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CLINICAL ARTICLE

A comparison of unilateral laminectomy with bilateral decompression and fusion surgery in the treatment of grade I lumbar degenerative spondylolisthesis

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Abstract
Background Although unilateral laminectomy and bilateral decompression (ULBD) is effective in the treatment of degenerative spondylolisthesis (DSPL), few reports have compared the outcomes of ULBD and instrumented fusion for the treatment of DSPL. We describe here the clinical and radiological outcomes of ULBD and instrumented fusion surgery for the treatment of DSPL after a minimum 3-year follow-up.
Methods We retrospectively analyzed the outcomes of 47 DSPL patients with radicular pain who underwent ULBD or instrumented fusion between January 2005 and December 2007. Clinical outcomes were assessed using the numeric rating scale (NRS) for back and leg pain, the Oswestry Disability Index (ODI), and Short Form-36 Health Survey (SF-36). Radiological outcomes of ULBD were analyzed by determining changes in slippage, disc height translation, and angular difference on simple and dynamic X-rays.
Results The mean NRS of back pain showed a significantly greater decrease in the fusion than the ULBD group, whereas the mean NRS of leg pain, mean ODI, and mean physical component summary and mental component summary of the SF-36 decreased similarly in the ULBD and fusion groups. Radiologically, the ULBD group showed a 2.1±3.10% change in mean slippage, a 0.15±1.58 mm change in mean translation, a -0.91±4.48° change in mean angular difference, and a -1.83±1.69 mm change in mean disc height. In the ULBD group, three patients had residual pain and three had recurrent pain. In comparison, no patient in the fusion group reported residual pain, whereas five patients experienced recurrent radicular pain caused by adjacent segmental disease.
Conclusions Our findings suggest that ULBD is the recommendable procedure for the treatment of patients with grade I DSPL who have mainly radicular pain. Although the two groups showed similar clinical outcomes overall, radiological degeneration was not as serious after ULBD treatment. In our analysis, foraminal stenosis is a contraindication for ULBD in the treatment of grade I DSPL.

Keywords Unilateral laminectomy and bilateral decompression (ULBD) · Degenerative spondylolisthesis (DSPL) · Fusion · Slippage · Translation · Residual pain

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Introduction

Unilateral laminotomy for bilateral decompression (ULBD) has been shown effective in the treatment of degenerative lumbar stenosis [3, 5, 21, 26, 28, 30, 33]. However, it remains unclear whether grade I degenerative spondylolisthesis (DSPL) is better managed with laminectomy alone or laminectomy with fusion [6, 8–10, 13, 17, 18, 20, 24]. Although ULBD has been shown effective in the treatment of DSPL, there have been few reports comparing the outcomes of such patients following ULBD or instrumented fusion [27, 31, 34]. Here we describe the clinical and radiological outcomes in patients who underwent ULBD or instrumented fusion surgery for the treatment of DSPL and were followed-up for a minimum of 3 years. We also analyzed the possible causes of clinical failures based on preoperative clinical and radiological data.

Methods and materials

We retrospectively analyzed the outcomes of 45 patients with grade I, single level DSPL (8 men, 37 women) with radicular pain who underwent ULBD (n=20) or instrumented fusion (n=25) between January 2005 and December 2007. Median patient age was 64.0 years (range, 45-84 years), and median follow-up duration was 62.9 months (range, 41-76 months). All patients had radiculopathy and were unresponsive to conservative treatment for more than 3 months. Patients with DSPL greater than grade I were excluded. We included all patients who had stable grade I DSPL (translation ≤ 5 mm; angular difference ≤ 10°) in this study. All ULBDs were performed by one senior surgeon, and all fusion surgeries were performed by another senior surgeon (Table 1).

ULBD surgery was performed in a standardized manner. We usually chose a left side approach unless there was significantly dominant pain on the right side. A midline skin incision was made, followed by muscle dissection. The facet capsule was preserved and half of the ipsilateral spinous process was removed with a burr drill to better visualize the contralateral side. After ipsilateral partial hemilaminectomy, contralateral bony undercutting and ligament flavectomy were performed. After identifying the remaining thecal sac and root decompression, the incision was closed. Patients were permitted to ambulate on the next day without a brace.

Fusion surgery consisted of decompression, interbody fusion with a polyester-ether-ketone (PEEK) cage, and local bone and pedicle screw fixation. Subtotal laminectomy and removal of the inferior articular process resulted in decompression of the thecal sac and bilateral roots. After discectomy via bilateral direction and endplate preparation, laminectomized bone was inserted into the empty disc space, followed by bilateral insertion of two PEEK cages (11 mm height and 4° angle in six patients, 10 mm and 4° in eight patients, and 9 mm and 4° in 11 patients) filled with laminectomized bone into the disc space under fluoroscopic guidance. Bilateral pedicle screws were inserted and compressed to tighten the disc space and secure a better lordotic angle. Patients were permitted to ambulate on the second day after surgery, and the external lumbosacral orthosis was maintained for 3 months.

The mean ages of the ULBD and fusion groups were 67.65 and 61.92 years, respectively (P=0.008). However, sex distribution, length of follow-up, mean body mass index (BMI), mean pre-operative disc height, slippage, translation, and angular differences did not differ significantly (Fig. 1 and Table 1).

Clinical outcomes of all patients were assessed using a numeric rating scale (NRS) of back and leg pain, the Oswestry Disability Index (ODI), and the physical component summary (PCS) and mental component summary (MCS) of the Short Form-36 Health Survey (SF-36). Residual pain was defined as no improvement in preoperative pain, whereas recurrent pain was defined as an improvement after surgery, followed later by the same or similar pain. Causes of residual and recurrent pain in each group were analyzed by pre- and postoperative magnetic resonance imaging (MRI) or X-rays. In addition, we analyzed several factors that might affect recurrent radicular pain, including age, sex, surgical level, mean BMI, disc height, facet inclination, slippage, translation, and angular difference.

Radiological outcomes of patients who underwent ULBD were analyzed by determining changes in slippage, disc height translation, and angular difference by simple and

Table 1 Basic characteristics of the two groups

	ULBD (n=20)	Fusion (n=25)	P value
Mean age (range), years	67.65 (55–84)	61.92 (45–77)	0.008
Sex (M/F)	5:15	3:22	>0.05
Surgical level			>0.05
L3-4	3	6	
L4-5	17	19	
Mean FU (range), months	54.9 (41–69)	69.4 (55–76)	>0.05
Mean BMI, kg/m^2	25.8±3.41	25.8±5.62	>0.05
Mean pre-op. disc height (mm)	9.7±1.88	10.2±0.74	>0.05
			>0.05
Mean facet inclination (°)	55.5±9.93	59.6±7.39	>0.05
Mean pre-op. slip (%)	14.1±4.56	14.7±4.59	>0.05
Mean pre-op. translation (mm)	2.3±1.54	2.3±1.43	>0.05
Mean pre-op. AD (°)	7.1±3.20	7.8±2.89	>0.05

FU follow-up, *BMI* body mass index, *AD* angular difference

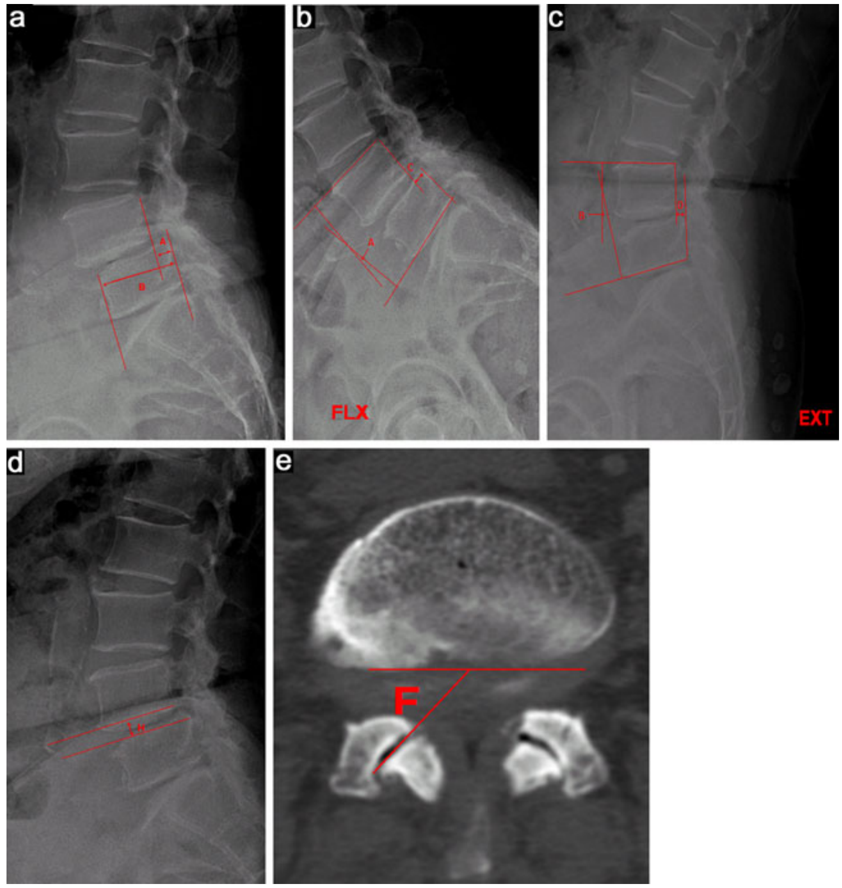

Fig. 1 **a** A simple lateral image in a patient. Slippage was calculated as *A*/*B* × 100%. Flexion (**b**) and extension (**c**) images of a patient. Translation was calculated as *D* - *C* and angular difference as *C* - *A*. **d** A simple lateral image. *H* indicates disc height. **e** Computed tomography axial image. *F* indicates facet inclination

dynamic X-rays. Radiologic outcomes in patients who underwent fusion were analyzed by determining the changes in upper and lower segmental disc height at the fusion level by simple X-rays. The adjacent segmental degeneration (ASD) grading system was used to assess the status of the segments adjacent to the fused segment on last follow-up simple X-ray [15, 22].

Statistical comparisons were performed using the Fisher's exact test, and Mann-Whitney *U* test to compare the pre-operative parameters of each group. Paired t-tests were used to compare the differences between pre- and post-operative values. Univariate logistic regression analysis was used to find affecting factor of pain recurrence in the ULBD group. A P value < 0.05 was considered statistically significant. All statistical analyses were performed using SPSS software, release 10.1.4 (SPSS, Chicago, IL).

Results

Clinical outcomes

The mean NRS of back pain decreased in both groups from 2.8±3.10 to 1.2±2.20 in the ULBD group and from 6.6±2.47 to 2.4±1.88 in the fusion group (P=0.001). The mean NRS of leg pain also decreased in both groups, from 7.8±0.91 to 2.4±2.53 in the ULBD group and from 8.0±0.87 to 2.5±1.80 in the fusion group (P=0.99). Mean ODI decreased from 29.8±4.40 to 15.45±7.06 in the ULBD group and from 24.6±5.38 to 11.0±7.09 in the fusion group (P=0.96). The mean PCS of the SF-36 groups increased from 29.2±3.67 to 47.2±9.42 in the ULBD group and from 26.1±5.33 to 46.3±7.41 in the fusion group (P=0.26), and the mean MCS of the SF-36 increased from 28.0±3.37 to 46.7±8.54 in the ULBD group and from 29.3±3.84 to 44.5±6.63 in the fusion group (P=0.25). According to the Odom's criteria, 13 patients in the ULBD and 14 in the fusion group showed excellent or good outcomes (P=0.50, Table 2).

Radiological outcomes

We also measured radiological changes in the ULBD group from baseline to last follow-up. We found that mean slippage change was 2.1±3.10%, mean translation change was 0.15±1.58 mm, mean change in angular difference was -0.91±4.48°, and mean change in disc height was -1.83±1.69 mm (Table 3). None of the patients in the fusion group experienced pseudoarthrosis. In this group, the mean reductions in upper and lower level disc heights from baseline to last follow-up were 1.38±1.10 mm, and

Table 2 Changes in clinical outcomes in the two groups

	ULBD (n=20)		Fusion (n=25)		*P* value
	Preoperation	Last FU	Preoperation	Last FU	
Mean NRS (back)	2.8±3.10	1.2±2.20	6.6±2.47	2.4±1.88	0.001
Mean NRS (leg)	7.8±0.91	2.4±2.53	8.0±0.87	2.5±1.80	0.99
ODI	29.8±4.40	15.45±7.06	24.6±5.38	11.0±7.09	0.96
Mean SF-36 (PCS)	29.2±3.67	47.2±9.42	26.1±5.33	46.3±7.41	0.26
Mean SF-36 (MCS)	28.0±3.37	46.7±8.54	29.3±3.84	44.5±6.63	0.25
Odom's Criteria					0.50
Excellent		3		4	
Good		10		10	
Fair		2		5	
Poor		5		6	

NRS numeric rating scale, *PCS* physical component summary, *MCS* mental component summary

1.19±0.80 mm, respectively. In the upper disc level, there were 11 grade I, 10 grade II, and 4 grade III ASDs. In the lower disc level, there were 21 grade I and 4 grade II ASDs (Table 3).

Residual and recurrent pain, and its causes

In the ULBD group, three patients had residual pain and another three patients had recurrent pain. The pre-operative MRI of one patient who had residual pain showed left L4-5 foraminal stenosis and narrowing of the disc space. An MRI taken 8 months postoperatively also showed persistent left L4-5 foraminal stenosis and a more reduced disc height. This patient's pain resolved after fusion surgery (Fig. 2). The other two patients who had residual pain also showed foraminal narrowing on preoperative MRI.

Three patients whose radicular pain recurred in the ULBD group complained of recurrent pain after 1, 1.5, and 2 years. We found that all of these patients had more unilaterally collapsed discs, which were on the painful side, on preoperative anterior-posterior (AP) X-ray. In addition, follow-up AP X-ray showed more unilateral collapse, especially on the decompression side. Follow-up MRI also showed unilateral foraminal root compression caused by unilateral disc height reduction, which was on the decompressed side (Fig. 3). However, no patients had segmentally collapsed discs on AP X-ray in the successful ULBD group. We compared several factors between patients with recurrent pain and those without and found no factors that significantly affected pain recurrence (Tables 4 and 5).

Among patients in the fusion group, none had residual pain, whereas five patients had recurrent pain and intermittent radiculopathy. Three patients in this group showed adjacent segment stenosis and degeneration on recent MRI (Fig. 4). Another patient also showed upper adjacent segment instability on dynamic X-rays. An X-ray of the other

Table 3 Changes in radiological outcomes in the two groups

		Last FU value - preoperation value
ULBD group	Mean slippage change	2.1±3.10%
	Mean translation change	0.15±1.58 mm
	Mean angular difference change	-0.91±4.48°
	Mean disc height change	-1.83±1.69 mm
Fusion group	Mean upper level disc height reduction	1.38±1.10 mm
	Mean lower level disc height reduction	1.19±0.80 mm
	ASD (upper disc level)	25
	Grade I	11
	Grade II	10
	Grade III	4
	ASD (lower disc level)	25
	Grade I	21
	Grade II	4

ASD adjacent segment degeneration

Fig. 2 Preoperative (**a-c**) and postoperative (**d, e**) T2 weighted MR images of a 69-year-old female patient with persistent pain after decompression in the ULBD group. **a** Midline sagittal MR image, showing degenerative grade I spondylolisthesis. **b** Left lateral sagittal MR image, showing L4-5 foraminal narrowing and root compression. **c** Axial MR image at the L4-5 level, showing induction of left side foraminal stenosis induced with same level disc bulging. **d** Left lateral sagittal MR image, showing sustained foraminal narrowing and high signal intensity in the facet joint. **e** Axial MR image at the L4-5 level, showing sustained foraminal stenosis

patient showed an upper vertebral body (L3) compression fracture.

Surgery-related complications

Operation-related complications included one patient with incidental durotomy in the ULBD group and one with wound infection in the fusion group.

Discussion

It is unclear whether fusion is the best treatment for DSPL, with some studies suggesting that good results can be obtained by decompression alone, whereas others regard fusion as providing better outcomes [2, 6, 8–10, 13, 14, 17, 18, 20, 24]. Although ASD can progress after fusion surgery for DSPL, instability progression after decompressive laminectomy may result in worse outcome. ULBD

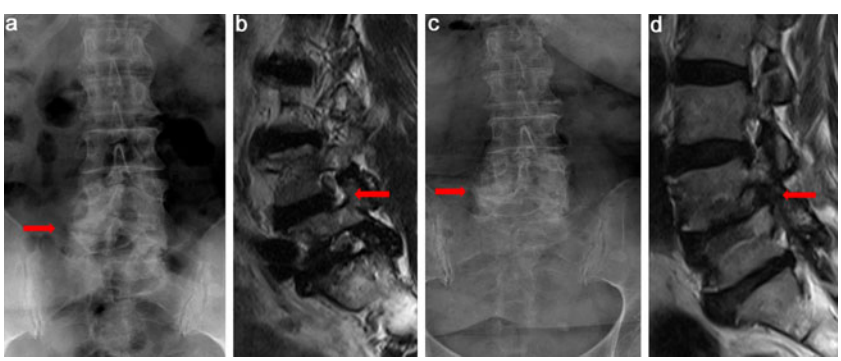

Fig. 3 Preoperative (**a, b**) and postoperative (**c, d**) AP X-ray and T2 weighted sagittal MR images of a 66-year-old female patient with recurrent pain after decompression in the ULBD group. **a** Preoperative AP X-ray image shows right side slight collapse and dark density of disc space in L4-5 level (*red arrow*). **b** Preoperative T2 weighted sagittal MR image shows foraminal stenosis is not severe and right L5 root is not compressed (*red arrow*). **c** AP X-ray image at 2 years post-operation shows right side complete collapse and nearly fused state at the L4-5 level (*red arrow*). **d** T2 weighted sagittal MR image at 2 years post-operation shows foraminal stenosis is severe, and severe right L5 root compression is noted (*red arrow*)

Table 4 Preoperative mean values and logistic regression analysis between successful and pain recurrent patients in ULBD group

	Patients who did not complain recurrent pain in ULBD group (n=14)	Patients who complained recurrent pain in ULBD group (n=3)	Odds ratio	P value
Mean age (range), years	65.79 (55–81)	68.33 (64–75)	1.08	0.49
Mean BMI, kg/m^2	25.6±3.26	28.4±1.56	1.50	0.20
Mean pre-op. disc height (mm)	10.1±1.68	9.3±1.73	0.74	0.44
Mean facet inclination (°)	54.9±9.38	45.3±6.81	0.90	0.14
Mean pre-op. slip (%)	13.3±4.75	16.0±5.58	1.16	0.29
Mean pre-op. translation (mm)	2.2±1.51	1.7±1.82	0.77	0.56
Mean pre-op. AD (°)	7.7±3.11	5.7±3.79	0.83	0.33

surgery was designed to delay the progression of instability after decompressive laminectomy for DSPL. We therefore compared the efficacy of minimally invasive ULBD and fusion surgery in selected patients with stable grade I DSPL.

The overall leg pain reduction and functional improvements in the two groups were similar. However, there was a degree of selection bias, in that patients with higher mean preoperative back pain score and younger age tended to be included in the fusion group.

Absence of hypermotility is an important prognostic factor in the success of decompression surgery for DSPL [2, 13, 14, 18]. The patients who were included in our study showed similar preoperative characteristics of segmental motion, such as translation and angular differences, between the groups (Table 1).

At last follow-up, the clinical outcomes were similar in the ULBD and fusion surgery groups. Considering the shorter recovery time and economic advantage of ULBD, we believe that ULBD is better option in specific groups of patients.

It remains unclear why some patients with DSPL experience good outcomes after treatment with decompression alone, whereas others do not. Factors influencing outcomes may include patient age, indications for surgery, degree of DSPL, orientation of facet joints, degenerative status of the disc, decompressive technique, eventual progression of postoperative spondylolisthesis, and comorbidities [1, 2, 4, 11, 12, 16, 17, 19, 23, 25]. All three patients who had foraminal stenosis preoperatively complained of residual pain. This result indicates that preoperative foraminal stenosis cannot be solved with decompression surgery. The characteristics of foraminal stenosis and its treatment are well known [7, 29, 32]. Complete removal of the offending lesion and preserving stability only with decompression surgery are very difficult and time-consuming procedures, especially with ULBD. All three patients who experienced residual pain after ULBD had foraminal stenosis on preoperative MRI. Thus, the presence of foraminal stenosis should be considered when selecting candidates for fusion operation rather than for ULBD surgery. In addition, we also attempted to identify the factors affecting pain recurrence after decompression. We found that segmental coronal collapse, even slight collapse, should be considered an important factor to achieve successful outcome in ULBD surgery. Our three patients who had pain recurrence showed progression of preoperative minimal coronal collapse after ipsilateral decompression with resulting foraminal root compression. For these DSPL patients, we believe that disc height restoration and correction of segmental coronal collapse with fusion surgery may be a better choice for better outcome. Decompression, even through unilateral laminectomy, in such a case may make vertebrae more unstable.

Decreased disc height has been reported to be associated with poor clinical outcomes [2, 10]. Although it was not statistically significant, the mean preoperative disc height of patients with recurrent pain was slightly less than that of patients successfully treated in the ULBD group. In addition, the amount of disc height reduction was also slightly

Table 5 Mean change of radiological parameters and logistic regression analysis between successful and pain recurrent patients in ULBD group

Last FU value - preoperation value	Patients who did not complain recurrent pain in ULBD group(n=14)	Patients who complained recurrent pain in ULBD group (n=3)	Odd ratio	P value
Mean slippage change	1.45±2.27	6.43±5.81	1.51	0.07
Mean translation change	0.36±1.58	1.06±0.66	1.44	0.44
Mean angular difference change	0.02±2.74	4.67±4.04	1.82	0.06
Mean disc height change	-2.01±1.68	-2.20±2.87	0.94	0.87

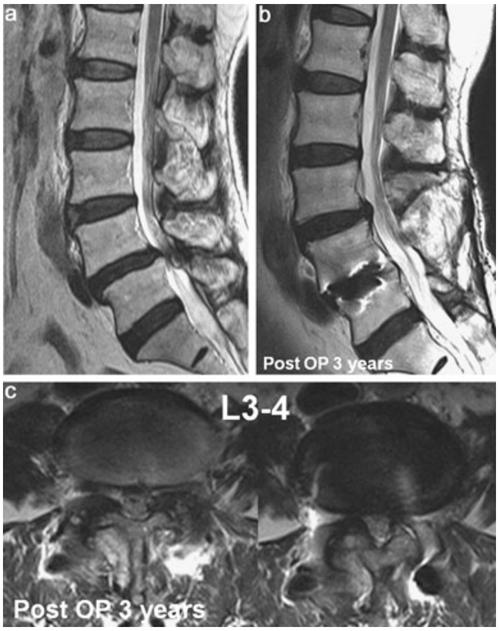

Fig. 4 Preoperative (**a**) and postoperative (**b, c**) T2 weighted MR images of a 67-year-old male patient of the fusion group. **a** Midline sagittal image, showing degenerative grade I spondylolisthesis at the L4-5 level but normal findings at the L3-4 level. **b** Midline sagittal image, showing disc bulging at the L3-4 level. **c** Axial MR image, suggesting that foraminal and central stenosis at the L3-4 level had progressed

bigger in patients with recurrent pain at last follow-up (Tables 4 and 5). We believe that unilateral collapse progression of the decompressed side, which was related to pain recurrence in the ULBD group, might be related to the decrease in disc height measured on lateral X-ray. However, this hypothesis must be tested with a prospective analysis of more cases.

Overall, patients who underwent ULBD showed slight increases in slippage and translation, and decreases in disc height. These changes, however, are comparable to the high occurrence of ASD in the fusion group. Although ASD was related to recurrence of pain in that group, longer follow-up times are required to verify the progression of radiological degeneration and pain recurrence after ULDB surgery.

Our study had several limitations, including patient selection bias stemming from the use of two different surgeons with different surgical policies, the small number of patients, the relatively short term follow-up, and the retrospective design of the study. Also, the statistical analysis to analyze prognostic factors remains a big issue since the small number of patients cannot provide robust statistical data and allow sound conclusions. In addition, we cannot exclude the possibility of measurement error of several radiological parameters. Specifically, the lack of interobserver reliability in the measurements can alter the reliability of the results. Prospective randomized comparisons of more patients with longer follow-up are needed to determine which of these methods is optimal.

Conclusion

Our findings suggest that ULBD is superior to fusion surgery for specifically selected patients with grade I DSPL who have mainly radicular pain. The two groups had similar clinical outcomes overall, although radiological degeneration was not as severe after ULBD treatment. In our analysis, foraminal stenosis is a contraindication for ULBD in the treatment of grade I DSPL. Because preoperative unilaterally collapsed disc on an AP X-ray has the potential to progress and cause pain recurrence, decompression surgery in such patients should be avoided.

Conflicts of interest None.

References

1. Booth KC, Bridwell KH, Eisenberg BA, Baldus CR, Lenke LG (1999) Minimum 5-year results of degenerative spondylolisthesis treated with decompression and instrumented posterior fusion. Spine 24(16):1721–1727
2. Bridwell KH, Sedgewick TA, O'Brien MF, Lenke LG, Baldus C (1993) The role of fusion and instrumentation in the treatment of degenerative spondylolisthesis with spinal stenosis. J Spinal Disord 6(6):461–472
3. Çavuşoğlu H, Kaya RA, Türkmenoglu ON, Tuncer C, Çolak İ, Aydın Y (2007) Midterm outcome after unilateral approach for bilateral decompression of lumbar spinal stenosis: 5-year prospective study. Eur Spine J 16(12):2133–2142
4. Cinotti G, Postacchini F, Fassari F, Urso S (1997) Predisposing factors in degenerative spondylolisthesis. A radiographic and CT study. Int Orthop 21(5):337–342
5. Costa F, Sassi M, Cardia A, Ortolina A, De Santis A, Luccarell G, Fornari M (2007) Degenerative lumbar spinal stenosis: analysis of results in a series of 374 patients treated with unilateral laminotomy for bilateral microdecompression. J Neurosurg Spine 7 (6):579–586
6. Epstein NE (1998) Decompression in the surgical management of degenerative spondylolisthesis: advantages of a conservative approach in 290 patients. J Spinal Disord 11(2):116–123
7. Epstein NE (2002) Foraminal and far lateral lumbar disc herniations: surgical alternatives and outcome measures. Spinal Cord 40 (10):491–500
8. Feffer HL, Wiesel SW, Cuckler JM, Rothman RH (1985) Degenerative spondylolisthesis. To fuse or not to fuse. Spine 10(3):287–289
9. Fischgrund JS, Mackay M, Herkowitz HN, Brower R, Montgomery DM, Kurz LT (1997) 1997 Volvo Award winner in clinical studies. Degenerative lumbar spondylolisthesis with spinal stenosis: a prospective, randomized study comparing decompressive laminectomy and arthrodesis with and without spinal instrumentation. Spine 22 (24):2807–2812
10. Ghogawala Z, Benzel EC, Amin-Hanjani S, Barker FG, Harrington JF, Magge SN, Strugar J, Coumans JV, Borges LF (2004) Prospective outcomes evaluation after decompression with or without instrumented fusion for lumbar stenosis and degenerative Grade I spondylolisthesis. J Neurosurg Spine 1(3):267–272
11. Grobler LJ, Robertson PA, Novotny JE, Ahern JW (1993) Decompression for degenerative spondylolisthesis and spinal stenosis at L4-5. The effects on facet joint morphology. Spine 18(11):1475–1482

12. Herkowitz HN (1995) Spine update. Degenerative lumbar spondylolisthesis. Spine 20(9):1084–1090
13. Herkowitz HN, Kurz LT (1991) Degenerative lumbar spondylolisthesis with spinal stenosis. A prospective study comparing decompression with decompression and intertransverse process arthrodesis. J Bone Joint Surg Am 73(6):802–808
14. Herron LD, Trippi AC (1989) L4-5 degenerative spondylolisthesis. The results of treatment by decompressive laminectomy without fusion. Spine 14(5):534–538
15. Kettler A, Wilke HJ (2006) Review of existing grading systems for cervical or lumbar disc and facet joint degeneration. Eur Spine J 15 (6):705–718
16. Konno S, Kikuchi S (2000) Prospective study of surgical treatment of degenerative spondylolisthesis: comparison between decompression alone and decompression with graf system stabilization. Spine 25(12):1533–1537
17. Kristof RA, Aliashkevich AF, Schuster M, Meyer B, Urbach H, Schramm J (2002) Degenerative lumbar spondylolisthesis-induced radicular compression: nonfusion-related decompression in selected patients without hypermobility on flexion-extension radiographs. J Neurosurg 97(3 Suppl):281–286
18. Mardjetko SM, Connolly PJ, Shott S (1994) Degenerative lumbar spondylolisthesis. A meta-analysis of literature 1970-1993. Spine 19(20 Suppl):2256S–2265S
19. Matsunaga S, Sakou T, Morizono Y, Masuda A, Demirtas AM (1990) Natural history of degenerative spondylolisthesis. Pathogenesis and natural course of the slippage. Spine 15(11):1204–1210
20. McCulloch JA (1998) Microdecompression and uninstrumented single-level fusion for spinal canal stenosis with degenerative spondylolisthesis. Spine 23(20):2243–2252
21. McCulloch JA, Young PA (1998) Essentials of spinal microsurgery. Lippincott-Raven, Philadelphia
22. Mimura M, Panjabi MM, Oxland TR, Crisco JJ, Yamamoto I, Vasavada A (1994) Disc degeneration affects the multidirectional flexibility of the lumbar spine. Spine 19(12):1371–1380
23. Mochida J, Suzuki K, Chiba M (1999) How to stabilize a single level lesion of degenerative lumbar spondylolisthesis. Clin Orthop Relat Res 368:126–134
24. Niggemeyer O, Strauss JM, Schulitz KP (1997) Comparison of surgical procedures for degenerative lumbar spinal stenosis: a meta-analysis of the literature from 1975 to 1995. Eur Spine J 6 (6):423–429
25. Nork SE, Hu SS, Workman KL, Glazer PA, Bradford DS (1999) Patient outcomes after decompression and instrumented posterior spinal fusion for degenerative spondylolisthesis. Spine 24(6):561–569
26. Oertel MF, Ryang Y-M, Korinth MC, Gilsbach JM, Rohde V (2006) Long-term results of microsurgical treatment of lumbar spinal stenosis by unilateral laminotomy for bilateral decompression. Neurosurgery 59(6):1264–1270
27. Palmer S, Turner R, Palmer R (2002) Bilateral decompressive surgery in lumbar spinal stenosis associated with spondylolisthesis: unilateral approach and use of a microscope and tubular retractor system. Neurosurg Focus 13(1):E4
28. Papavero L, Thiel M, Fritzsche E, Kunze C, Westphal M, Kothe R (2009) Lumbar spinal stenosis: prognostic factors for bilateral microsurgical decompression using a unilateral approach. Neurosurgery 65(6 Suppl):182–187
29. Park JH, Bae CW, Jeon SR, Rhim SC, Kim CJ, Roh SW (2010) Clinical and radiological outcomes of unilateral facetectomy and interbody fusion using expandable cages for lumbosacral foraminal stenosis. J Korean Neurosurg Soc 48(6):496–500
30. Poletti C (1995) Central lumbar stenosis caused by ligamentum flavum:unilateral laminotomy for bilateral ligamentectomy: preliminary report of two cases. Neurosurg 37:343–347
31. Sasai K, Umeda M, Maruyama T, Wakabayashi E, Iida H (2008) Microsurgical bilateral decompression via a unilateral approach for lumbar spinal canal stenosis including degenerative spondylolisthesis. J Neurosurg Spine 9(6):554–559
32. Sengupta DK, Herkowitz HN (2003) Lumbar spinal stenosis. Treatment strategies and indications for surgery. Orthop Clin North Am 34(2):281–295
33. Spetzger U, Bertalanffy H, Reinges MH, Gilsbach JM (1997) Unilateral laminotomy for bilateral decompression of lumbar spinal stenosis. Part II: Clinical experiences. Acta Neurochir (Wein) 139 (5):397–403
34. Toyoda H, Nakamura H, Konishi S, Dohzono S, Kato M, Matsuda H (2011) Clinical outcome of microsurgical bilateral decompression via unilateral approach for lumbar canal stenosis: minimum five-year follow-up. Spine 36(5):410–415