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Surgical Treatment of Low-Grade Lumbar Spondylolisthesis

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Research Article

History

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ABSTRACT

Lumbar spondylolisthesis is a prevalent cause of lower back pain and is a focal interest of spinal surgery. A diverse set of decompression and fusion techniques are used in surgery.

To investigate the surgical and clinical outcomes patients with spondylolisthesis who received surgical intervention.

Data from 25 patients (15 women; 10 men; mean age, 48.8 ± 12.4 years; range, 27–66 years) with low-grade spondylolisthesis who received surgical intervention were retrospectively analyzed. Posterolateral and posterior interbody fusion was used in 17 and 8 patients, respectively, and 19 received posterior pedicle screws and 6 received only fusion and decompression.

According to the Kirkaldy–Willis criteria, the clinical outcomes of 11 (44%), 9 (36%), 3 (12%), and 2 (8%) patients were rated excellent, good, fair, and poor, respectively, with a success rate of 80%. Furthermore, fusion was observed in 21 patients (84%). Favorable outcomes were achieved in 17 (90%) patients with pedicle screws and in 3 (50%) with only decompression and fusion ($p=0.048$; $p<0.05$). The rate of favorable outcome was 75% of patients who smoked ($p=0.226$; $p>0.05$). Two out of three patients with revision surgery had poor clinical outcomes ($p=0.091$; $p<0.05$).

The addition of pedicle screw fixation to posterolateral fusion increases fusion rates and yields satisfactory clinical results. Previous history of surgery is a risk factor that should be considered before deciding to perform surgery. Furthermore, the transpedicular screw fixation technique can be made less complicated and effective via effective and experienced teamwork. Herein, we reviewed recent studies and discussed the indications, complications, and outcomes of surgical treatment of low-grade spondylolisthesis.

Keywords: Lumbar spondylolisthesis, pedicle screws, fusion

Düşük Dereceli Lomber Spondilolistezisin Cerrahi Tedavisi

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ÖZ

Lomber spondilolistezis bel ağrısının yaygın bir nedenidir ve omurga cerrahisinin odak noktasıdır. Cerrahide çok çeşitli dekompresyon ve füzyon teknikleri kullanılmaktadır.

Cerrahi girişim uygulanan spondilolistezisli hastaların cerrahi ve klinik sonuçlarını araştırmak.

Düşük dereceli spondilolistezis nedeniyle cerrahi girişim uygulanan 25 hastanın (15 kadın; 10 erkek; ortalama yaş, 48,8 ± 12,4 yıl; aralık, 27-66 yıl) verileri retrospektif olarak analiz edildi. Sırasıyla 17 ve 8 hastaya posterolateral ve posterior interbody füzyon uygulandı ve 19'una posterior pedikül vidası, 6'sına ise sadece füzyon ve dekompresyon uygulandı.

Kirkaldy-Willis kriterlerine göre 11 (%44), 9 (%36), 3 (%12) ve 2 (%8) hastanın klinik sonuçları mükemmel, iyi, orta ve kötü olarak derecelendirildi. sırasıyla %80 başarı oranıyla. Ayrıca 21 hastada (%84) füzyon gözlendi. Hastaların 17'sinde (%90) pedikül vidası, 3'ünde (%50) ise sadece dekompresyon ve füzyon ile olumlu sonuçlar elde edildi ($p=0,048$; $p<0,05$). Sigara içen hastalarda olumlu sonuç oranı %75 idi ($p=0,226$; $p>0,05$). Revizyon cerrahisi yapılan üç hastanın ikisinde kötü klinik sonuçlar elde edildi ($p=0,091$; $p<0,05$).

Posterolateral füzyona pedikül vidası fiksasyonunun eklenmesi füzyon oranlarını arttırmakta ve tatmin edici klinik sonuçlar vermektedir. Önceki ameliyat öyküsü, ameliyata karar vermeden önce dikkate alınması gereken bir risk faktörüdür. Ayrıca etkili ve deneyimli bir ekip çalışmasıyla transpediküler vida tespit tekniği daha az karmaşık ve etkili hale getirilebilir. Burada güncel çalışmaları gözden geçirdik ve düşük dereceli spondilolistezisin cerrahi tedavisinin endikasyonlarını, komplikasyonlarını ve sonuçlarını tartıştık.

Anahtar sözcükler: Lomber spondilolistezis, pedikül vidaları, füzyon

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Introduction

Lumbar spondylolisthesis is an important cause of spinal canal stenosis and is often associated with back and leg pain, restriction in daily activities, and significant work disability. Various techniques intended for the surgical treatment of lumbar spondylolisthesis have been developed thus far, and the development of new techniques has continued. [1,2,3,4] No golden standard for the surgical treatment of spondylolisthesis has been established thus far. Fusion is an indispensable part of spondylolisthesis treatment and other conditions of spinal instability. However, achieving adequate fusion and favorable clinical outcomes is not always possible in adults with spondylolisthesis. [5] The technique involving stabilization with the posterior pedicle screw has garnered increased use in recent years and was believed to provide a better solution. The disadvantages of this technique include that it is a major surgical procedure, has relatively high complications, and is an expensive surgical technique; thus, exercising precaution during patient selection is important. [6,7] The present study aimed to determine the patient group and the extent to which the patients would benefit from surgical treatment and review the problems associated with the treatment in light of the recent studies.

Material and Method

This retrospective study included 25 patients who received surgical intervention for low-grade lumbar spondylolisthesis between September 1991 and January 1998 at the Neurosurgical Clinics of Şişli Etfal and Taksim Education and Research Hospitals. The article was derived from a dissertation study. Study data, including age, sex, preoperative complaints, physical examination, and radiologic findings, were recorded. Patients underwent follow-up examinations and radiologic tests for a mean period of 31 months (range from 6 months to 4 years) postoperatively. Kirkaldy–Willis criteria (excellent, good, fair, and poor) were used to assess the effectiveness of the surgical intervention. [8] The patients deemed eligible for surgery showed clinical and radiological findings compatible with spondylolisthesis, and these patients did not benefit from conservative treatment methods, including bed rest, medical treatment, and physical therapy and rehabilitation. The prerequisites for surgical indication were neurologic deficit, neurogenic claudication, spondylolisthesis, and postural abnormality, among others.

Dynamic lumbosacral radiography was used to radiologically confirm spondylolisthesis, a tensional movement of ≥4 mm, in the patients. The techniques accommodated during the surgical interventions included fenestration, laminectomy, posterior lumbar interbody fusion (PLIF) with no cage, posterolateral fusion (PLF), and stabilization with posterior pedicle screw technique. A combination of these techniques was used based on the indication of the cases. Reduction was not used in any patient. Autologous graft, collected from the iliac wing bone, was used for fusion. Fusion was believed to have occurred upon observation of bilateral trabecular bone continuity between the fused segments.

Statistical Analyses

The Number Cruncher Statistical System (NCSS) 2020 Statistical Software (NCSS LLC, Kaysville, Utah, USA) was used for statistical analysis. Fisher's Exact Test was used to compare qualitative data. Results were analyzed at a 95% confidence interval, and a p level of <0.05 indicated statistical significance.

Surgical Technique

Patients were placed in a prone position to expose the abdomen. Prophylactic antibiotherapy was administered, and surgery was commenced under general anesthesia after determining the vertebral level using fluoroscopy. A vertical incision was made into the midline to clearly view the surgical area. The paravertebral muscles were bilaterally, subperiosteally dissected, after which the laminae, facet joints, pars interarticularis, and transverse processes were exposed. Pedicle screw entry points at the instrumentation levels were set using the intersection technique. First, the entry point was prepared with a curette and then the screw path was prepared with a special pedicle curette, while accounting for the transverse and sagittal pedicle angles. Meanwhile, the screw path was intermittently controlled using Kirshner wires. When a transition from cortical bone to soft tissue was detected, another nearby point was selected to provide secure fixation. After determining the screws according their respective levels, the screws were placed into the prepared pathways in an orientation as appropriate to their angles. Due care was taken to avoid trespassing the anterior cortex in terms of implantation depth. Necessary decompression was then performed. Bone graft from the iliac wing bone was shaped to fit the distance in cases of interbody fusion. The graft was placed in the disc space, allowing minimal neural manipulation. The posterior lumbar fusion (PLF) was placed in the form of lamellae on the facets and between the transverse processes. Screw–rod connection was ensured by shaping the rods to fit their physiologic curvatures. Hemostasis was achieved before closure.

Results

Among the 25 patients who received surgical intervention for lumbar spondylolisthesis, 10 were male (40%), 15 were female (60%), and the mean patient age was 48.8 ± 12.4 years (range, 27–66 years). (Figure 1) Lower back pain was the leading complaint at a presentation by all the patients included in the study. (Table 1) Pain radiating to the leg was unilateral in 14 patients and bilateral in 4. The mean duration of pain experienced by the patients was 4.8 years (range, 4 months to 11 years). Upon physical examination of the patients, the most prevalent finding was the positive straight leg raising test and sensory deficit (Table 2).

Figure 1. Distribution of cases based on age and gender.

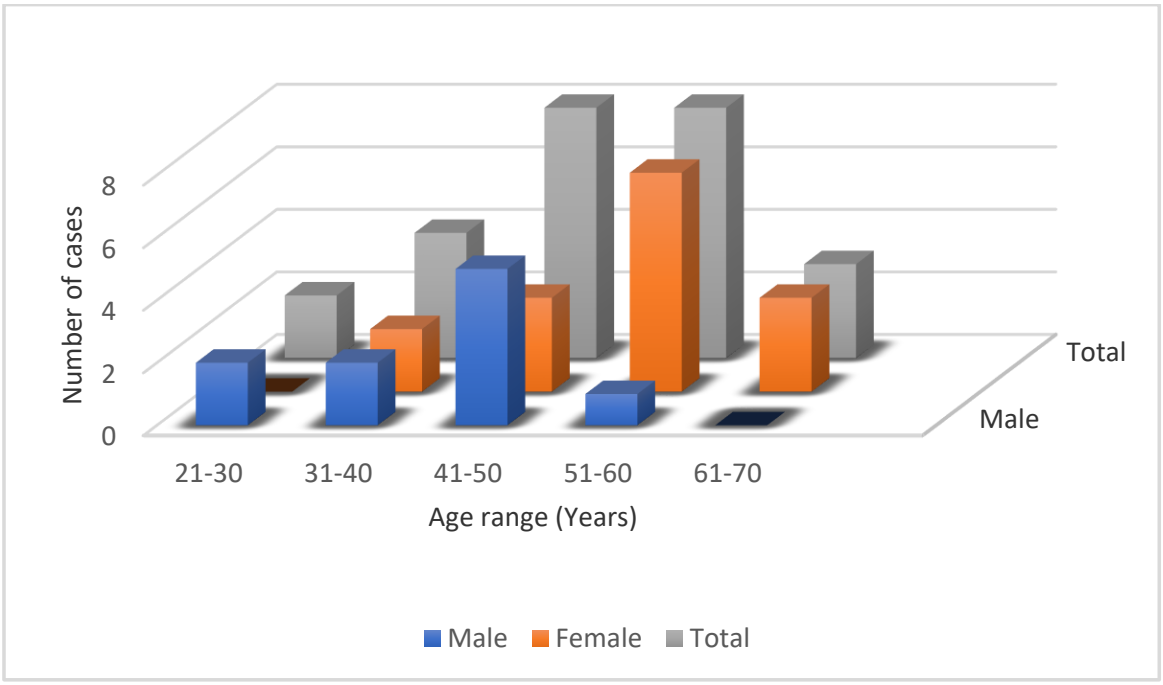


Table 1. Patients' complaints at admission

Symptoms	Number of cases (%)
Lower back pain	25 (100%)
Pain radiating to the leg	18 (72%)
Muscle weakness	5 (20%)
Numbness in the foot	4 (16%)

Table 2. Examination findings of the patients

FINDINGS	Case (%)
Straight leg raise test	18 (72%)
Motor deficit	11 (44%)
Sensory deficit	18 (72%)
Reflex deficit	12 (48%)
Neurogenic claudication	7 (28%)
Atrophy	5 (20%)

The mean slippage rate was 24% (range, 15%–51%) based on Tailard's method. [9] Furthermore, isthmic, degenerative, and postoperative spondylolisthesis was observed in 11, 13, and 1 patients, respectively (Figure 2). The age of patients with degenerative spondylolisthesis was 41–60 years, whereas patients with isthmic spondylolisthesis were distributed across all age groups (Figure 3).

Spondylolisthesis was at the level of L5–S1 in 11 patients, L4–5 in 9, L3–4 in 4, and L2–3 in 1. Comorbid lumbar stenosis and lumbar disc herniation was observed in 9 and 7 patients with spondylolisthesis, respectively. Of the 19 patients who received stabilization with the posterior pedicle screw technique, 4 had six screws, and 15 had four screws. A total of 6 patients only underwent decompression and PLF, whereas 19 patients underwent fenestration and foraminotomy, with 6 patients receiving decompression with laminectomy. PLF was performed in 17 patients, and PLIF was performed in the remaining 8 patients. The mean duration of

hospitalization was 13.5 days, and the mean duration of surgery was 3.5 hours.

In total, 20 patients were rated as excellent or good and 5 as fair or poor based on the Kirkaldy–Willis Grading system. Good outcome was observed in 17 (90%) patients with pedicle screws and in 3 (50%) patients with only decompression and fusion. The difference was significant (p=0.048; p<0.05), with a higher rate of good outcome in the patients with pedicle screws. In patients who smoked, 75% of the patients showed good results. The patients who smoked showed no significant difference when compared with those who did not smoke (p=0.226; p<0.05).

The clinical outcome in patients without revision surgery was good in 19 patients (86.4%). A good outcome was achieved in only one of the 3 patients (33.3%) who received revision surgery. Although the difference was not significant, the p value was close to the level of significance. A significantly high rate of good outcomes was noted in patients who did not undergo revision surgery (p=0.091; p<0.05). Radiologic examination revealed the absence of an increase in the slippage percentage in these patients. Furthermore, fusion was observed in 21 patients (84%).

Figure 2. Distribution of the type of spondylolisthesis

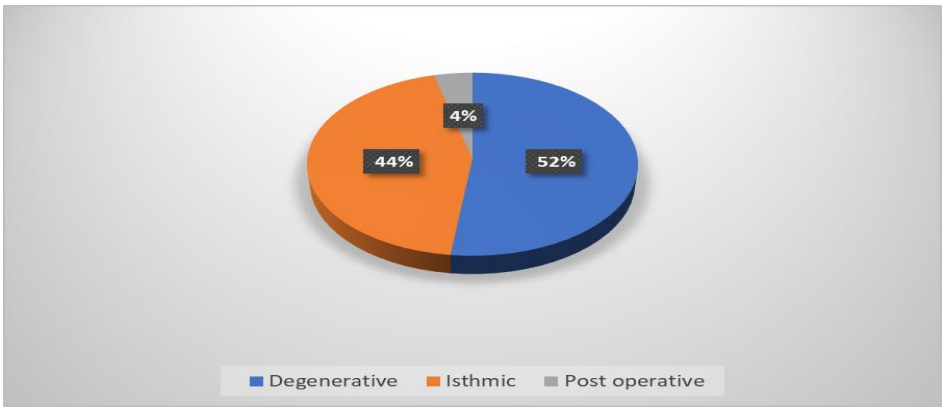
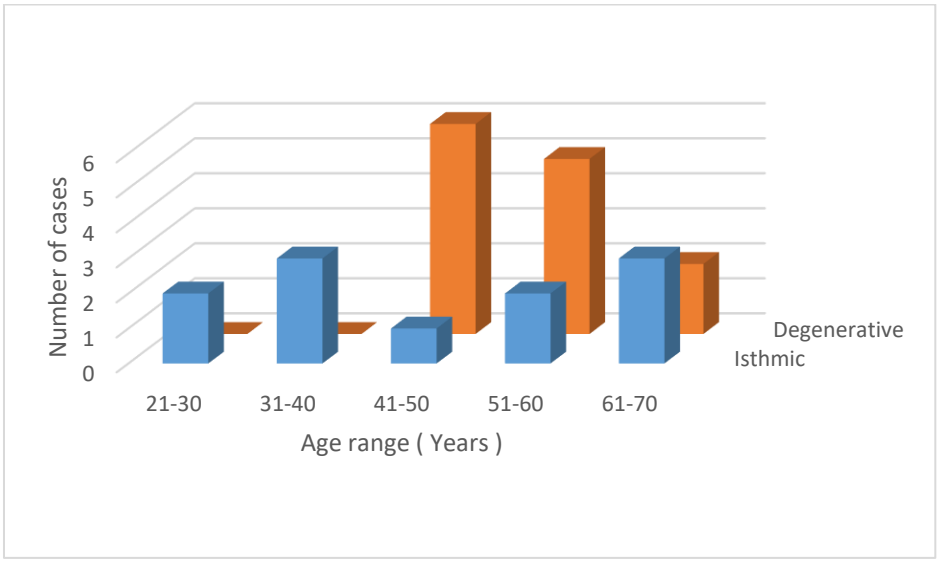


Figure 3. Age incidence of the most common types of spondylolisthesis



Complications

Two patients with a superficial infection at the surgical site were treated via antibiotherapy and dressing. No surgical intervention was considered necessary. All patients, who received grafts from the iliac bone wing, experienced severe postoperative pain at the origin of the iliac bone area. Analgesics were used to treat pain, and these pains did not persist for a prolonged period. Major postoperative complications were observed in 5 patients. One patient experienced a cerebrospinal fluid (CSF) fistula, which was successfully managed with conservative treatment involving measures such as bed rest, maintaining an upright position, and avoiding activities that could raise intracranial pressure, including lifting and straining. Wound care was administered using dressings, and by the third day, the leakage had ceased. One patient had an abscess at the paravertebral muscles, which was treated by draining the abscess and administering antibiotherapy. In one patient, root compression occurred upon narrowing the foramen because the screw appeared to be misoriented; this was treated by repositioning the screw during revision surgery. The grafts in one patient with PLIF had slipped into the spinal canal, and pedicle screw penetration was visible via the lumbar computed tomography imaging performed for control purposes. The reoperated patient had bone grafts removed from the disc space and PLF and screw repositioning were performed. The patient's clinical condition did not improve after revision surgery, and therefore, the instruments were removed through reoperation. In another patient who had undergone PLIF, the grafts had slipped into the spinal canal, inducing increased pain. The patient was treated by repositioning the grafts and removing the compression, which resulted in successful decompression.

Discussion

A golden standard for the principles of surgical treatment for low-grade spondylolisthesis has not been established thus far, and debate regarding decompression, fusion technique, instrumentation, and graft type is ongoing. Furthermore, different techniques have been used, which include microdecompression [10], transvertebral screw fixation [11], and defect repair with screws and hooks[12] and with screws and wiring [13]. Significant treatment progress could have been achieved through the introduction of spinal instrumentation in the treatment of spondylolisthesis. However, on the grounds that conventional treatment methods continue to be indispensable, fusion can only be achieved in combination with spinal instrumentation. The aim of surgical treatment in the treatment of spondylolisthesis should be to prevent deficits, provide maximum improvement in existing deficits, relieve pain, ensure stability, stop the progression of slippage, and improve quality of life [14].

Most patients with low-grade spondylolisthesis without neurologic deficit benefit from conservative treatment. [15, 16] Evan D Boyd et al. studied a group of 46 patients with grade 1 spondylolisthesis and spondylolysis and reported that favorable outcomes can be achieved through conservative treatment. [17] Nava-Bringas et al. achieved good outcomes in terms of pain and function in a study with exercise groups and reported no difference in clinical outcome between different exercise programs. [18] However, Matsunaga suggested that listhesis may increase up to 30% after conservative treatment. [19]

Although fusion is one of the main principles of treatment in spondylolisthesis, only decompression can achieve minimal intervention. A review of the clinical results in patients who underwent decompression without fusion revealed highly satisfactory results. [20, 21, 22] However, Jang JW et al. suggested that slippage increased in cases where decompression alone was performed. [23] Muslim et al. reported that bilateral microdecompression with unilateral intervention was associated with satisfactory results, and there was no increase in slippage. [24]

Reportedly, a clinically significant difference in quality of life was observed in patients with degenerative low-grade spondylolisthesis following the addition of lumbar spinal fusion to decompression. [25, 26] Takahiro Tsutsumimoto et al. achieved a 69% recovery rate after decompression and non-instrumented fusion. [27] Despite a 74% fusion in the above series, no significant difference was noted in terms of the clinical outcome between those with and without fusion. However, previous studies with fusion alone, reported a significant rate of pseudoarthrosis compared with instrumented fusion. [28] In their review article, Martin et al. reported that fusion had a favorable effect on the clinical outcome compared with the clinical outcomes of patients who underwent decompression alone. Accordingly, they reported that the use of instruments increased fusion rates but did not ensure significant superiority in terms of clinical outcome.

A study combined fusion and decompression and reported satisfactory outcomes through the use of instrumented fusion and interbody fusion at a rate of 77% and 79%, respectively, compared with 64%

satisfactory results with fusion alone. [29] Yong-ping Ye et al. suggested that instrumentation increased fusion rates but was not associated with satisfaction. [30] In the present study, all the patients received fusions with a success rate of 84%. The fusion rate was variable in adults, and obesity, osteoporosis, smoking, and systemic diseases may lead to lower-than-expected results. [31] Fusion rates were better in children than in adults. According to a study by Jalenko et al., 85% fusion was achieved in children who received non-instrumented intervention in isthmic spondylolisthesis, whereas the same rate was 65% in adults. [32]

PLIF can be performed in patients undergoing discectomy. In recent years, the application of PLIF technique has become increasingly popular. As observed in the present study, PLIF is performed with cages in the majority of cases despite the fact that PLIF was typically performed without cages in the past. However, anterior lumbar interbody fusion (ALIF) and PLIF alone were reported to be biomechanically inferior to instrumented fusion and were not considered a standard for spinal fusion. [33, 34] Therefore, PLIF may be considered suitable for use in instrumented fusion surgeries. A number of previous studies have reported successful results using PLIF. In most of those studies, a higher rate of fusion was obtained through PLIF than via PLF. [35, 36] However, the existence of a difference between the two methods in terms of clinical outcome remains unclear. In their review article, Okuda et al. reported that a mean of 82% satisfactory results were achieved in the PLIF series. [37] Liu et al. suggested that PLIF was associated with fewer complications and higher fusion rates than PLF. [38]

Instrumentation has been adopted by a wide range of authors on the grounds that it provides a rigid fixation and increases the likelihood of fusion. Fixation, when combined with decompression, reduces pain, stops deformity progression, and allows for early mobilization. The transpedicular screw system is the most preferred technique because pedicle screws provide biomechanically stronger three-column stabilization than other fixation options. Pedicle screws do not require an intact posterior element. Despite the risk of neural damage, CSF fistula, vascular damage, and increased risk of infection, pedicle screws have been proven to be safe in experienced hands.

Whether bone fusion correlates with clinical outcome remains a controversial issue. Certain authors reported that clinical outcomes correlated well with fusion rates. [39] However, Fritzell et al. suggested that radiologic fusion did not correlate significantly with clinical outcome. [40] Inamdar et al. preferred PLF to PLIF due to the simplicity of the procedure, low rate of complications, and better clinical and radiologic results, although both groups reported a fusion rate of 100%. [41] Hallett et al. compared decompression alone, PLF + pedicle screw, and transforaminal lumbar interbody fusion (TLIF) + pedicle screw technique and reported that >90% fusion was achieved in the PLF group without significant intergroup difference in terms of functional results. [42] In the cases included in the present study, the clinical outcome was good or excellent in 90% of the patients, who underwent pedicle screws.

Fischgrund et al. investigated the effect of instrumentation in lumbar stenosis secondary to degenerative spondylolisthesis in a prospective randomized study. Sixty-seven patients received instrumented and non-instrumented decompression and fusion. After completing the follow-up, fusion rates of 82% and 48% were achieved in instrumented and non-instrumented cases, respectively. [43] Considering that there were reports on patients with spondylolisthesis, who received pedicle screw fixation without any success, despite an increased fusion rate, solid fusion was believed to not be the only factor that influenced clinical outcomes. Despite a fusion rate of 84% in the cases included in the present study, the good clinical outcome rate was 80%.

Fusion assessment was reported to be challenging in several studies, and identifying fusion using radiologic examinations is particularly difficult in all cases. Pseudoarthrosis may be painful as well as asymptomatic. [44] When patients who were radiologically considered to have fusion underwent re-operation for other etiologies, some patients appeared to not have fusion. Therefore, it can be suggested that “the best identification of fusion is by intraoperative inspection, albeit not practical.” [45]

Smoking is an important risk factor associated with preventing return to pre-disease activity and pain relief. In studies with a number of fusion series, poor results and high pseudoarthrosis rate were reported among smokers. [31, 44] However, studies in the past have also suggested that smoking had no effect on fusion. [45] Although the rate of clinically good outcome was lower (75%) in smokers in the present study, this rate was not significant.

The need for revision surgery was one of the most prominent factors affecting the outcome of lumbar decompression and fusion surgery. [36] A recent study reported a 13.5% re-operation rate in a database analysis of lumbar fusion surgery. [46] Patients who underwent repeated operations showed

remarkably poor outcomes, and even in cases of re-operation, the results were unsatisfactory. [36] Seung-Pyo Suh et al. reported a fusion rate of 71% in patients, who underwent revision surgery for pseudoarthrosis, with satisfactory results in only 52%. [47] Derman et al. reported in a review article that revision with PLF resulted in pseudoarthrosis in 35%–51% of cases. In addition, no significant difference was observed between different techniques, including TLIF, ALIF, and PLIF, in terms of patients' quality of life after PLF revision surgeries. Therefore, a study suggested that the surgical strategy of each revision case should be different. [48] In the series included in the present study, 3 cases underwent revision surgery and had a good clinical outcome rate of 33%. A major infection occurred in one patient (4%), consistent with the reported rate of 0.7%–11.9%. [49] Contrary to the previous studies, the instrument did not have to be removed as a result of the infection.

Limitations

The primary limitation to the present study was the comparatively low number of cases. More optimized results could be achieved through future studies with a larger number of cases. Another limitation is that the factors that might have an effect of fusion and satisfaction rates could not be comprehensively investigated. This is attributable to the retrospective nature of the study. Therefore, future prospective studies should address the issue in a more detailed approach by accommodating different parameters.

Conclusion

Several alternatives to the surgical treatment exist intended for low-grade spondylolisthesis. The widespread use of a modern and contemporary stabilization technique, including the posterior pedicle screw in orthopedics and neurosurgery, has opened new horizons in spinal surgery. The fusion rates have increased and better stabilization can be achieved through the pedicle screw technique. It is widely accepted that the most effective stabilization can be provided using fusion. Therefore, the combination of pedicle screw fixation and fusion, with the addition of decompression, as necessary, may be considered the ideal surgical method. However, patient selection is one of the most important aspects of treatment. Previous surgery is an important risk factor that should be considered before deciding the surgical treatment. In conclusion, it is possible to make use of the transpedicular screw fixation technique in a less complicated and effective approach through an effective and experienced teamwork.

Conflict Of Interest

The authors declared they do not have anything to disclose regarding conflict of interest with respect to this manuscript.

References

1. Santoni BG, Hynes RA, McGilvray KC, Rodriguez-Canessa G, Lyons AS, Henson MA, et al. Cortical bone trajectory for lumbar pedicle screws. Spine J. 2009;9:366-73.
2. Holly LT, Foley KT. Three-dimensional fluoroscopy-guided percutaneous thoracolumbar pedicle screw placement. Technical note. J Neurosurg. 2003;99;Suppl:324-9.
3. Lee CK, Park JY, Zhang HY. Minimally invasive transforaminal lumbar interbody fusion using a single interbody cage and a tubular retraction system: technical tips, and perioperative, radiologic and clinical outcomes. J Korean Neurosurg Soc. 2010;48:219-24.
4. Grob D, Humke T, Dvorak J. Direct pediculo-body fixation in cases of spondylolisthesis with advanced intervertebral disc degeneration. Eur Spine J. 1996;5:281-5.
5. Wang SJ, Han YC, Liu XM, Ma B, Zhao WD, Wu DS, et al. Fusion techniques for adult isthmic spondylolisthesis: a systematic review. Arch Orthop Trauma Surg. 2014;134:777-84.
6. Aimar E, Iess G, Mezza F, Gaetani P, Messina AL, Todesca A, et al. Complications of degenerative lumbar spondylolisthesis and stenosis surgery in patients over 80 s: comparative study with over 60 s and 70 s. Experience with 678 cases. Acta Neurochir (Wien). 2022;164:923-31.
7. Fehlings MG, Rabin D. Surgical complications in adult spondylolisthesis. J Neurosurg Spine. 2010;13:587-8; discussion 588.
8. Kirkaldy-Willis WH, Paine KW, Cauchoix J, McIvor G. Lumbar spinal stenosis. *Clin Orthop Relat Res*. 1974;(99):30-50.
9. Taillard WF. Etiology of spondylolisthesis. *Clin Orthop Relat Res*. 1976;(117):30-39.
10. Austevoll IM, Gjestad R, Solberg T, Storheim K, Brox JI, Hermansen E, et al. Comparative effectiveness of microdecompression Alone vs decompression plus instrumented fusion in lumbar degenerative spondylolisthesis. JAMA Netw Open. 2020;3:e2015015.
11. Chen SR, Gibbs CM, Zheng A, Dalton JF, Gannon EJ, Shaw JD, et al. Use of L5-S1 transdiscal screws in the treatment of isthmic spondylolisthesis: a technical note. J Spine Surg. 2021;7:510-5..

12. Zayan M, Hussien MA, El Zahlawy H. Pars interarticularis repair using pedicle screws and laminar hooks fixation technique in patients with symptomatic lumbar spondylolysis. SICOT J. 2022;8:13.
13. Pai VS, Hodgson B, Pai V. Repair of spondylolytic defect with a cable screw reconstruction. Int Orthop. 2008;32:121-5.
14. Tang L, Wu Y, Jing D, Xu Y, Wang C, Pan J. A Bayesian network meta-analysis of 5 different fusion surgical procedures for the treatment of lumbar spondylolisthesis. Med (Baltim). 2020;99:e19639.
15. Bydon M, Alvi MA, Goyal A. Degenerative lumbar spondylolisthesis: definition, natural history, conservative management, and surgical treatment. Neurosurg Clin N Am. 2019;30:299-304.
16. Dunn AS, Baylis S, Ryan D. Chiropractic management of mechanical low back pain secondary to multiple-level lumbar spondylolysis with spondylolisthesis in a United States Marine Corps veteran: a case report. J Chiropr Med. 2009;8:125-30.
17. Boyd ED, Mundluru SN, Feldman DS. Outcome of conservative management in the treatment of symptomatic spondylolysis and Grade I spondylolisthesis. Bull Hosp Jt Dis (2013) 2019;77:172-82.
18. Nava-Bringas TI, Romero-Fierro LO, Trani-Chagoya YP, Macías-Hernández SI, García-Guerrero E, Hernández-López M, et al. Stabilization exercises versus flexion exercises in degenerative spondylolisthesis: A randomized controlled trial. Phys Ther. 2021;101:pzab108.
19. Matsunaga S, Sakou T, Morizono Y, Masuda A, Demirtas AM. Natural history of degenerative spondylolisthesis. Pathogenesis and natural course of the slippage. Spine (Phila Pa 1976). 1990;15:1204-10.
20. Eismont FJ, Norton RP, Hirsch BP. Surgical management of lumbar degenerative spondylolisthesis. J Am Acad Orthop Surg. 2014;22:203-13.
21. Mori G, Mikami Y, Arai Y, Ikeda T, Nagae M, Tonomura H, et al. Outcomes in cases of lumbar degenerative spondylolisthesis more than 5 years after treatment with minimally invasive decompression: examination of pre- and postoperative slippage, intervertebral disc changes, and clinical results. J Neurosurg Spine. 2016;24:367-74.
22. Kimura R, Yoshimoto M, Miyakoshi N, Hongo M, Kasukawa Y, Kobayashi T, et al. Comparison of posterior lumbar interbody fusion and microendoscopic muscle-preserving interlaminar decompression for degenerative lumbar spondylolisthesis with >5-year follow-up. Clin Spine Surg. 2019;32:E380-5.
23. Jang JW, Park JH, Hyun SJ, Rhim SC. Clinical outcomes and radiologic changes after microsurgical bilateral decompression by a unilateral approach in patients with lumbar spinal stenosis and Grade I degenerative spondylolisthesis with a minimum 3-year follow-up. Clin Spine Surg. 2016;29:268-71.
24. Müslüman AM, Cansever T, Yılmaz A, Çavuşoğlu H, Yüce İ, Aydın Y. Midterm outcome after a microsurgical unilateral approach for bilateral decompression of lumbar degenerative spondylolisthesis. J Neurosurg Spine. 2012;16:68-76.
25. Pazarlis K, Frost A, Försth P. Lumbar spinal stenosis with degenerative spondylolisthesis treated with decompression Alone. A cohort of 346 patients at a large spine unit. Clinical outcome, complications and subsequent surgery. Spine (Phila Pa 1976). 2022;47:470-5.
26. Ghogawala Z, Dziura J, Butler WE, Dai F, Terrin N, Magge SN, et al. Laminectomy plus Fusion versus laminectomy Alone for Lumbar spondylolisthesis. N Engl J Med. 2016;374:1424-34.
27. Tsutsumimoto T, Shimogata M, Yoshimura Y, Misawa H. Union versus nonunion after posterolateral lumbar fusion: a comparison of long-term surgical outcomes in patients with degenerative lumbar spondylolisthesis. Eur Spine J. 2008;17:1107-12.
28. Martin CR, Gruszczynski AT, Braunsfurth HA, Fallatah SM, O'Neil J, Wai EK. The surgical management of degenerative lumbar spondylolisthesis: a systematic review. Spine (Phila Pa 1976). 2007;32:1791-8.
29. Endler P, Ekman P, Möller H, Gerdhem P. Outcomes of posterolateral fusion with and without instrumentation and of interbody fusion for isthmic spondylolisthesis: A prospective study. J Bone Joint Surg Am. 2017;99:743-52.
30. Ye YP, Chen D, Xu H. The comparison of instrumented and non-instrumented fusion in the treatment of lumbar spondylolisthesis: a meta-analysis. Eur Spine J. 2014;23:1918-26..
31. Cruz A, Ropper AE, Xu DS, Bohl M, Reece EM, Winocour SJ, et al. Failure in lumbar spinal fusion and current management modalities. Semin Plast Surg. 2021;35:54-62.
32. Jalanko T, Helenius I, Remes V, Lamberg T, Tervahartiala P, Yrjönen T, et al. Operative treatment of isthmic spondylolisthesis in children: a long-term, retrospective comparative study with matched cohorts. Eur Spine J. 2011;20:766-75.
33. Voor MJ, Mehta S, Wang M, Zhang YM, Mahan J, Johnson JR. Biomechanical evaluation of

posterior and anterior lumbar interbody fusion techniques. J Spinal Disord. 1998;11:328-34.
34. DiPaola CP, Molinari RW. Posterior lumbar interbody fusion. J Am Acad Orthop Surg. 2008;16:130-9.
35. Guppy KH, Royse KE, Norheim EP, Harris JE, Brara HS. PLF versus PLIF and the fate of L5-S1: analysis of operative nonunion rates among 3065 patients with lumbar fusions from a regional spine registry. Spine (Phila Pa 1976). 2021;46:E584-93.
36. Okuda S, Fujimori T, Oda T, Maeno T, Yamashita T, Matsumoto T, et al. Factors associated with patient satisfaction for PLIF: patient satisfaction analysis. Spine Surg Relat Res. 2017;1:20-6.
37. Liu X, Wang Y, Qiu G, Weng X, Yu B. A systematic review with meta-analysis of posterior interbody fusion versus posterolateral fusion in lumbar spondylolisthesis. Eur Spine J. 2014;23:43-56.
38. Kim KT, Lee SH, Lee YH, Bae SC, Suk KS. Clinical outcomes of 3 fusion methods through the posterior approach in the lumbar spine. Spine (Phila Pa 1976). 2006;31:1351-7; discussion 1358.
39. Fritzell P, Hägg O, Wessberg P, Nordwall A, Swedish Lumbar Spine Study Group. Chronic low back pain and fusion: a comparison of three surgical techniques: a prospective multicenter randomized study from the Swedish lumbar spine study group. Spine (Phila Pa 1976). 2002;27:1131-41.
40. Inamdar DN, Alagappan M, Shyam L, Devadoss S, Devadoss A. Posterior lumbar interbody fusion versus intertransverse fusion in the treatment of lumbar spondylolisthesis. J Orthop Surg (Hong Kong). 2006;14:21-6.
41. Hallett A, Huntley JS, Gibson JN. Foraminal stenosis and single-level degenerative disc disease: a randomized controlled trial comparing decompression with decompression and instrumented fusion. Spine (Phila Pa 1976). 2007;32:1375-80.
42. Fischgrund JS, Mackay M, Herkowitz HN, Brower R, Montgomery DM, Kurz LT. 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 (Phila Pa 1976). 1997;22:2807-12.
43. Gruskay JA, Webb ML, Grauer JN. Methods of evaluating lumbar and cervical fusion. Spine J. 2014;14:531-9.
44. Li Y, Zheng LM, Zhang ZW, He CJ. The effect of smoking on the fusion rate of spinal fusion surgery: A systematic review and meta-analysis. World Neurosurg. 2021;154:e222-35.
45. Luszczyk M, Smith JS, Fischgrund JS, Ludwig SC, Sasso RC, Shaffrey CI, et al. Does smoking have an impact on fusion rate in single-level anterior cervical discectomy and fusion with allograft and rigid plate fixation? Clinical article. J Neurosurg Spine. 2013;19:527-31.
46. Cummins D, Hindoyan K, Wu HH, Theologis AA, Callahan M, Tay B, et al. Reoperation and mortality rates following elective 1 to 2 level lumbar fusion: A large state database analysis. Glob Spine J. 2022;12:1708-14.
47. Suh SP, Jo YH, Jeong HW, Choi WR, Kang CN. Outcomes of revision surgery following instrumented posterolateral fusion in degenerative lumbar spinal stenosis: A comparative analysis between pseudarthrosis and adjacent segment disease. Asian Spine J. 2017;11:463-71.
48. Derman PB, Singh K. Surgical strategies for the treatment of lumbar pseudarthrosis in degenerative spine surgery: A literature review and case study. HSS J. 2020;16:183-7.
49. Schimmel JJ, Horsting PP, de Kleuver M, Wonders G, van Limbeek J. Risk factors for deep surgical site infections after spinal fusion. Eur Spine J. 2010;19:1711-9.