *BMC Musculoskelet Disord*. 2017;18:121.
14. Indrekvam K, Bånerud IF, Hermansen E, et al. The Norwegian degenerative spondylolisthesis and spinal stenosis (NORDSTEN) study: study overview, organization structure and study population. *Eur Spine J*. 2023;32:4162–4173.
15. Hicks GE, George SZ, Nevitt MA, Cauley JA, Vogt MT. Measurement of lumbar lordosis: inter-rater reliability, minimum detectable change, and longitudinal variation. *J Spinal Disord Tech*. 2006;19:501–506.
16. Chang HS. Influence of lumbar lordosis on the outcome of decompression surgery for lumbar canal stenosis. *World Neurosurg*. 2018;109:e684–e690.
17. Fairbank JCT, Pynsent PB. The oswestry disability index. *Spine (Phila Pa 1976)*. 2000;25:2940–2952.
18. Ferreira-Valente MA, Pais-Ribeiro JL, Jensen MP. Validity of four pain intensity rating scales. *Pain*. 2011;152:2399–2404.
19. Schwab F, Patel A, Ungar B, Farcy JP, Lafage V. Adult spinal deformity-postoperative standing imbalance: how much can you tolerate? An overview of key parameters in assessing alignment and planning corrective surgery. *Spine (Phila Pa 1976)*. 2010;35:2224–2231.
20. Hatakka J, Pernaa K, Rantakokko J, Laaksonen I, Saltychev M. Effect of lumbar laminectomy on spinal sagittal alignment: a systematic review. *Eur Spine J*. 2021;30:2413–2426.
21. Chang HS. Effect of sagittal spinal balance on the outcome of decompression surgery for lumbar canal stenosis. *World Neurosurg*. 2018;119:e200–e208.
22. Isart A, Vila-Canet G, et al. Lumbar lordosis in patients undergoing non-instrumented spinal stenosis. *Int J Spine Res*. 2021;3:011–015.
23. Ogura Y, Shinozaki Y, Kobayashi Y, et al. Impact of decompression surgery without fusion for lumbar spinal stenosis on sagittal spinopelvic alignment: minimum 2-year follow up. *JNeurosurg Spine*. 2019;30:743–749.
24. Imagama S, Ito Z, Wakao N, et al. Influence of spinal sagittal alignment, body balance, muscle strength, and physical ability on falling of middle-aged and elderly males. *Eur Spine J*. 2013;22:1346–1353.
25. Chun SW, Lim CY, Kim K, Hwang J, Chung SG. The relationships between low back pain and lumbar lordosis: a systematic review and meta-analysis. *Spine J*. 2017;17:1180–1191.
26. Costa MA, Silva PS, Vaz R, Pereira P. Correlation between clinical outcomes and spinopelvic parameters in patients with lumbar stenosis undergoing decompression surgery. *Eur Spine J*. 2021;30:1–8.
27. Wänman J, Åkerstedt J, Banitalebi H, et al. The association between lumbar lordosis preoperatively and changes in PROMs for lumbar spinal stenosis patients 2 years after spinal surgery: radiological and clinical results from the NORDSTEN-spinal stenosis trial. *Eur Spine J*. 2024;22. doi:10.1007/s00586-024-08137-5