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ORIGINAL ARTICLE

# Adjacent segment degeneration after posterolateral lumbar fusion: results and complications of posterior revision surgery

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## ABSTRACT

BACKGROUND: Lumbar fusion is an important technique for the treatment of degenerative pathologies. Adjacent segment degeneration is a known complication after lumbar fusion that causes significant morbidity. Our objective was to evaluate the demographics, risk factors, type of surgery, and surgical complications in patients who underwent reoperation through a posterior route due to adjacent segment degeneration.
METHODS: We performed a retrospective analysis of all patients who underwent instrumented posterolateral fusion in the lumbar spine for the treatment of degenerative diseases from January 2000 to December 2015 at a single institution. Patients who developed symptomatic adjacent segment degeneration requiring a second surgery were noted and compared with patients who did not develop adjacent segment degeneration.
RESULTS: A total of 750 patients with degenerative pathologies who underwent fusion with instrumentation were identified. Forty-five patients (6%) required a second surgery for symptomatic adjacent segment degeneration. The average onset of adjacent segment degeneration symptoms after fusion was 5.89 years. Adjacent segment degeneration occurred above the level of fusion in 40 cases and below in 5 cases. The risk factor identified in our series was L5-S1 fusion. The main complication seen after the second surgery was infection in 5 cases (11%).
CONCLUSIONS: This study identifies the L5-S1 fusion as a possible risk factor for adjacent segment degeneration. Reoperation through a posterior route is a therapeutic option but is associated with considerable morbidity. Further studies are necessary to elucidate this pathology and the best options for its management.

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KEY WORDS: Lumbar vertebrae; Postoperative complications; Reoperation; Risk factors; Intervertebral disc degeneration.

Lumbar fusion is an important technique for the treatment of degenerative pathologies and has been used widely and with great success. Between 1996 and 2001, there was an increase of 113% in the number of arthrodesis performed in the USA.[1, 2] Although arthrodesis has good clinical results, adjacent segment degeneration (ASD) is a critical complication and its incidence has also concomitant risen over the last years.[2-6] In recent times, two entities have been reported more frequently: radiological degeneration and symptomatic degeneration.[2, 5-7] In a recent systematic review on the topic, Donnally *et al*. use the definition of these two concepts: adjacent segment degeneration (ASDeg), which refers to "new radiographic changes at levels adjacent to a fusion construct," and clinical adjacent segment disease (ASDis), which refers to "new clinical symptoms from the progressing adjacent segment pathology."[7] A variable prevalence of ASD has been reported in the literature, ranging from less than 10 to 100%.[8, 9] The incidence increases over a period after lumbar fusion, increasing from 16.5% in 5 years to 36.1% in 10 years postoperatively.[4] Studies have reported variable rates of reoperation, ranging from 4% to 18.5%.[10-14] Zhang *et al*. found a 5.9% rate of ASDeg and a 1.8% rate of surgical revision for ASDis per year.[2] There is no consensus about the best therapeutic options for ASD. Minimally invasive techniques[15, 16] or posterolateral route[17-19] have been advo-

cated as gold-standard treatments. Endoscopy is used as an alternative and with satisfactory results.[20-22] In the present study, we examined the demographics, risk factors, type of surgery, and surgical complications in patients who underwent reoperation through a posterior route due to ASD.

## Materials and methods

We retrospectively analyzed all patients who underwent instrumented posterolateral fusion (PLF) for the treatment of degenerative pathologies of the lumbar spine from January 2000 to December 2015 at a single private institution. All patients were operated on by the senior author (FLRD). Magnetic resonance imaging of the lumbar spine was part of the preoperative assessment of all patients, except in cases in which there were any contraindications for the examination; in those cases, lumbar spine computed tomography or myelotomography was performed. A conventional midline open approach with traditional pedicle screw insertion was performed in all cases, and the screw trajectory was parallel to the superior endplate of the vertebral body in the sagittal plane. Posterior lumbar interbody fusion (PLIF) was performed mainly in cases of degenerative spondylolisthesis. Standard clinical follow-up consisted of appointments at 1, 6, 12, and 24 months postoperatively. Plain films were obtained at outpatient follow-up visits, and lumbar spine magnetic resonance imaging or dynamic radiography was performed for patients who developed clinical symptoms of ASD or signs of instability. Pre- and postoperative radiological examinations were analyzed by the senior author. After 24 months, annual appointments with clinical evaluations were proposed for the asymptomatic patients. Patients who developed symptomatic ASD requiring a second surgery were noted. Exclusion criteria were previous revision surgery, malignancy, infection, first surgery performed at another institution, and trauma. The data considered for analysis included age, sex, diagnosis of the condition for which the first surgery was performed, duration of symptoms before revision surgery, number of levels, and postoperative complications. Symptomatic ASD was considered as the development of new clinical symptoms that corresponded to radiographic changes adjacent to the level of the previous spinal fusion (presented in the form of disc herniation, stenosis, spondylolisthesis, and scoliosis). The criteria for adjacent segment instability were defined as well-defined spondylolisthesis or dynamic instability with slippage of more than 4 mm, and/or an angle change of more than 10° on flexion and extension. We performed a comparative analysis between the group of patients who developed symptomatic ASD and were reoperated (ASD group) and the group who did not develop symptomatic ASD (Non-ASD group).

### Statistical analysis

The numerical variables are described as mean, standard deviation, and range. The mean ages between the groups were compared using a two-tailed test. Patients were compared regarding age, sex, fused levels, the average number of fused levels, short *vs*. long constructs, fusion to S1, and concomitant fusion with PLIF. Sex distributions were described in proportion and compared using the Chi-square test. The number of ASD in each fused level, short *vs*. long constructs, fusion to S1, the average number of fused levels, and fusion with or without PLIF were compared using the Chi-square test. The level of significance determined for the study was $P \leq 0.05$. The software used for analysis was the online calculator Social Science Statistics.[23]

### Data availability

The data associated with the paper are not publicly available but are available from the corresponding author on reasonable request.

## Results

A total of 750 patients with degenerative pathologies of the lumbar and lumbo-sacral spine who underwent instrumented PLF were identified. The patients were divided into two groups: those requiring reoperation for ASD (ASD group) and those who did not develop symptomatic ASD (non-ASD group). Patient demographics and surgical characteristics are summarized in Table I. The duration of follow-up ranged from 24 to 180 months (average 9.2 years). Forty-five patients (6%) required a second surgery for symptomatic ASD. The average age of the patients who developed ASD was 64.7 years (range 32-86 years). There was no significant difference between the groups regarding age ($t$=0.85; P=0.39). The male/female rate in both groups was 0.80 and there was no significant difference between the groups ($\chi^2$=2.07; P=0.149). Previous pathologies in the ASD group were lumbar spine stenosis (27), spondylolisthesis (11), degenerative disc disease (DDD) (4), and scoliosis (3). Seventeen of the forty-five patients underwent concomitant PLIF. ASD was manifested in the form of stenosis in 23 patients, spondylolisthesis in 17 patients, and herniated discs in 5 patients. Degeneration occurred above the level of fusion in 40 cases and below the level of fusion in 5 cases

TABLE I.—*Demographic and surgical characteristics.*

| Parameters | ASD group | Non-ASD group | P value |
|---|---|---|---|
| Number of patients | 45 | 705 | |
| Average age (range) | 64.7±14.8 years (32-86 years) | 60.6±14.5 years (18-86 years) | 0.39 |
| Sex (male/female) | 20/25 | 314/391 | 0.14 |
| Fusion level | | | |
| L2-L4 | 1 | 8 | 0.51 |
| L2-L5 | 4 | 44 | 0.48 |
| L2-S1 | 4 | 43 | 0.45 |
| L3-L5 | 6 | 80 | 0.68 |
| L3-S1 | 6 | 90 | 0.91 |
| L4-L5 | 7 | 110 | 0.99 |
| L4-S1 | 12 | 223 | 0.48 |
| L5-S1 | 5 | 31 | 0.04* |
| Other | - | 76 | - |
| Fusion to S1 | 27 | 418 | 0.92 |
| Long fusion (≥3 levels) | 14 | 234 | 0.77 |
| Average number of fused levels | 2.13 | 2.18 | 0.23 |
| PLIF | 17 | 213 | 0.28 |
| Previous pathology | | | |
| Lumbar spine stenosis | 27 | 404 | |
| Spondylolisthesis | 11 | 236 | |
| Scoliosis | 3 | 36 | |
| DDD | 4 | 5 | |
| Other | - | 24 | |

ASD: adjacent segment degeneration; PLIF: posterior lumbar interbody fusion; DDD: degenerative disc disease.
*Statistically significant.

(88.9% and 11.1%, respectively). The average period of onset of ASD symptoms after fusion surgery was 5.89 years, with a peak at 8 years (Figure 1). All 45 patients underwent reoperation using a posterior route with open surgery and standard midline posterior approach, but different techniques were used depending on the preference of the surgeon in each case. There was no randomization to determine the technique for each patient. Isolated decompression with laminectomy at the level of degeneration was performed in five cases, decompression with laminectomy at the level of degeneration associated with removal of the synthesis material in five cases, decompression with laminectomy at the level of degeneration associated with the placement of pedicle screws at that level with fusion extension using connectors in 10 cases, and decompression at the level of degeneration with replacement of the previous synthesis material and fusion extension with new additional pedicle screw fixation in 25 cases (Figure 2, 3). The main complication after the second surgery in this series was infection in five cases (11.1%), four of which also presented with cerebrospinal fluid (CSF) leak (8.8%). Two patients (4.4%) who developed infection died due to wound infection followed by septicemia. In addition, deep venous thrombosis of the lower limb was seen in 1 case (2.2%), and paresis in dorsiflexion of the foot in 1 case, with partial recovery (2.2%). In 1 case, we were unable to remove the material as the manufacturer of the previous material had exited the market and appropriate instruments could not be used. The total rate of complications was 15.5% (Table II). The only risk factor with statistical significance for the development of symptomatic ASD was L5-S1 fusion (P=0.04). There was no statistical difference between the groups regarding age, sex, and the average number of fused levels. In addition, there was no significant difference in the rate of ASD regarding long constructs, fusion to S1, and concomitant fusion with PLIF. Sagittal balance measures were not evaluated in our study.

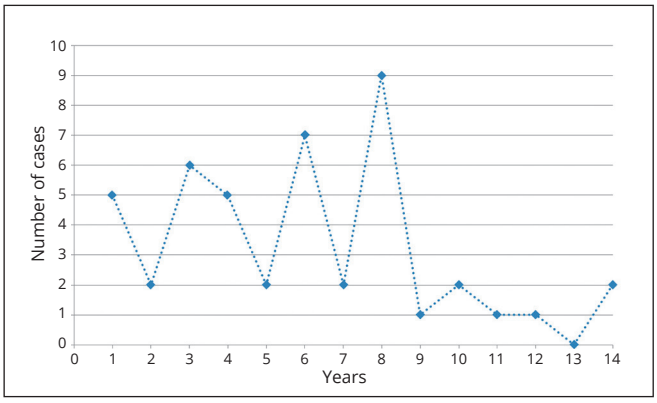


Figure 1.—The period of time after lumbar fusion until the development of symptomatic adjacent segment degeneration.

## Discussion

Adjacent segment degeneration (ASD) is the most common long-term complication after lumbar fusion. The precise definition of ASD is variable in the literature. Some authors defined ASD as a radiological alteration that occurs in the adjacent segment after spinal fusion, with the presence of clinical symptoms.[5] Others suggested that the rate of reoperation should be the criterion for defining the pathology of the adjacent segment.[24] Radiological parameters are also used to confirm the presence of degeneration at the adjacent level: complete collapse of the disc space with endplate sclerosis, sagittal or coronal translation >3 mm, more than a 5º wedging of the disc space on a coronal view, angular instability >10º on dynamic X-ray, and significant spinal canal compression on

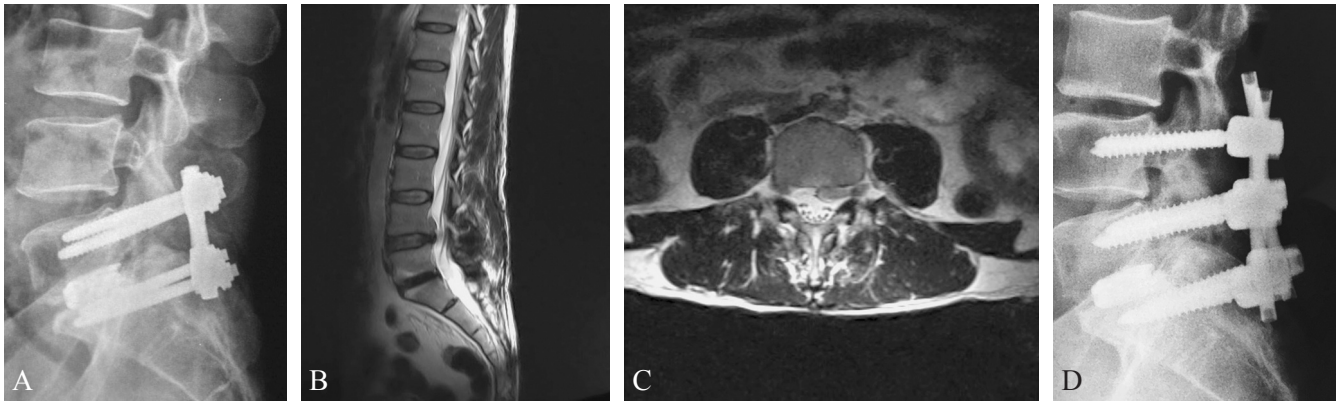


Figure 2.—A 58-year-old man who previously underwent L5-S1 PLIF developed symptomatic herniated disc at L4-L5 9 years after the first surgery. Lateral radiography showing previous L5-S1 PLIF (A). Sagittal (B) and axial (C) T2-weighted magnetic resonance imaging demonstrating herniated disc at L4-L5. The patient underwent removal of the previous instrumentation and L4-S1 fusion with new synthesis material. Immediate postoperative lateral radiography showing L4-S1 fusion (D).

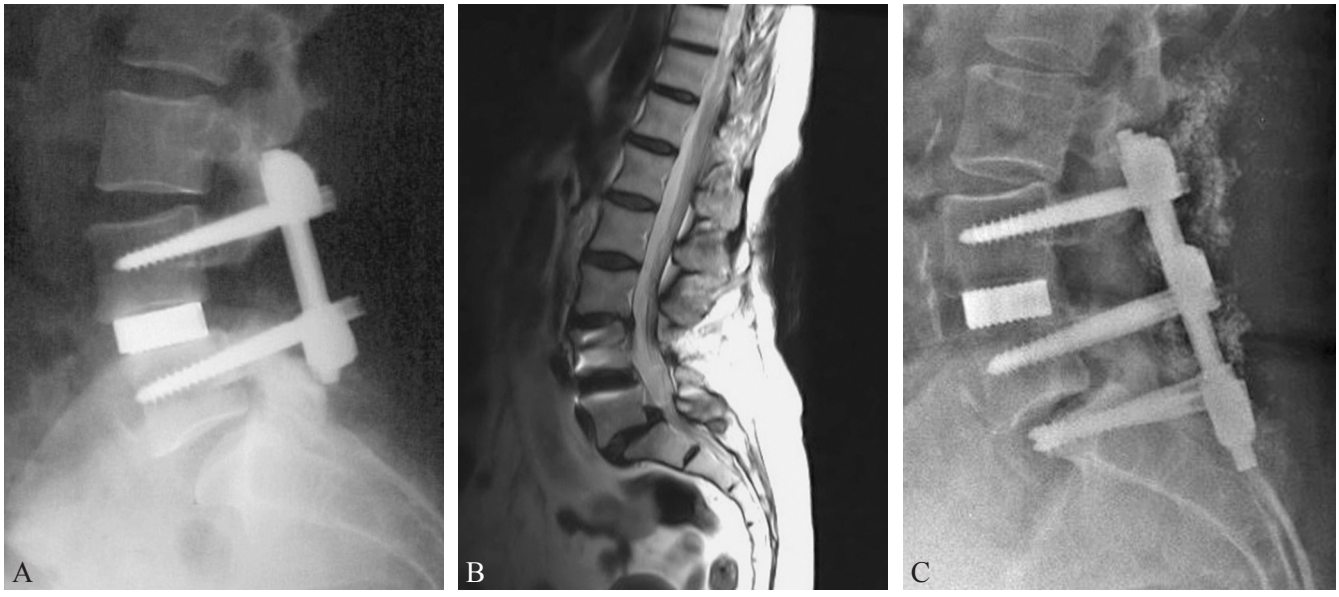


Figure 3.—A 66-year-old woman previously underwent L4-L5 PLIF for the treatment of degenerative spondylolisthesis: 8 years after the first surgery she developed symptomatic L5-S1 spondylolisthesis. Control lateral radiography after the first surgery showing L4-L5 PLIF (A). T2-weighted magnetic resonance imaging of the lumbar spine demonstrating adjacent segment degeneration at L5-S1, with grade I spondylolisthesis. She underwent fusion extension to S1. Immediate postoperative lateral radiography showing L4-S1 fusion (C).

magnetic resonance imaging.[25] There are several risk factors for ASD and they differ between the studies. Several specific aspects of lumbar fusion including instrumentation, level, use of cages (interbody), extent of fusion, and number of laminectomy levels have been considered as risk factors for ASD, although none of these have been proven to be associated with ASD.[26] In a meta-analysis by Pan *et al*., the authors compared the risk of ASDeg and ASDis between rigid and dynamic systems. The rate of prevalence of ASDeg, ASDis, and reoperation rate for rigid systems were 37.5%, 14.4%, and 7.7% respectively. In the dynamic group the rates were 18.6%, 5.1%, and 1.1%, respectively, which was significantly lower compared to that in the fusion group. The limitation of this study was that the average follow-up period was only 3.6 years.[27] In a systematic review with a total of 4,206 patients, Zhang *et al*. compared ASDeg *versus* ASDis after fusion in degenerative pathologies. The inci-

TABLE II.—*Characteristics of ASD group.*

| Parameters | Number | % |
|---|---|---|
| Number of patients | 45 | |
| ASD manifestation | | |
| Stenosis | 23 | 51.1 |
| Spondylolisthesis | 17 | 37.7 |
| Herniated disc | 5 | 11.1 |
| Degeneration level | | |
| Above fusion | 40 | 88.9 |
| Below fusion | 5 | 11.1 |
| Type of surgery for reoperation | | |
| Isolated laminectomy | 5 | 11.1 |
| Laminectomy with removal of the synthesis material | 5 | 11.1 |
| Laminectomy with fusion extension | 10 | 22.2 |
| Laminectomy with fusion extension and replacement of the synthesis material | 25 | 55.5 |
| Complication after reoperation | | |
| Infection | 5 | 11.1 |
| CSF leak | 4 | 8.8 |
| Death | 2 | 4.4 |
| Deep venous thrombosis | 1 | 2.2 |
| Paresis in dorsiflexion | 1 | 2.2 |

ASD: adjacent segment degeneration; CSF: cerebrospinal fluid.

dence of ASDeg was 5.9% per year *versus* 1.8% of ASDis. In this study, the fusion length was the most important factor associated with development of ASD.[2] Regarding the number of fused levels, Gillet found a 32% rate of degeneration with a single-level fusion and 66% with three- or four-level fusion.[28] Abraham *et al*., in a series of 217 patients who underwent fusion of three or more levels, found the rate of ASD that required reoperation to be 9%.[17] In our series, fusion extension was not considered a risk factor for the development of ASD. It is not clear whether the use of 360º fusion, which seems to improve the rate of fusion, is a protective or risk factor for ASD. PLF associated with PLIF was related to long-term increase in the incidence of ASDis to 9.6% and 24.6% in 5 and 10 years, respectively.[29] In our series there was no significant difference between the groups in terms of the development of ASD regarding concomitant fusion with PLIF. Anandjiwala *et al*., in a study with 68 patients with 5 years of follow-up, reported that the most important risk factor is the presence of a degenerated disc adjacent to the fusion. Data such as age, sex, sagittal balance, and length of fusion had no influence according to their study.[25] Other authors also draw attention to the fact that the presence of a pre-existing degenerated disc adjacent to the fusion has a higher chance of progression compared to normal discs.[2, 30] Other risk factors for ASD have been reported, such as age above 60 years, multilevel fusion, fusion that did not include S1, and laminectomy adjacent to the fusion.[31, 32] In our study, the average age of patients who developed ASD was not statistically different from the average age of those who did not develop ASD. Much has been discussed about the importance of sagittal balance and its relationship with ASD in patients undergoing lumbar fusion. Di Martino *et al*., in a series comprising 22 patients who underwent surgery for ASD and a control group of 83 patients who did not require reoperation, concluded that patients with pelvic tilt >21º and sacral slope <39º preoperatively, were at higher risk for symptomatic degeneration.[33] Rothenfluh *et al*. demonstrated that patients with a mismatch (pelvic incidence–lumbar lordosis) <10° had a surgical revision rate of 25.5% as compared with 78.3% in patients with a mismatch of ≥10°, demonstrating that those with a high pelvic incidence and diminished lumbar lordosis were predisposed to develop ASD.[34] Other authors believe that maintaining or restoring the lordosis of the lumbar spine does not prevent the development of ASD.[35, 36] It is critical to emphasize the importance of the L4-S1 segment in maintaining lumbar lordosis. Fusion of these levels can predispose patients to adjacent degeneration.[35, 37, 38] However, there are still controversies in the literature regarding the levels included in the instrumentation and the rates of postoperative ASD. Some authors have shown higher rates of ASD after fusion ending at L5.[31, 39] Other authors have found no difference between stopping fusion at L5 or S1.[25, 35, 40] In our series, we found a higher rate of degeneration after the L5-S1 fusion. There are controversies in the literature as to whether the L4-L5 fixation would increase the rate degeneration in L5-S1. Miyakoshi *et al*.[9] reported no ASD, whereas Ghiselli *et al*., and Park *et al*. reported ASD at L5-S1 after L4-L5 fusion in 7.2% and 10.7% of the patients, respectively.[4, 30] Multiple risk factors related to ASDeg and ASDis were reported in a recent systematic review, such as age, genetic factors, high body mass index, pre-existing adjacent segmental degeneration, laminectomy at the adjacent level of fusion, excessive distraction of the fusion level, inadequate lumbar lordosis, multilevel fixation, floating fusion, coronal wedging of L5-S1 disc, pelvic tilt, and osteoporosis. The authors suggested some strategies to avoid adjacent segment complications in the lumbar spine, including minimal disc space distraction for cages, and preservation of adjacent posterior elements.[39] In a recent meta-analysis, Wang *et al*. analyzed 19 retrospective studies with a total of 2,896 patients. The rate of

ASD after lumbar fusion was 18.6%. In their analysis, mean age, body mass index, history of smoking and hypertension, preoperative adjacent disc degeneration, long-segment fusion, preoperative superior facet violation, high lumbosacral joint angle, pre- and postoperative L1-S1 sagittal vertical axis, postoperative lumbar lordosis, and preoperative pelvic incidence were associated with a higher risk of developing ASD.[41] In our series, long-segment fusion was not associated with a higher risk of ASD. In their analysis, fusion to S1 did not increase the risk of symptomatic ASD, which was also found in our results. The ideal treatment for symptomatic ASD after lumbar fusion is still controversial. Isolated decompression can be performed in cases of root compression without an axial component; however, it has a risk of late instability. The most frequently used treatment is posterior revision with laminectomy and extension of the fusion, requiring the exposure of previously fixed implants, which can lead to greater bleeding and pain,[42] risk of damage to the dura mater with CSF leak and fibrosis,[43] and excessive bleeding.[44] In our study, we observed CSF leak in 8.8% of the cases, and a higher number of complications in patients wherein decompression associated with the exposure and replacement of all instrumentation was performed. In our last cases, we preferred to perform simple laminectomy at the affected level with an extension of the instrumentation above or below, using two pedicle screws and two connectors to join the old system with the new ones, avoiding greater exposure. It is important to leave a larger portion of the caudal and rostral rod in the first fusion surgery, in case connection with the new system is necessary in the future. Due to the difficulties involved, and to avoid complications of the posterior route, other surgical options have been proposed. Wang *et al*.[15] proposed an alternative using a minimally invasive lateral route with cage and plaque, a technique initially described by Pimenta *et al*.[45] In this series of 21 patients, fusion was achieved in all cases, with no intraoperative complications, short hospital stay (2.4 days), and low rates of bleeding. Only 1 patient required late fusion and direct decompression.

However, this study had several limitations: a short to medium duration of follow-up (only 23.6 months) and decompression performed indirectly, which might be inadequate in cases of severe stenosis; and definitive fusion has not been defined with certainty. Formica *et al*., using this same technique in 36 patients, reported no cases of pseudarthrosis or implant failure. However, they reported a complication rate of 19.4% including CSF leak, infection, subsidence, motor and sensory deficits, and radiculopathy.[46] Aichmair *et al*. using lateral lumbar interbody fusion (LLIF) with cage stand-alone in 52 cases for the treatment of ASD, reported an improvement in pain, increase in segmental lordosis, decrease in segmental coronal angulation, and restoration of disc height. However, this study showed a high rate of reoperation (21.2%) with the need to complement the fixation posteriorly. The group with cage stand-alone presented a lower fusion rate of 53.8% compared to 87.5% in the circumferential fusion group. The authors concluded that LLIF might be an effective option for ASD, although it is associated with a narrower spectrum of adverse effects than circumferential fusion, and posterior instrumentation might be necessary to increase segmental stability.[16] Recently, a retrospective study comparing stand-alone LLIF (23 patients) *versus* open laminectomy and PLF (24 patients) reported that the LLIF group had lower intraoperative morbidity and shorter hospital stay. However, both techniques showed good outcomes in terms of restoring sagittal balance and good clinical results.[47]

### Limitations of the study

Our study has some limitations: it is retrospective in design, descriptive, and was carried out at a single institution. In addition, the study did not include an analysis of the sagittal balance, as it was an older series. Despite these limitations, it is a study with many patients and prolonged average follow-up, operated on by a single surgeon using the same surgical technique (posterior route) in all cases.

## Conclusions

In conclusion, the development of ASD after lumbar fusion in degenerative pathologies is probably multifactorial in origin. Our study identified the fusion of L5-S1 as a possible risk factor for the development of ASD. In this series, we had a considerable number of complications after surgical revision by a posterior route. The best surgical option to correct ASD remains debatable. Prospective studies are necessary to better understand ASD and to minimize its occurrence.

## References

**1.** Deyo RA, Gray DT, Kreuter W, Mirza S, Martin BI. United States trends in lumbar fusion surgery for degenerative conditions. Spine 2005;30:1441–5, discussion 1446–7.

**2.** Zhang C, Berven SH, Fortin M, Weber MH. Adjacent Segment De-

generation Versus Disease After Lumbar Spine Fusion for Degenerative Pathology: A Systematic Review With Meta-Analysis of the Literature. Clin Spine Surg 2016;29:21–9.

**3.** Lee CK, Langrana NA. Lumbosacral spinal fusion. A biomechanical study. Spine 1984;9:574–81.

**4.** Ghiselli G, Wang JC, Bhatia NN, Hsu WK, Dawson EG. Adjacent segment degeneration in the lumbar spine. J Bone Joint Surg Am 2004;86:1497–503.

**5.** Hilibrand AS, Robbins M. Adjacent segment degeneration and adjacent segment disease: the consequences of spinal fusion? Spine J 2004;4:190S–4S.

**6.** Harrop JS, Youssef JA, Maltenfort M, Vorwald P, Jabbour P, Bono CM, *et al.* Lumbar adjacent segment degeneration and disease after arthrodesis and total disc arthroplasty. Spine 2008;33:1701–7.

**7.** Donnally CJ 3rd, Patel PD, Canseco JA, Divi SN, Goz V, Sherman MB, *et al.* Current incidence of adjacent segment pathology following lumbar fusion versus motion-preserving procedures: a systematic review and meta-analysis of recent projections. Spine J 2020;20:1554–65.

**8.** Pihlajamäki H, Böstman O, Ruuskanen M, Myllynen P, Kinnunen J, Karaharju E. Posterolateral lumbosacral fusion with transpedicular fixation: 63 consecutive cases followed for 4 (2-6) years. Acta Orthop Scand 1996;67:63–8.

**9.** Miyakoshi N, Abe E, Shimada Y, Okuyama K, Suzuki T, Sato K. Outcome of one-level posterior lumbar interbody fusion for spondylolisthesis and postoperative intervertebral disc degeneration adjacent to the fusion. Spine 2000;25:1837–42.

**10.** Aota Y, Kumano K, Hirabayashi S. Postfusion instability at the adjacent segments after rigid pedicle screw fixation for degenerative lumbar spinal disorders. J Spinal Disord 1995;8:464–73.

**11.** Etebar S, Cahill DW. Risk factors for adjacent-segment failure following lumbar fixation with rigid instrumentation for degenerative instability. J Neurosurg 1999;90:163–9.

**12.** Hambly MF, Wiltse LL, Raghavan N, Schneiderman G, Koenig C. The transition zone above a lumbosacral fusion. Spine 1998;23:1785–92.

**13.** Kanayama M, Hashimoto T, Shigenobu K, Harada M, Oha F, Ohkoshi Y, *et al.* Adjacent-segment morbidity after Graf ligamentoplasty compared with posterolateral lumbar fusion. J Neurosurg 2001;95:5–10.

**14.** Okuda S, Iwasaki M, Miyauchi A, Aono H, Morita M, Yamamoto T. Risk factors for adjacent segment degeneration after PLIF. Spine 2004;29:1535–40.

**15.** Wang MY, Vasudevan R, Mindea SA. Minimally invasive lateral interbody fusion for the treatment of rostral adjacent-segment lumbar degenerative stenosis without supplemental pedicle screw fixation. J Neurosurg Spine 2014;21:861–6.

**16.** Aichmair A, Alimi M, Hughes AP, Sama AA, Du JY, Härtl R, *et al.* Single-Level Lateral Lumbar Interbody Fusion for the Treatment of Adjacent Segment Disease: A Retrospective Two-Center Study. Spine 2017;42:E515–22.

**17.** Abraham EP, Manson NA, McKeon MD. The Incidence of Adjacent Segment Breakdown in Polysegmental Thoracolumbar Fusions of Three or More Levels with Minimum 5-Year Follow-up. Global Spine J 2014;4:83–8.

**18.** Lee JK, Jo YH, Kang CN. Cost-effectiveness Analysis of Existing Pedicle Screws Reusing Technique in Extension Revision Operation for Adjacent Segmental Stenosis After Lumbar Posterolateral Fusion. Spine 2016;41:E785–90.

**19.** Kim TH, Lee BH, Moon SH, Lee SH, Lee HM. Comparison of adjacent segment degeneration after successful posterolateral fusion with unilateral or bilateral pedicle screw instrumentation: a minimum 10-year follow-up. Spine J 2013;13:1208–16.

**20.** Li T, Zhu B, Liu X. Revision Strategy of Symptomatic Lumbar Adjacent Segment Degeneration: Full Endoscopic Decompression versus Extended Posterior Interbody Fusion. World Neurosurg 2020;142:e215–22.

**21.** Ba Z, Pan F, Liu Z, Yu B, Fuentes L, Wu D, *et al.* Percutaneous endoscopical transforaminal approach versus PLF to treat the single-level adjacent segment disease after PLF/PLIF: 1-2 years follow-up. Int J Surg 2017;42:22–6.

**22.** Telfeian AE. Transforaminal Endoscopic Surgery for Adjacent Segment Disease After Lumbar Fusion. World Neurosurg 2017;97:231–5.

**23.** Social Science Statistics. Homepage; 2021 [Internet]. Available from: https://www.socscistatistics.com [cited 2022, Mar 24].

**24.** Lee JC, Lee SH, Peters C, Riew KD. Adjacent segment pathology requiring reoperation after anterior cervical arthrodesis: the influence of smoking, sex, and number of operated levels. Spine 2015;40:E571–7.

**25.** Anandjiwala J, Seo JY, Ha KY, Oh IS, Shin DC. Adjacent segment degeneration after instrumented posterolateral lumbar fusion: a prospective cohort study with a minimum five-year follow-up. Eur Spine J 2011;20:1951–60.

**26.** Radcliff KE, Kepler CK, Jakoi A, Sidhu GS, Rihn J, Vaccaro AR, *et al.* Adjacent segment disease in the lumbar spine following different treatment interventions. Spine J 2013;13:1339–49.

**27.** Pan A, Hai Y, Yang J, Zhou L, Chen X, Guo H. Adjacent segment degeneration after lumbar spinal fusion compared with motion-preservation procedures: a meta-analysis. Eur Spine J 2016;25:1522–32.

**28.** Gillet P. The fate of the adjacent motion segments after lumbar fusion. J Spinal Disord Tech 2003;16:338–45.

**29.** Maruenda JI, Barrios C, Garibo F, Maruenda B. Adjacent segment degeneration and revision surgery after circumferential lumbar fusion: outcomes throughout 15 years of follow-up. Eur Spine J 2016;25:1550–7.

**30.** Park JY, Chin DK, Cho YE. Accelerated L5-S1 Segment Degeneration after Spinal Fusion on and above L4-5 : Minimum 4-Year Follow-Up Results. J Korean Neurosurg Soc 2009;45:81–4.

**31.** Sears WR, Sergides IG, Kazemi N, Smith M, White GJ, Osburg B. Incidence and prevalence of surgery at segments adjacent to a previous posterior lumbar arthrodesis. Spine J 2011;11:11–20.

**32.** Djurasovic MO, Carreon LY, Glassman SD, Dimar JR 2nd, Puno RM, Johnson JR. Sagittal alignment as a risk factor for adjacent level degeneration: a case-control study. Orthopedics 2008;31:546.

**33.** Di Martino A, Quattrocchi CC, Scarciolla L, Papapietro N, Beomonte Zobel B, Denaro V. Estimating the risk for symptomatic adjacent segment degeneration after lumbar fusion: analysis from a cohort of patients undergoing revision surgery. Eur Spine J 2014;23:693–8.

**34.** Rothenfluh DA, Mueller DA, Rothenfluh E, Min K. Pelvic incidence-lumbar lordosis mismatch predisposes to adjacent segment disease after lumbar spinal fusion. Eur Spine J 2015;24:1251–8.

**35.** Liao JC, Chen WJ, Chen LH, Niu CC, Keorochana G. Surgical outcomes of degenerative spondylolisthesis with L5-S1 disc degeneration: comparison between lumbar floating fusion and lumbosacral fusion at a minimum 5-year follow-up. Spine 2011;36:1600–7.

**36.** Lai PL, Chen LH, Niu CC, Chen WJ. Effect of postoperative lumbar sagittal alignment on the development of adjacent instability. J Spinal Disord Tech 2004;17:353–7.

**37.** Zencica P, Chaloupka R, Hladíková J, Krbec M. [Adjacent segment degeneration after lumbosacral fusion in spondylolisthesis: a retrospective radiological and clinical analysis]]. Acta Chir Orthop Traumatol Cech 2010;77:124–30. [Czech].

**38.** Alentado VJ, Lubelski D, Healy AT, Orr RD, Steinmetz MP, Benzel EC, *et al.* Predisposing Characteristics of Adjacent Segment Disease After Lumbar Fusion. Spine 2016;41:1167–72.

**39.** Hashimoto K, Aizawa T, Kanno H, Itoi E. Adjacent segment degeneration after fusion spinal surgery-a systematic review. Int Orthop 2019;43:987–93.

**40.** Wai EK, Santos ER, Morcom RA, Fraser RD. Magnetic resonance imaging 20 years after anterior lumbar interbody fusion. Spine 2006;31:1952–6.

**41.** Wang T, Ding W. Risk factors for adjacent segment degeneration after posterior lumbar fusion surgery in treatment for degenerative lumbar disorders: a meta-analysis. J Orthop Surg Res 2020;15:582.

**42.** Parker SL, Shau DN, Mendenhall SK, McGirt MJ. Factors influencing 2-year health care costs in patients undergoing revision lumbar fusion procedures. J Neurosurg Spine 2012;16:323–8.

**43.** Khan IS, Sonig A, Thakur JD, Bollam P, Nanda A. Perioperative complications in patients undergoing open transforaminal lumbar interbody fusion as a revision surgery. J Neurosurg Spine 2013;18:260–4.

**44.** Smorgick Y, Baker KC, Bachison CC, Herkowitz HN, Montgomery DM, Fischgrund JS. Hidden blood loss during posterior spine fusion surgery. Spine J 2013;13:877–81.

**45.** Ozgur BM, Aryan HE, Pimenta L, Taylor WR. Extreme Lateral Interbody Fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. Spine J 2006;6:435–43.

**46.** Formica M, Zanirato A, Cavagnaro L, Basso M, Divano S, Felli L, *et al.* Extreme lateral interbody fusion in spinal revision surgery: clinical results and complications. Eur Spine J 2017;26:464–70.

**47.** Louie PK, Haws BE, Khan JM, Markowitz J, Movassaghi K, Ferguson J, *et al.* Comparison of Stand-alone Lateral Lumbar Interbody Fusion Versus Open Laminectomy and Posterolateral Instrumented Fusion in the Treatment of Adjacent Segment Disease Following Previous Lumbar Fusion Surgery. Spine 2019;44:E1461–9.

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*Conflicts of interest*
The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

*Authors' contributions*
All authors read and approved the final version of the manuscript.

*History*
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