Clinical and radiological outcomes of unilateral transforaminal lumbar interbody fusion

Mohammed Serry, El-Said Abd El-Latif

Department of Orthopaedic Surgery, Mansoura University, Mansoura, Egypt

Correspondence to Mohammed Serry, MD, Department of Orthopaedic Surgery, Mansoura University Hospital, Mansoura University, Mansoura, Egypt
Tel: +20 122 738 0263;
e-mail: mserry2005@yahoo.com

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Background

Interbody fusion techniques provide solid fixation, maintain the load-bearing capacity of the spine, maintain proper disc and foraminal heights, have higher fusion rates, and prevent implant failure. Unilateral transforaminal lumbar interbody fusion (TLIF) is a one-stage posterior approach to the disc space that allows unilateral larger cage insertion without violation of the spinal canal by avoiding dural retraction, which is advantageous in revision cases and in higher lumbar levels above L3.

Aim

The aim of the study was to describe the technique and study the clinical and radiological results of unilateral TLIF.

Study design

This is a retrospective study on 40 patients with different etiologies treated by unilateral TLIF.

Patients and methods

A retrospective analysis was performed on 40 patients who had undergone unilateral TLIF during the period from April 2006 to December 2008 for chronic low back pain and radicular leg pain of different etiologies, including isthmic and degenerative spondylolisthesis, and revision cases with failed conservative treatment of more than 3 months. Radiographic assessment was carried out by means of anteroposterior, lateral, and dynamic flexion-extension plain radiographs and MRI. Bony fusion was assessed using the Bridwell anterior fusion grading system. Functional assessment was made using the visual analogue scale (0–10) for back and leg pain and the Oswestry Disability Index questionnaire.

Results

Unilateral TLIF achieves statistically significant reduction in spondylolisthesis from an average of 35.55 ± 11.62% preoperatively to an average of 3.49 ± 3.29% postoperatively with minimal change seen at final follow-up with restoration of segmental lordosis in all patients. Disc and foraminal heights were restored and corrected from an average of 7.24 ± 1.30 and 13.53 ± 1.91 mm, respectively, preoperatively to 11.80 ± 1.075 and 19.76 ± 1.79 mm, respectively, postoperatively without significant change at last follow-up. Ninety percent of patients had G1 bony fusion and 10% had G2 bony fusion. No patient had G3 or G4 fusion. All patients showed significant postoperative improvement in leg and back pain immediately postoperatively and at last follow-up. Leg pain improved from 7.24 ± 0.61 to 2.26 ± 0.84 SD postoperatively and to 0.65 ± 0.70 SD at last follow-up, and back pain improved from 7.78 ± 0.86 to 2.76 ± 0.89 SD postoperatively and to 0.98 ± 0.75 SD at last follow-up. The average preoperative Oswestry Disability Index score improved from 54.95 ± 7.02 to 10.73 ± 3.28 SD at last follow-up. There were no major intraoperative complications.

Conclusion

Unilateral TLIF s a safe and effective technique. It provides good clinical and radiological outcomes in different lumbar spinal pathologies. It is especially effective and safe in revision cases with epidural fibrosis when the standard posterior lumbar interbody fusion technique is contraindicated.

Keywords:

interbody fusion, spondylolisthesis, transforaminal lumbar interbody fusion

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Introduction

Interbody fusion techniques have several advantages in different pathological conditions of the lumbar spine. It provides solid fixation, maintains the load-bearing capacity of the spine, maintains proper disc and foraminal heights, prevents implant failure, and achieves higher fusion rates [1]. The anterior column bears 80% of compression, torsion, and shear forces [2,3]. The posterior approach to the interbody fusion is a one-stage procedure that avoids the morbidity factors associated with the anterior path to the spine [4–6]. Posterior lumbar interbody fusion

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(PLIF), first introduced by Cloward in 1945 [7], is limited by its medialized approach requiring bilateral exposure and necessitating significant dural retraction leading to neural injury and radiculitis [8]. It is limited to levels lower than L3 and is not suitable for revision cases with epidural fibrosis. The transforaminal lumbar interbody fusion technique (TLIF) was first introduced by Harms and Jeszenszky in 1982 [9] to avoid many of the complications of the PLIF technique. The line of access to the disc space passes through the far lateral portion of the vertebral foramen, increasing the angle of inclination for cage insertion without the need for excessive neural retraction. Thus, it can be used in more proximal levels above L3 and in revision cases with significant epidural fibrosis. It allows unilateral insertion of larger cages, preserving the interlaminar surface of the contralateral side and facet as additional sites for fusion [8]. It allows for both direct and indirect decompression of the exiting nerve root. The aim of this study was to evaluate the clinical and radiological results of the unilateral TLIF procedure in patients with low back pain with different etiologies.

Patients and methods

This study consisted of 40 patients with low back pain and radicular leg pain with different etiologies treated by means of the TLIF procedure and posterior instrumentation at Mansoura University Hospital, Mansoura, Egypt, during the period from April 2006 to December 2008. All patients had low back pain and radicular leg pain that had been refractory to conservative treatment for at least 3 months. This study approved by the Ethical Committee of Mansoura University.

Radiographic assessment

Patients were evaluated preoperatively by means of plain radiographs and MRI. Plain radiographs included posterior-anterior, standing lateral, and flexion-extension dynamic films to assess the disc and foraminal heights, percentage of spondylolisthesis, segmental instability, segmental kyphosis angle, and sagittal plane profile.

Postoperatively and during follow-up visits, radiological evaluation was done by posterior-anterior, lateral, and dynamic plain radiographs. Radiological evaluation focused on the percentage of slip and percentage of reduction in spondylolisthesis, disc space and foraminal heights, cage position, and fusion rate. Fusion was diagnosed by progressive increase in interspace bone density, by blurring of adjacent endplates, presence of bridging bone trabeculae between the adjacent endplates with absence of vertebral movement in flexion-extension films, and no implant failure. Bony fusion was graded by means of the Bridwell anterior fusion grading system [10], consisting of four grades: G1 indicates evidence of fusion with remodeling and trabeculae present; G2 indicates evidence of intact graft with incomplete remodeling or incorporation and without lucency; G3 indicates evidence of intact graft with lucency both above and below the graft and absence of fusion; and G4 indicates evidence of collapsed or resorbed graft and absence of fusion.

Functional outcome

Patients were asked to complete preoperative and postoperative questionnaires assessing back and leg pain using the visual analogue scale (VAS) from 0 to 10, with 10 indicating severe pain. The Oswestry Disability Index (ODI) questionnaire [11], which is the gold standard for measurement of long-term disability, was used. Patients were asked whether they would undergo the surgery again on the basis of the degree of perceived improvement or deterioration in pain and function from their preoperative status.

Operative procedures

The patient is operated upon in the prone position under general hypotensive anesthesia with the hips in maximum extension to maintain lumbar lordosis and allow for partial reduction in spondylolisthesis. Care should be taken to ensure that the abdomen hangs free from compression to prevent venous congestion of the abdominal veins as this could lead to severe epidural venous congestion and severe epidural bleeding, making the procedure very difficult and increasing the amount of blood loss. Levelling is done by fluoroscopy. This will limit the length of the incision and muscle dissection. Through a standard midline incision, the spine is exposed bilaterally up to the base of the transverse processes. We start by decompression first before pedicle screw fixation. The side of the TLIF is selected on the basis of the preoperative symptoms. TLIF was performed on the symptomatizing side in unilateral symptoms. In cases of bilateral symptoms, the TLIF was performed on the side of the most severe symptoms. If there is central stenosis such as in degenerative spondylolisthesis, central decompression with excision of the ligamentum flavum (the main compressing element in degenerative cases) and partial facetectomy on the contralateral side are carried out. The spinous processes and the supraspinous and interspinous ligaments were preserved for later muscle suturing and attachment. Unilateral laminotomy up to hemilaminectomy and facetectomy excising the whole inferior facet of the proximal vertebra and the superior portion of the superior facet of the caudal vertebra just proximal to the lower pedicle was performed.

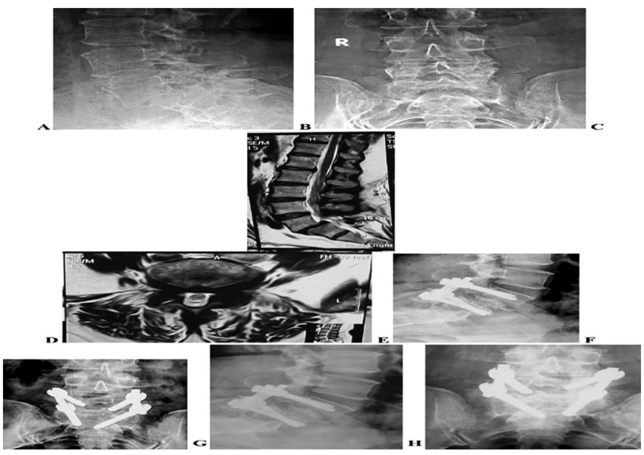
Bleeding from epidural veins is usually encountered on completion of facetectomy. This is controlled by using bipolar electrocautery, gelfoam, and compression with a cotton patty, together with saline wash. The exiting nerve root is exposed, freed, and decompressed completely from its shoulder until the far lateral portion of the foramen by excising all bony, ligamentous, or fibrous tissue together with excision of any disc material below the dorsal root ganglion in the foramen. The traversing nerve root is exposed and protected with slight retraction. After completion of decompression, the disc space is prepared by first finding the line of the disc space by means of a knife to avoid violation of the endplates and making a rectangular annulotomy. Then the disc shavers are introduced in a sequential manner, first parallel to the disc space and then rotated to evacuate the disc material. The inferior endplate of the superior vertebral body is usually concave, and it is often necessary to excise the posterior aspect of the vertebral body by a kerrison to facilitate cage insertion without much distraction and avoid undersizing of the cage. Final disc space preparation was done by gentle curettage, avoiding endplate penetration. Pedicle screws are inserted by free-hand technique under direct visualization of the pedicle on the ipsilateral side of the TLIF and confirmed by fluoroscopy. The size of the cage is determined with a trial cage after distraction on the screws. Avoid overdistraction by direct testing of the nerve root tension and by fluoroscopy, comparing with the height of the nearby healthy disc and facet joint space. Distraction is done on the screws on the same side after discectomy and release as this gives maximum distraction than distraction on the contralateral side. In degenerative cases with osteoporosis, distraction can be done on the intact spinous processes. Local bone graft taken from the spinous processes, lamina, and facet is cleaned of any soft tissue, prepared taking the cancellous bone and avoiding the sclerosed bone, and inserted into the anterior third of the disc space by rongeur and impacted by bone tamp. A unilateral banana-shaped TLIF cage is then filled with local bone graft and inserted obliquely toward the midline into the disc space in its posterior third. In cases of local kyphosis, the cage is located slightly anterior with more distraction to allow for correction of kyphosis without decrease in the up–down height of the foramen after compressing the cage to restore lumbar lordosis. In cases without kyphosis, the cage is located slightly posterior to avoid excessive narrowing of the foramen with later compression. Bone graft is added to the posterolateral gutter, increasing the surface area for fusion. Finally, the nerve roots are inspected for tension and for any loose bony fragments in the canal, together with control of any opened epidural bleeder after cage insertion. A rod of adequate length that avoids impingement on the nearby facets (to avoid fusion disease) is contoured to the desired lordosis and connected to the screws. This will restore segmental lordosis and compress the cage simultaneously without having to perform compression, avoiding further stresses on the screws.

The contralateral side is instrumented in the same manner, and the laminae and facet joint are decorticated and bone grafted, adding more bed for circumferential fusion. The wound is closed in layers over the suction drainage (Figs. 1 and 2).

Postoperatively

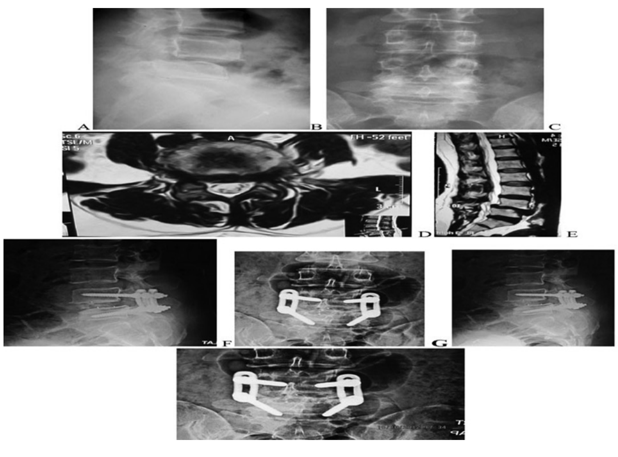
Patients are allowed mobilization on the first postoperative day in a lumbosacral support. For the

Figure 1



A 50-year-old woman with chronic, severe, persistent mechanical low back pain and left radicular leg pain secondary to G2 isthmic spondylolisthesis of L5–S1 with severe disc collapse.

Figure 2



A 40-year-old woman complaining of chronic, severe, mechanical low back pain and left radicular leg pain secondary to G2 isthmic spondylolisthesis of L4–L5. (a, b) Lateral and anteroposterior (AP) radiographs: note the disc collapse, foraminal height, and segmental kyphosis.

first 6 weeks postoperatively, patients are instructed on a progressive walking program and allowed to return to routine activities as tolerated. At the sixth week, progressive range of motion and strengthening exercises are initiated, and by 3 months the patients are allowed low-impact activities as tolerated. Full activities are resumed at 6 months. Patients are advised not to perform bending or heavy lifting exercises for at least 4–6 months postoperatively. They are then followed up at regular intervals with periodic radiographs until the last follow-up.

Statistical analysis

Data were analyzed using SPSS (Statistical Package for Social Sciences) version 15 (Techopedia.com, 405-10158 103 Street NW, Edmonton, Alberta, Canada, T5J 0X6) and presented as mean ± SD. The paired *t*-test was used for comparison within groups. The Student *t*-test was used to compare between two groups. The *F*-test (one-way analysis of variance) was used to compare between more than two groups. *P* values less than 0.05 were considered statistically significant.

Results

There were 40 patients in this study, 21 men and 19 women. The average age at presentation was 48.5 ± 13.83 years (range = 18–80 years). Follow-up averaged 32.23 ± 6.78 years (range = 25–50 months). Twenty-four patients underwent single-level TLIF, and 16 patients underwent double-level TLIF. Most of them were revision cases. The indications for the TLIF procedure were isthmic spondylolisthesis in 19 patients, degenerative spondylolisthesis in seven patients, and revision lumbar spine surgery in 14 patients, including postdiscectomy disc collapse, kyphosis and instability in five patients, peudoarthrosis and failed posterolateral fusion in three cases, and postlaminectomy spondylolisthesis in six patients. The average operative time was 142.25 ± 27.55 min (range = 100–200 min) and the average amount of blood loss was 381 ± 70.21 ml (range = 250–600 ml) for the whole group. The average operative time was 128 ± 19.75 ml (range = 100–170 min) for single-level TLIF and 162 ± 24.96 min (range = 120–200 min) for double-level TLIF. The average amount of blood loss was 350 ± 60.46 ml (range = 250–480 ml) for single-level fusion and 426 ± 59.07 ml (range = 300–500 ml) for double-level fusion. There was statistically significant difference in the operative time and amount of blood loss between isthmic spondylolisthesis, degenerative spondylolisthesis, and revision cases. Isthmic spondylolisthesis showed the lowest operative time and amount of blood loss. Degenerative spondylolisthesis showed the highest blood loss, and revision cases showed the highest operative time (Table 1). The average length of hospital stay was 3.10 ± 0.62 days (range = 2–5 days). The average of spondylolisthesis was 35.55 ± 11.62% (range = 20–65%) preoperatively and this improved to 3.49 ± 3.29% (0–15%) postoperatively and to 3.51 ± 3.29% at final follow-up. The average reduction of spondylolisthesis was 91.52% immediately postoperatively with minimal change at follow-up. The average loss of reduction was 0.02 ± 0.00 (range = 0–1.67). Disc space and foraminal heights were restored and maintained during follow-up until fusion. The average preoperative disc and foraminal heights were significantly improved from 7.24 ± 1.30 mm (range = 5–9 mm) and 13.53 ± 1.91 mm (range = 9–17 mm), respectively, to 11.80 ± 1.07 mm (range = 9–13 mm) and 19.76 ± 1.79 mm (range = 16–23 mm), respectively, postoperatively without significant change at last follow-up, indicating no sinking or collapse. There was statistically significant postoperative improvement in the local kyphosis angle with restoration of normal sagittal plane profile in all patients. The average local kyphosis angle significantly improved from 9.38 ± 3.09° (range = 5.00–15°) preoperatively to 0.98 ± 1.34° (range = 00–1.00°) immediately postoperatively and to 1.03 ± 1.35° at final follow-up without significant loss of correction (Table 2). With regard to fusion, employing the Bridwell anterior fusion grading system, 75% of the patients (30 patients) attained a grade 1 fusion and 20% (10 patients) attained a grade 2 fusion at 1-year follow-up. This percentage improved at 2-year follow up, wherein 90% were grade 1 and the remaining 10% were grade 2. There was no grade 3 or 4. There was significant functional improvement in all patients postoperatively. No patient reported greater postoperative pain than their preoperative level. The average VAS for radicular leg pain improved from 7.98 ± 0.61 SD (range = 7–9) preoperatively to 2.26 ± 0.84 SD (range = 00.0–4.00) immediately postoperatively, to 1.05 ± 00.90 SD (range = 0.00–3.00) at the end of the eighth month and to 0.65 ± 0.70 SD (range = 0.00–3.0) at last follow-up. The average VAS

Table 1 Operative time and blood loss in different pathological conditions and single-level versus double level transforaminal lumbar interbody fusion

Pathological Condition	*n*	Operative time	Blood loss
Isthmic spondylolisthesis	19	12.26 ± 14.76	341.32 ± 56.88
Degenerative spondylolisthesis	7	157.14 ± 11.13	425.71 ± 44.29
Revision cases	14	164.64 ± 23.49	412.86 ± 70.21
P value		<0.001	0.001
Single level	24	128.54 ± 19.75	350.63 ± 60.46
Double level	16	162.81 ± 24.96	426.88 ± 59.07
P value		<0.001	<0.001

Table 2 Radiological results

Pathology	Pre	Post	2 years	Pre vs. post	Post vs. 2 years
Disc height	7.24 ± 1.30	11.80 ± 1.07	11.80 ± 1.09	<0.001	0.952
Foraminal height	13.53 ± 1.91	19.76 ± 1.79	19.72 ± 1.77	<0.001	0.153
% Slip	35.55 ± 11.62	3.49 ± 3.29	3.51 ± 3.29	<0.001	0.023
LKA	9.38 ± 3.09	1.23 ± 2.07	1.03 ± 1.35	<0.001	0.433

LKA, local kyphosis angle.

for back pain significantly improved from 7.78 ± 0.86 SD (range = 6.0–10.0) preoperatively to 2.76 ± 0.89 SD (range = 1.00–4.00) postoperatively, to 1.46 ± 0.95 SD (range = 0.00–3.00) at 8 months after surgery and to 0.98 ± 0.75 SD (range = 0.00–3.0) at final follow-up. Leg pain improved earlier and more rapidly than back pain. Most of the improvement in pain occurred immediately postoperatively with further significant improvement at the eighth month and after 2 years (Table 3). The average preoperative ODI score in all patients was 54.95 ± 7.02% (range = 40–68%) with all of the patients having moderate to severe disability. This was significantly improved to 10.73 ± 3.28% (range = 6.0–19.0%) at final follow-up, which is less than 20%, indicating minimal disability. No patient became less able to perform activities of daily living in this study. There was no significant difference in the average pain scores, with a statistically significant difference in the average ODI scores at 2 years between isthmic spondylolisthesis, degenerative spondylolisthesis, and revision cases. The ODI score was highest in revision cases (12.29 ± 4.05) (Table 4). When they asked whether they would undergo the surgery again based on their outcome, all patients (100%) said they would. There was no statistically significant correlation between the radiological and functional results (Table 5).

There was no case of intraoperative mortality in this study, nor were there cases of deep or superficial wound infection, cases of significant loss of disc space or foraminal height, cases of radiculitis, and cases of implant failure or screw loosening. Transient postoperative numbness and tingling sensation in the leg of the TLIF side was present in five patients, which resolved within 1–4 weeks.

Table 3 Functional results

Time	Back pain	Leg pain	ODI
Preoperative	7.78 ± 0.86	7.98 ± 0.61	54.95 ± 7.02
Postoperative	2.76 ± 0.89	2.26 ± 0.84	
8 months' follow-up	1.46 ± 0.95	1.05 ± 0.90	17.98 ± 3.53
2 years' follow-up	0.98 ± 0.75	0.65 ± 0.70	10.73 ± 3.28
Pre vs. post	<0.001	<0.001	
Pre vs. 2 years	<0.001	<0.001	<0.001
Post vs. 8 months	<0.001	<0.001	
8 months vs. 2 years	<0.001	<0.001	<0.001

ODI, Oswestry Disability Index.

Table 4 Correlation of functional results between different pathological conditions

Condition	Isthmic listhesis (*n* = 19)	Degenerative listhesis (*n* = 7)	Revision cases (*n* = 14)	*P* value
ODI	9.37 ± 2.50	11.29 ± 1.98	12.29 ± 4.05	0.032
Back pain	0.92 ± 0.65	0.57 ± 0.79	1.25 ± 0.80	0.135
Leg pain	0.63 ± 0.60	0.43 ± 0.53	0.79 ± 0.89	0.550

ODI, Oswestry Disability Index.

Table 5 Correlation between functional and radiological results

Outcome	Fusion grade 1 (*n* = 36)	Fusion grade 2 (*n* = 4)	*P* value
ODI	10.89 ± 3.38	9.25 ± 1.89	0.350
Back pain	0.99 ± 0.77	0.88 ± 0.63	0.783
Leg pain	0.69 ± 0.71	0.25 ± 0.50	0.233

ODI, Oswestry Disability Index.

Discussion

Interbody fusion techniques have gained popularity in recent years and have become the standard of care for all spinal surgeons managing different lumbar spinal disorders because they are associated with higher fusion rates and better clinical outcomes. They have several advantages over posterolateral fusion. These include immediate anterior column load-sharing reconstruction, which bears 80% of the body weight, minimizing the stresses on the posterior implants and decreasing the failure rate, especially after disc evacuation or after some distraction of the disc space. The graft in the anterior column is subjected to compression forces instead of the tension forces in cases of posterolateral fusion. This together with the larger surface area of cancellous bone in the body and absence of a gap leads to higher fusion rate [12]. In addition, interbody fusion provides the ability to restore disc and foraminal heights, restore lumbar lordosis, indirectly decompress the exiting nerve roots, and help in reducing the spondylolisthesis. Posterolateral fusion cannot address discogenic back pain in some cases of posterolateral fusion, and interbody fusion appears to be the most effective treatment for discogenic back pain that is unresponsive to conservative treatment after posterolateral fusion. Weatherley *et al.* [13] reported on five patients over a 10-year period having persistent back pain despite solid posterolateral fusion. All patients had a positive discogram and experienced pain relief after interbody fusion. Derby *et al.* [14] noted that highly sensitive discs as determined by pressure-controlled discography achieved better long-term outcomes after combined anterior-posterior (AP) fusion than with intertransverse fusion.

Interbody fusion can be achieved through anterior, posterior, or combined AP approaches. Stand-alone anterior lumbar interbody fusion allows excellent anterior column reconstruction and prevents fusion disease [15,16] but does not allow adequate decompression of the neural structures and is associated with the risk for great vessel injury, delayed rehabilitation and venous thromboembolism, retrograde ejaculation in men, and high failure rate [4–6,17]. Combined AP fixation is often needed to improve the biomechanical properties of the construct. The AP approach is associated with increased blood loss, increased operative time, increased length of time in the ICU, increased hospital stay and cost, and two-fold-increased complication rate, including higher pseudoarthrosis rate, infection rate, and radiculopathy [18,19]. The incidence of major complications was high in AP lumbar fusion surgery (up to 62%) with no major complications in the open TLIF group in most studies [18,19]. Because of these limitations, there has been growing interest in recent years to perform interbody fusions from a posterior-only approach. The PLIF procedure has gained popularity, with indications including spinal canal stenosis instability, degenerative disc disease, spondylolisthesis, spondylolysis, and central disc herniations. However, it has complications and contraindications. It requires excessive retraction of the dura out to the midline that may lead to nerve damage, neurogenic pain, and radiculitis and is contraindicated in revision cases with epidural fibrosis. It is limited to L3–S1 levels because of increased risk for damage to the conus medullaris and cauda equine. PLIF requires a bilateral approach, which increases the operative time, blood loss, and risk for complications [8]. In the TLIF procedure, the angle of approach to the disc space passes through the far lateral portion of the neuroforamen, allowing a unilateral approach to the disc space without excessive dural retraction, minimizing the incidence of nerve damage and pain, decreasing the operative time and blood loss, and allowing more bed for posterolateral fusion on the contralateral side to achieve circumferential fusion. This was demonstrated in this study. There was no case of postoperative radiculitis. Only transient postoperative pain was present in five patients due to irritation and edema of the exiting nerve root in the foramen during decompression that resolved rapidly after the operation. The technique was safe and easy in revision cases, allowing entry into the disc space from the far lateral portion of the foramen away from the adhesions and fibrosis in the central canal through a unilateral approach, minimizing the incidence of dural tears and allowing easy repair of any lateral dural tear if it occurred. Dural tears occurred in two revision cases and were easily repaired. Epidural bleeding is less of a problem than with the standard bilateral PLIF because of the unilateral approach, and with experience, cage placement within the disc space is consistently achieved. The average operative time and amount of blood loss for the whole study group were 142 min and 381 ml, respectively, because of the unilateral approach of the technique, and the rapidly developing learning curve. Humphreys *et al.* [8], comparing between TLIF and PLIF, reported similar operative time (159 min in PLIF vs. 144.4 min in TLIF), blood loss (347.6 vs. 346.2 ml), and hospital stay (5.2 vs. 4.8 days) in single-level fusion but significantly less blood loss with TLIF in two-level fusion (672.5 ml in PLIF vs. 408.7 ml in TLIF). There were no complications in the TLIF group compared with 10 complications in the PLIF group, including four cases with radiculitis. Ray [20] noted 13 dural tears and 10% incidence of transient foot weakness in his follow-up study of 236 patients treated by PLIF. Turner [21] reported cauda equine injuries in 19% of patients in one series, with permanent nerve dysfunction in three patients. Our study was not a comparative study but it assesses the immediate and short-term results and advantages of TLIF and compares with similar studies in the literature for other fusion techniques. There were no cases of radiculitis in this study and no major complications because of less retraction of the neural elements and the unilateral approach to the disc space.

Unilateral TLIF can correct segmental kyphosis related to disc collapse as in postdiscectomy disc collapse and spondylolisthesis to a relatively normal sagittal contour. In this study all patients had restored normal lumbar lordosis without significant loss of correction at last follow-up. Correction of segmental kyphosis decreases the pathologic forces on the adjacent motion segment, which may be a factor leading to adjacent segment disease or transitional syndrome. Spondylolisthesis of grades G2 and G3 can be corrected and the correction maintained until solid fusion using unilateral TLIF. In this study, the average correction of spondylolisthesis was 91.55% without significant correction loss or failure of implant at final follow-up. This is due to adequate anterior column reconstruction, which bears 80% of compression, shear, and torsion forces. Anterior column reconstruction is very important after disc evacuation or distraction as in cases of disc collapse and spondylolisthesis. Otherwise failure and recollapse will occur. Unilateral TLIF leads to good decompression of the neural elements, especially the exiting nerve root, both directly through excision of all compressing tissues in the neuroforamen under direct vision and indirectly through restoration of the disc and foraminal heights. All patients show improvement in their radicular leg pain and back pain immediately postoperatively with further significant improvement at final follow-up. Most of the improvement in pain occurs within the first postoperative week, indicating good decompression and stabilization achieved by the TLIF together with excision of the degenerated disc material. Although pseudoarthrosis is sometimes related to worsened clinical results [22], there are extensive data showing that excellent radiological fusion does not necessarily correlate with good clinical results [23,24]. In this study, there was also no significant correlation between the functional and radiological results.

Unilateral TLIF combined with posterior instrumentation provides circumferential fusion through a single posterior approach, enabling three-column stability allowing high fusion rate with less morbidity, better clinical results, and high patient satisfaction in a variety of outcome measures. In 2002, Lowe *et al.* [25] reported on the results on 40 patients with degenerative lumbar conditions treated by TLIF with an average 3-year follow-up. Twenty-three patients had degenerative disc disease, 13 had spondylolisthesis, and four had recurrent disc herniations. Good to excellent clinical results were achieved in 79% of patients and solid radiographic fusion in 90% of patients. Salehi *et al.* [26] reported 92% solid radiologic fusions and satisfactory outcomes in the majority of patients using the modified Prolo scores. In this study, solid radiographic fusion averaged 90% and satisfactory clinical outcomes were achieved in all patients using the ODI questionnaire, which is the gold standard of outcome measures. This corresponded with marked improvement in radicular and axial back pain. The bone graft used in this study was from local bone to avoid donor site morbidity of iliac bone graft, especially the posterior ilium. Although local bone graft has lower osteoinductivity than iliac auto graft because of lower cancellous bone content, it can give rise to a high fusion rate as reported in this study and by most other studies [25,26]. The only study reporting lower fusion rate of 65% using local bone graft by Deutsch and Musacchio [27] did so because of the short follow-up period of 6 months. Local bone graft can be used after proper endplate preparation, good cleaning of the bone of any soft tissue, using the cancellous bone of the lamina and spinous processes mixed with blood, and avoiding the sclerosed bone. This together with impaction and loading the graft under compression achieves a high fusion rate after adequate follow-up.

Although surgical techniques now tend toward the minimally invasive approach, conventional open TLIF can be performed with less surgical trauma using short incision after careful levelling using fluoroscopy and care in muscle stripping, minimizing soft tissue trauma and avoiding injury to the nearby facet capsule. Unilateral TLIF preserves the interspinous and supraspinous ligaments for later muscle attachment, and the contralateral facet and lamina, minimizing posterior destabilization and allowing circumferential fusion. It preserves the anterior and most of the posterior longitudinal ligaments, which provides a tension band for compression and prevention of retropulsion of the graft. It avoids soft tissue dissection inside the spinal canal, which may help prevent scarring and instability of adjacent segments as well as the exiting nerve root [25]. It is less technically demanding with a smaller learning curve. Conventional open TLIF technique is the treatment of choice for high-grade spondylolisthesis to facilitate reduction [28]. All studies comparing the minimally invasive TLIF with conventional open TLIF show no difference between the two techniques with respect to long-term functional and radiological outcomes. Minimally invasive TLIF is a less-invasive surgical modality having the advantages of a smaller skin incision, lower blood loss, less muscle trauma, and dissection but it is technically demanding with a higher learning curve. It is associated with higher rate of major intraoperative and perioperative complications due to higher neural injury and screw malposition [10,28–30].

We see that unilateral TLIF is easy to be mastered by the spinal surgeon with a small learning curve paying attention to some important technical aspects to avoid complications and make the technique easier and familiar. The exiting nerve root must be identified first and protected during all steps of the procedure. The line of direction of the disc space must be identified first by a scalpel before using the disc shavers to avoid violation of the bony endplates. Attention to disc removal is essential. The most lateral part of the posterior annulus and disc in the foramen below the exiting nerve root should be excised to allow for decompression and mobility of the root and to increase the inclination of the shavers during disc preparation. The disc material just ventral to the posterior annulus in the midline should be excised by kerrison and pituitary rongeurs to facilitate oblique cage placement and centralization. The largest surface area possible for fusion should be prepared by interiorly directing the disc shavers laterally and toward the midline. Avoid penetration of the bony endplate to avoid sinking of the cage. Rely on indirect visualization and tactile feedback, feeling the anterior edge of the body, and measure the depth to which the instruments should enter in the disc space and avoid opening the anterior annulus to avoid catastrophic vascular complications. Use intraoperative fluoroscopy to show the anterior extent of disc preparation. To avoid screw loosening, avoid excessive and unnecessary distraction. Excise the posterior vertebral body lip by kerrison to increase the space for cage placement without the need for excessive distraction. Avoid unnecessary distraction on the screws by limiting the distraction to the step during placement of trial and definitive cages. Distraction does not have to be performed during disc preparation. Also, performing distraction after disc excision and release decreases the rigidity of the spinal segment and the amount of required distraction. Lordosing the rod before connection to the screws restores lumbar lordosis and simultaneously compresses the cage while tightening the nuts without the need to further compress and put stress on the screws. Inserting bone graft anterior to the cage has many benefits. It allows larger surface area for fusion and allows later radiographic assessment of fusion anterior to the cage. It facilitates placement of the cage in the posterior half of the disc space near the axis of rotation of the motion segment, maximizing lordosis correction and avoiding excessive narrowing of the neuroforamen after compression. During placement of the cage in spondylolisthesis, the cage should pass easily without the slightest hammering after sufficient distraction, as this will increase the shear force and increase the spondylolisthesis. Hammering can be done for final impaction of the cage only after connecting the rod to the screws. During correction of spondylolisthesis of high grade (G3), unilateral TLIF can be applied by introducing a blunt instrument or disc shaver into the disc space after disc preparation and release, levering and elevating the listhesed vertebra, and then temporarily connecting a straight rod to the screws on the contralateral side, further increasing the reduction, followed by cage placement. The listhesed vertebra can be pulled back by using the screw holder connected to the screw after disc evacuation and release.

Unilateral TLIF is more versatile, allowing all lumbar levels to be approached through a single approach, which is the posterior approach. It allows early rehabilitation and quickens and improves the patient's recovery, as most of the patients show immediate pain improvement; TLIF also restores the load-carrying capacity of the spine by providing a stable three-column fixation. Unilateral TLIF preserves the spinous processes, which are the bony attachments of the lumbar spinal musculature. Altering the attachment sites for the muscular envelope produced by the erector spinae muscles is likely to affect the mechanics of the spine [31]. This could lead to a change in the direction of applied forces on the spinal column, increased pain during the recovery process, and a prolonged recovery time. Patwardhan *et al.* [32] determined that the compressive load-carrying capacity of the lumbar spine increased when the load path remained within a small range around the rotation centers of the lumbar segments. By using and preserving the bony attachment sites of the lumbar spine, unilateral TLIF can quicken and improve the patient's recovery.

Conclusion

Unilateral TLIF is a less-invasive, simple, safe, effective, and stable technique that achieves good functional and radiological outcomes in different lumbar spinal pathologies with good patient satisfaction. It is especially useful and safe in lumbar spine revision cases with epidural fibrosis in which the classic PLIF technique is contraindicated.

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Conflicts of interest

There are no conflicts of interest.

References

1 Stonecipher T, Wright S. Posterior lumbar interbody fusion with facet-screw fixation. Spine (Phila Pa 1976) 1989; 14:468–471.

2 Yang SW, Langrana NA, Lee CK. Biomechanics of lumbosacral spinal fusion in combined compression-torsion loads. Spine (Phila Pa 1976) 1986; 11:937–941.

3 Ishihara H, Osada R, Kanamori M, Kawaguchi Y, Ohmori K, Kimura T, *et al.* Minimum 10-year follow-up study of anterior lumbar interbody fusion for isthmic spondylolisthesis. J Spinal Disord 2001; 14:91–99.

4 Christensen FB, Bünger CE. Retrograde ejaculation after retroperitoneal lower lumbar interbody fusion. Int Orthop 1997; 21:176–180.

5 Loguidice VA, Johnson RG, Guyer RD, Stith WJ, Ohnmeiss DD, Hochschuler SH, Rashbaum RF. Anterior lumbar interbody fusion. Spine (Phila Pa 1976) 1988; 13:366–369.

6 Isiklar ZU, Lindsey RW, Coburn M. Ureteral injury after anterior lumbar interbody fusion. A case report. Spine (Phila Pa 1976) 1996; 21:2379–2382.

7 Cloward RB. The treatment of ruptured lumbar intervertebral discs by ventral fusion. Indications, operative technique, after care. J Neurosurg 1953; 10:154.

8 Humphreys SC, Hodges SD, Patwardhan AG, Eck JC, Murphy RB, Covington LA. Comparison of posterior and transforaminal approaches to lumbar interbody fusion. Spine (Phila Pa 1976) 2001; 26:567–571.

9 Harms JG, Jeszenszky D. The unilateral, transforaminal approach for posterior lumbar interbody fusion. Orthop Traumatol 1998; 6:88–99.

10 Peng CW, Yue WM, Poh SY, Yeo W, Tan SB. Clinical and radiological outcomes of minimally invasive versus open transforaminal lumbar interbody fusion. Spine (Phila Pa 1976) 2009; 34:1385–1389.

11 Fairbank JK, Pinsent PB. The Oswestry Disability Index. Spine (Phila Pa 1976) 2000; 25:2940–2952.

12 Lin PM, Cautilli RA, Joyce MF. Posterior lumbar interbody fusion. Clin Orthop Relat Res 1983; 180:154–168.

13 Weatherley CR, Prickett CF, O'Brien JP. Discogenic pain persisting despite solid posterior fusion. J Bone Joint Surg Br 1986; 68:142–143.

14 Derby R, Howard MW, Grant JM, Lettice JJ, Van Peteghem PK, Ryan DP. The ability of pressure-controlled discography to predict surgical and

nonsurgical outcomes. Spine (Phila Pa 1976) 1999; 24:364-371. Discussion 371–372.

15 Mathews HH, Evans MT, Molligan HJ, Long BH. Laparoscopic discectomy with anterior lumbar interbody fusion. A preliminary review. Spine (Phila Pa 1976) 1995; 20:1797-1802.

16 Zucherman JF, Zdeblick TA, Bailey SA, Mahvi D, Hsu KY, Kohrs D. Instrumented laparoscopic spinal fusion. Preliminary results. Spine (Phila Pa 1976) 1995; 20:2029-2034. Discussion 2034–2035.

17 Escobar E, Transfeldt E, Garvey T, Ogilvie J, Graber J, Schultz L. Video-assisted versus open anterior lumbar spine fusion surgery: a comparison of four techniques and complications in 135 patients. Spine (Phila Pa 1976) 2003; 28:729–732.

18 Hee HT, Castro FP Jr, Majd ME, Holt RT, Myers L. Anterior/posterior lumbar fusion versus transforaminal lumbar interbody fusion: analysis of complications and predictive factors. J Spinal Disord 2001; 14:533–540.

19 Villavicencio AT, Burneikiene S, Bulsara KR, Thramann JJ. Perioperative complications in transforaminal lumbar interbody fusion versus anterior-posterior reconstruction for lumbar disc degeneration and instability. J Spinal Disord Tech 2006; 19:92–97.

20 Ray CD. Threaded titanium cages for lumbar interbody fusions. Spine (Phila Pa 1976) 1997; 22:667-679. discussion 679–680

21 Turner PL. Neurologic complications of posterior lumbar interbody fusion, presented at the annual meeting of the Spine Society of Australia; 14 May 1994; Melbourne, Australia.

22 Kornblum MB, Fischgrund JS, Herkowitz HN, Abraham DA, Berkower DL, Ditkoff JS. Degenerative lumbar spondylolisthesis with spinal stenosis: a prospective long-term study comparing fusion and pseudarthrosis. Spine (Phila Pa 1976) 2004; 29:726–733. Discussion 733–734.

23 Frymoyer JW, Hanley ENJr, Howe J, Kuhlmann D, Matteri RE. A comparison of radiographic findings in fusion and nonfusion patients ten or more years following lumbar disc surgery. Spine (Phila Pa 1976) 1979; 4:435–440.

24 Madan SS, Harley JM, Boeree NR. Anterior lumbar interbody fusion: does stable anterior fixation matter? Eur Spine J 2003; 12:386–392.

25 Lowe TG, Tahernia AD, O'Brien MF, Smith DA. Unilateral transforaminal posterior lumbar interbody fusion (TLIF): indications, technique, and 2-year results. J Spinal Disord Tech 2002; 15:31–38.

26 Salehi SA, Tawk R, Ganju A, LaMarca F, Liu JC, Ondra SL. Transforaminal lumbar interbody fusion: surgical technique and results in 24 patients. Neurosurgery 2004; 54:368–374.

27 Deutsch H, Musacchio MJ Jr. Minimally invasive transforaminal lumbar interbody fusion with unilateral pedicle screw fixation. Neurosurg Focus 2006; 20:E10.

28 Etame AB, Wang AC, Than KD, Park P. Clinical and radiographic outcomes after minimally invasive transforaminal lumbar interbody fusion. SAS J 2010; 4:47–53.

29 Dhall SS, Wang MY, Mummaneni PV. Clinical and radiographic comparison of mini-open transforaminal lumbar interbody fusion with open transforaminal lumbar interbody fusion in 42 patients with long-term follow-up. J Neurosurg Spine 2008; 9:560–565.

30 Schizas C, Tzinieris N, Tsiridis E, Kosmopoulos V. Minimally invasive versus open transforaminal lumbar interbody fusion: evaluating initial experience. Int Orthop 2009; 33:1683–1688.

31 Goel VK, Kong W, Han JS, Weinstein JN, Gilbertson LG. A combined finite element and optimization investigation of lumbar spine mechanics with and without muscles. Spine (Phila Pa 1976) 1993; 18:1531–1541.

32 Patwardhan AG, Havey RM, Meade KP, Lee B, Dunlap B. A follower load increases the load-carrying capacity of the lumbar spine in compression. Spine (Phila Pa 1976) 1999; 24:1003–1009.