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Outcomes of Extended Transforaminal Lumbar Interbody Fusion for Lumbar Spondylosis: A Retrospective Cohort Study

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Abstract

Objectives: The present study aims to assess the results of extended Transforaminal Lumbar Interbody Fusion (TLIF) for a two-surgeon, single institution series.

Methods: 57 cases of extended TLIF with bilateral decompression were performed. Pain, ASIA scores, patient demographics, BMI, perioperative indices and radiographic measurements were recorded and analysed.

Results: 57 operations were performed between February 2011 and January 2014, there were 38 female and 19 male patients. Mean patient age was 62.86 years, mean BMI was 30.31 kg/m2. In 49 patients spondylolisthesis was the primary indication. The mean intraoperative time was 284.65 min, this decreased as the series progressed. The median length of stay was 5 days, ranging from 2 to 9 days. The surgical complication rate was 22.8%. Two patients died from cardiopulmonary complications. 78.9% of the cohort had single-level TLIF, L4/5 was the most commonly fused level. Significant pain reduction was achieved from a mean Pre-operative VAS of 8.28 ± 1.39 to post-op VAS of 1.50±1.05 at 12 months. No patients deteriorated neurologically. Spondylolisthesis was significantly corrected from a pre-operative mean of 6.82 mm to 2.80 mm post-operatively. There is a learning curve associated with the procedure.

Discussion: TLIF with bilateral facet joint removal and decompression appeared to be a safe and effective alternative to other fusion techniques, and is comparable to other published case series. Stabilisation and correction of spinal deformity reduces pain, aids neurologic recovery and improves quality of life.

Keywords: Transforaminal; Bilateral decompression; Spinal fusion; Lumbar spondylosis

Abbreviations: ALIF: Anterior Lumbar Interbody Fusion; ASIA: American Spinal Injury Association; BMI: Body Mass Index; DDD: Degenerative Disc Disease; LBP: Lower Back Pain; LLIF: Lateral Lumbar Interbody Fusion; LOS: Length of Stay; MIS: Minimally Invasive Surgery; PEEK: Poly Ethyl Ethyl Ketone; PLIF: Posterior Lateral Interbody Fusion; TLIF: Transforaminal Lumbar Interbody Fusion; VAS: Visual Analogue Scale

Introduction

Fusion of the spine was first described in the medical literature by Albee in 1911 as an operation for Pott's disease, using a tibial graft for stabilization [1] and by Hibbs who described the technique for stabilizing spinal deformities such as scoliosis [2]. Chandler was the first to use spinal fusion for treatment of lower back pain and sciatica [3]. Barr proposed the "combined operation" of discectomy and fusion to overcome the problem of discectomy alone which left patients with residual pain, which can be due to underlying structural disc weakness [4].

Lumbar interbody fusion is now an accepted treatment for a variety of spinal disorders including trauma, infectious and neoplastic conditions [5]. It involves placement of an implant (spacer, graft or cage) within the intervertebral space after discectomy and end plate preparation. Currently lumbar interbody fusion is performed using four main approaches, posterior (PLIF), transforaminal (TLIF), anterior (ALIF) and lateral (LLIF). There is no evidence that one approach is superior to the others. These operations can also be performed using mini-open or minimally invasive (MIS) approaches [6]. Interbody fusion has been reported to have lower rates of post-operative complications and rates of pseudoarthrosis [7,8].

Posterolateral fusion places the graft in the posterolateral gutter to allow fusion from one transverse process to another. This avoids stenosis, which can be caused by a direct posterior approach to fusion [9,10]. The TLIF, a modified and unilateral approach to the PLIF, was first described by Harms and Rollinger in 1982 [11]. It gained popularity after further work by Harms et al. in the 1990s [12]. The technique was developed with the view to achieve a circumferential fusion with minimal risk to neural structures or the need for two-staged operations. Retraction on the neural structures is less than PLIF and hence can be safely performed above L2 as there is less conus medullaris retraction and risk for injury. TLIF preserves the interspinous ligament and spinous processes posterior to the thecal sac, as well as other midline structural supports [13]. TLIF may be preferable for revision surgery of a prior posterior approach, especially when an anterior approach is problematic or the surgeon is not familiar with ALIF. These benefits have led to the TLIF becoming increasingly popular over the last 15 years. Multiple versions of this technique have now emerged including unilateral instrumented fusion, unilateral pedicle screws with contralateral facet screws and more recently, minimally invasive techniques for interbody fusion with bilateral pedicle screws with or without a posterolateral fusion [14-17]. Limitations of TLIF include the significant muscle retraction and dissection, which can lead to post-operative pain, delayed rehabilitation and impaired spinal motion long-term [18]. Although we have listed benefits here, and this is the author's preferred fusion technique, evidence has not shown any

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benefit of TLIF over other fusion techniques in long-term studies in terms of clinical symptoms and fusion rates.

The present study examines the experience of a two-surgeon series with an extended transforaminal lumbar interbody fusion for degenerative spinal disease.

Methods

This is a retrospective study of 57 cases of extended transforaminal lumbar interbody fusion (TLIF) the authors performed from February 2011 to January 2014. All patients had pre-operative and post-operative CT of the affected spinal area. American Spinal Injury Association (ASIA) impairment score was used to document the neurological function. Visual analog scale (VAS) was used to assess the level of pain before and after surgery. Pain was subclassified into severe (VAS 7-10), moderate (VAS 5-6) and mild (VAS 0-4). Cobb angle was used to measure the degree of lumbar lordosis. Distance of antero- or retrolisthesis was measured at the level of fusion before and after surgery, using midsaggital CT slices. Peri-operative complications, pre- and post-operative neurological function and pain were analysed. Informed consents were obtained from all patients in accordance with institutional policy.

Surgical technique – extended TLIF

All patients were anaesthetised with an endotracheal general anaesthesia and placed prone on a Wilson frame. Radiographs were then taken to localise the pathological level. Preparation and draping was completed in the usual fashion. A midline incision was made and dissection was then made to expose the spine. The paraspinal muscles were retracted in a subperiosteal fashion to expose the laminae of the affected segments. Under image intensifier guidance pedicle screws were inserted into the bodies of the vertebrae one level above and below the pathological level. Bilateral decompression was then carried out by removing the left and right facet joints and completing a laminectomy at each affected level. Disectomy and end plate preparation was then performed through the transforaminal windows created by removing the facet joints. Bone graft was then packed into the disc spaces to be fused before a banana shaped poly ethyl ethyl ketone (PEEK) cage is inserted into the disc space. Rods were then placed bilaterally to connect the pedicle screws and a reduction manoeuvre performed to reduce spondylolisthesis if present. Screws were then locked after compression and 1 cross link with 2 parts was placed. Further bone graft was then packed into the interspace as required. Haemostasis was then achieved and the wound closed in multiple layers. Post-operative CT scans were obtained. Figure 1 demonstrates an illustrative case.

Results

Clinical data

57 patients were included in this study, 19 males and 38 females. The age of patients ranged from 25-82 years, the mean age was 62.86 years. The Body Mass Index (BMI) of patients ranged from 20 to 51 kg/m^2 (mean=30.31 kg/m^2). The mean BMI for male patients was 28.46 kg/m^2 and for female patients 31.16 kg/m^2. Two patients had emergency surgery one for acute foot drop (patient 35) and another due to cauda equina syndrome (patient 47). The remaining 55 had elective procedures, of which 49 patients (86%) had spondylolisthesis as the primary indication for surgery, 28 of these patients had concomitant central canal stenosis, 5 patients had concomitant foraminal stenosis. Apart from the two patients who presented with emergent presentations, the remaining patients all presented with lower back pain (LBP) and radicular lower limb pain. Table 1 demonstrates the clinical, radiographic and operative data of our series.

Operative time and estimated blood loss

The length of operating time and estimated blood loss was taken from the intraoperative anaesthetic charts for these patients. Estimated blood loss was only able to collected for 21 patients (35.6%) and hence was excluded from this report. The operating time ranged from 150 to 600 minutes, mean=284.65 min.

Complications and Length of Stay

The length of stay for the present cohort ranged from 2 to 9 days

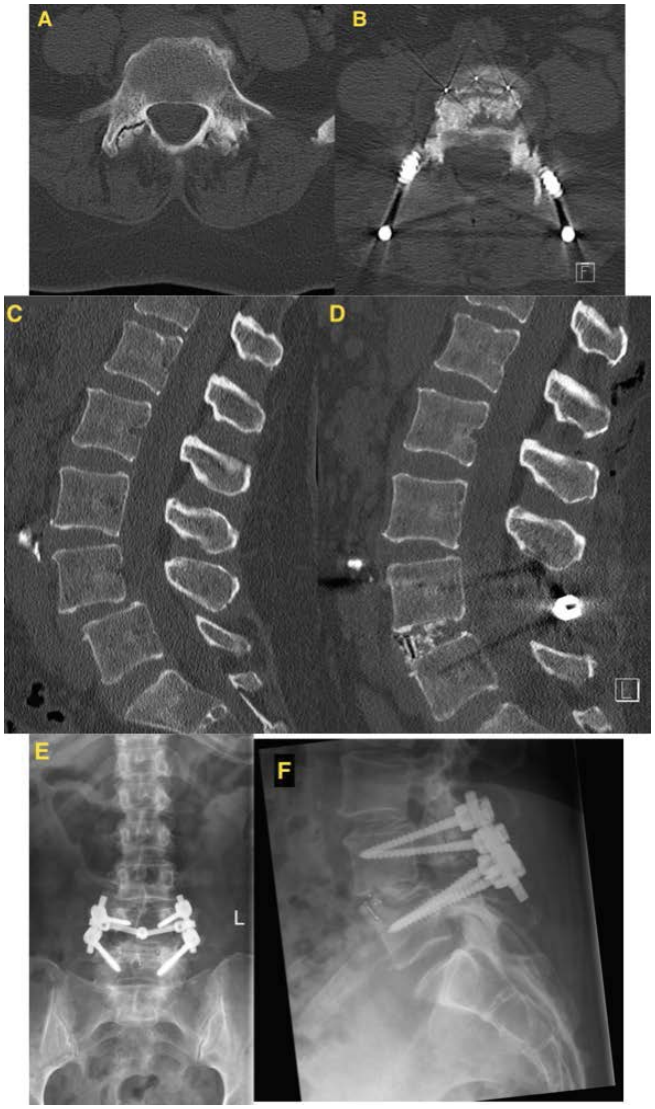

Figure 1: An illustrative case of the extended TLIF described herein. (A) pre-operative axial computed tomography scan of the superior endplate of L5, showing bilateral facet joint degeneration. (B) Axial CT scan showing the L4/5 disc space packed with bone graft, PEEK cage and transpedicular screws. (C) midsaggital section pre-operative CT scan showing an 8 mm anterolisthesis at L4/5. (D) Post-operative midsaggital CT showing corrected anterolisthesis, cage and graft packed into the L4/5 interspace. (E) AP radiograph taken at 3 months post-operative demonstrating good placement of the pedicle screws, rods and cross-link. (F) 3 month post-operative lateral radiograph which shows good position of the pedicle screws within the vertebral bodies of L4 and L5, it also shows partial fusion across the L4/5 interspace and good correction of spondylolisthesis.

Patient ID	Gender	Age at surgery	BMI (kg/m²)	Radiographic findings	Operation performed	Spinal Level affected	No of Levels Fused	Operative time (min)	Length of stay (days)
1	F	53	36.471	Spondylolisthesis	L4/5 TLIF	L4/5	1	480	6
2	F	65	46.740	Spondylolisthesis	L4/5 TLIF	L4/5	1	390	5
3	F	46	25.381	Spondylolisthesis	L5/S1 TLIF	L5	1	300	6
4	M	43	23.389	Spondylolisthesis, foraminal stenosis	L5/S1 TLIF	L5/S1	1	470	4
5	M	25	unknown	Spondylolisthesis	L5/S1 TLIF, rhizolysis	L5/S1	1	315	4
6	F	42	22.972	Spondylolisthesis	L4/5 TLIF	L4/5	1	285	5
7	F	53	22.309	R sided disc prolapse and spondylolisthesis	L4/5 TLIF	L4/5	1	515	4
8	M	31	26.235	R sided disc prolapse	L2/3 TLIF	L2/3	1	300	4
9	F	60	27.348	Spondylolisthesis and canal stenosis	L2/3, 3/4 TLIF, L4/5 laminectomy	L2/3, 3/4, 4/5	2	540	56
10	F	61	40.975	Spondylolisthesis and canal stenosis	L4/5 TLIF	L4/5	1	600	5
11	M	81	21.274	Spondylolisthesis and canal stenosis	L4/5 TLIF	L4/5	1	405	4
12	F	36	22.408	Spondylolisthesis, canal stenosis, disc prolapse	L4 laminectomy and L4/5 TLIF	L4/5	1	495	7
13	M	67	31.020	Spondylolisthesis and canal stenosis	L4/5, L5/S1 TLIF	L4/5, L5/S1	2	300	6
14	M	67	30.483	Spondylolisthesis and canal stenosis	L3/4 TLIF, laminectomy	L3/4	1	300	3
15	F	48	22.432	Spondylolisthesis, foraminal stenosis	L4/5 TLIF	L4/5	1	390	4
16	F	70	30.483	Spondylolisthesis and canal stenosis	L4/5 TLIF	L4/5	1	300	6
17	M	65	25.965	Spondylolisthesis and canal stenosis	L4/5 TLIF	L4/5	1	375	5
18	M	49	unknown	Spondylolisthesis and canal stenosis	L3/4, 4/5 TLIF, laminectomy	L3/4, 4/5	2	420	5
19	F	62	33.178	Spondylolisthesis and canal stenosis	L3/4 TLIF	L3/4	1	270	5
20	F	79	29.903	Spondylolisthesis and canal stenosis	L3/4, 4/5 TLIF, laminectomy	L3/4, 4/5	2	330	6
21	F	65	unknown	Spondylolisthesis and canal stenosis	L3/4, 4/5 TLIF	L3/4, 4/5	2	300	7
22	M	74	34.064	Spondylolisthesis and canal stenosis	L3/4 laminectomy, L4/5 TLIF	L3/4, 4/5	1	300	3
23	F	67	25.510	Spondylolisthesis and canal stenosis	L4/5, L5/S1 TLIF	L4/5, L5/S1	2	240	6
24	M	78	23.716	Spondylolisthesis and canal stenosis	L4/5 TLIF, laminectomy	L4/5	1	195	6
25	F	61	50.937	Spondylolisthesis and canal stenosis	L4/5 TLIF	L4/5	1	195	4
26	M	73	21.307	Spondylolisthesis, foraminal stenosis	L4/5 TLIF	L4/5	1	225	3
27	F	57	30.488	L sided disc prolapse and foraminal stenosis	L3/4 TLIF, laminectomy & rhizolysis	L3/4	1	180	5
28	M	70	24.212	Spondylolisthesis and canal stenosis	L4 laminectomy and L4/5 TLIF	L4/5	1	240	5
29	M	64	34.602	Spondylolisthesis	L5/S1 TLIF	L5/S1	1	210	4
30	F	72	31.179	Spondylolisthesis	L2/3 TLIF	L2/3	1	150	5
31	F	72	29.643	Spondylolisthesis and canal stenosis	L4/5 TLIF	L4/5	1	240	5
32	F	46	24.465	Spondylolisthesis and canal stenosis	L3/4 TLIF, R S1 rhizolysis	L3/4	1	210	5
33	F	74	41.091	Spondylolisthesis and canal stenosis	L4/5 TLIF	L4/5	1	225	7
34	F	57	26.446	Spondylolisthesis and recurrent disc herniation	L5/S1 TLIF, L3/4 laminectomy	L5/S1	1	270	5
35	F	76	20.285	Spondylolisthesis and foraminal stenosis	L4/5 TLIF	L4/5	1	195	6
36	F	73	32.813	Spondylolisthesis	L4/5, L5/S1 TLIF	L4/5, L5/S1	2	300	6
37	F	59	29.411	Spondylolisthesis	L4/5 TLIF	L4/5	1	240	3
38	F	66	35.156	Spondylolisthesis and canal stenosis	L4/5 TLIF, L3-5 Laminectomy	L3/4, 4/5	1	240	n/a
39	F	71	25.437	Spondylolisthesis	L4/5 TLIF, laminectomy	L4/5	1	210	4
40	F	70	30.078	Spondylolisthesis	L4/5 TLIF, L3-5 Laminectomy	L3-5	1	180	6
41	F	69	25.097	Spondylolisthesis	L4/5, L5/S1 TLIF	L4/5, L5/S1	2	270	6
42	M	56	27.102	Spondylolisthesis and canal stenosis	L4/5 TLIF	L4/5	1	180	3
43	F	64	39.001	Spondylolisthesis and canal stenosis	L4/5 TLIF	L4/5	1	240	3
44	F	58	37.333	Spondylolisthesis, canal stenosis, foraminal stenosis	L5/S1 TLIF	L5/S1	1	315	9
45	M	73	22.321	Spondylolisthesis and foraminal stenosis	L4/5 TLIF	L4/5	1	180	2
46	M	41	39.464	foraminal stenosis	L4/5 TLIF	L4/5	1	240	2
47	M	78	38.200	Nerve root compression (cauda equina)	L4/5 TLIF	L4/5	1	270	7
48	F	65	35.456	Spondylolisthesis and disc prolapse	L3/4, L4/5, L5/S1 TLIF	L3/4, 4/5, L5/S1	3	270	3
49	F	59	33.305	Spondylolisthesis and canal stenosis	L4/5, L5/S1 TLIF	L4/5, L5/S1	2	255	3
50	F	78	37.109	Spondylolisthesis and osteoarthritis	L4/5 TLIF	L4/5	1	210	7

51	M	78	28.406	Spondylolisthesis, canal stenosis, osteoarthritis	L4/5 TLIF	L4/5	1	240	4
52	F	69	30.471	Spondylolisthesis and canal stenosis	L3/4,4/5 TLIF	L3/4, 4/5, L5/S1	2	240	5
53	F	66	32.431	Spondylolisthesis and canal stenosis	L4/5 TLIF, laminectomy, rhizolysis	L4/5	1	165	5
54	F	74	33.299	Spondylolisthesis and canal stenosis	L4/5 TLIF, rhizolysis	L4/5	1	165	5
55	F	64	27.778	Osteoarthritis and canal stenosis	L3/4, 4/5 TLIF	L3/4, 4/5, L5/S1	2	240	3
56	F	63	27.916	Spondylolisthesis	L4/5 TLIF	L4/5	1	210	3
57	M	82	32.046	Spondylolisthesis and canal stenosis	L4/5 TLIF, L2-5 Laminectomy	L2/3, 3/4, 4/5, L5/S1	1	210	8
Abbreviations: M: Male; F: Female; R sided: Right sided; L sided: Left sided; TLIF: Transforaminal Lumbar Interbody Fusion.									

Table 1: Demographic and Clinical Data who underwent extended TLIF.

excluding 2 patients that were outliers. The median length of stay was 5 days. Patient 9 suffered a myocardial infarction associated with a prolonged operation and was hence an inpatient for 56 days at our institution. However the patient was transferred from the neurosurgical ward to a rehabilitation unit after 14 days post-op. Patient 38 died whilst an inpatient on day 6 post-op from a deep venous thrombosis and pulmonary embolus and was hence never discharged from hospital.

19 patients encountered post-operative complications (33.3%). The most common of these was anaemia requiring a post-operative transufusion, which occurred in 8 patients (14.0% of our cohort). 2 patients (3.5%) had wound infections in the immediate post-operative period, only one of which required CT-guided aspiration. Both were treated with appropriate antibiotics for 6 weeks. Patient 47 had post-operative hypotension and was admitted to an intensive care unit for correction of this, Patient 10 had pressure sores on her breast and airway oedema from a prolonged operation in the prone position and Patient 28 had a pseudomeningocoele develop post-operatively. Two patients encountered cardiopulmonary complications as previously mentioned. Table 2 lists all the post-operative complications in our cohort.

Spinal levels

47 patients had one level TLIF performed (82.4% of the cohort), 10 patients (17.544%) underwent 2 level TLIF and 2 patients (3.5%) had a 3 level TLIF. The most commonly affected level was L4/5 with 44 patients (77.2%) having this level fused. Followed by L3/4, which 15 patients (26.3%) patients had fused then L5/S1, which was fused in 11 patients. L2/3 was fused in 4 patients.

Pain score

There was a significant reduction of pain from a mean pre-operative VAS 8.28 ± 1.39 to post-operative VAS 2.73 ± 2.03 at 3 months, VAS 2.04 ± 1.68 at 6 months and VAS 1.50 ± 1.05 at 12 months (Figure 2). All patients were followed up for at least 6 months, for some it has not yet been 12 months at the time of writing (n=15, 28.1% of our cohort) and hence they have no VAS score at 12 months post-op.

Neurological status

27 patients presented with neurological deficits. Pre-operatively 2 patients had an ASIA score of C, 25 were ASIA D and the remainders were ASIA E. No patient's neurological function worsened post-operatively. 5 patients maintained the same ASIA score after 12 months of follow up. All others improved at least one grade on the ASIA scale. At the 12 month follow up interval, 33 patients were ASIA grade E. As with VAS scores for some it has not yet been 12 months at the time of writing (n=15, 26.3% of our cohort) and hence they have no ASIA grade for the 12 months follow up interval.

Deformity correction

Significant correction of slip distance was achieved in our cohort. The distance of antero- or retrolisthesis decreased from a mean 6.82 ± 2.75 mm pre-operatively to 2.80 ± 2.14 mm post-operatively ($p<0.0001$) (Figure 3). Cobb angle was used to measure restoration of lumbar lordosis, this increased from a mean 21.76° pre-operatively to 25.32° post-operatively, however this change was not significant ($p=0.051$) (Figure 4).

Discussion

After its first description by Harms and Rollinger in the early 1980s [11], the TLIF increased in popularity after further work by Harms in the later part of the 20th century [12]. The outcomes of the Swedish Lumbar Spine Study demonstrating for the first time that lumbar fusion was significantly more effective than conservative treatment for low back pain [19], allowed lumbar fusion, and the TLIF to become the standard of care. The technique was initially developed with the view to achieve a circumferential fusion without the needs for combined anterior and posterior approaches. It had the added benefits of accessing the spinal canal through the lateral portion of the vertebral foramen, which avoids signficant nerve root and theca retraction. The TLIF is a well-established and safe technique, which has been in mainstream neurosurgical and orthopaedic practice for at least 10 years [15,16,20]. Foley subsequently developed the minimally invasive TLIF (MI-TLIF) which has been gaining popularity ever since [21]. Since the turn of the century there have been case series reported that details experience

Complication	Number of Patients Affected
Systemic Complications	
Anaemia requiring transfusion	8
Urinary Tract Infection	3
Pulmonary Embolus	1
Myocardial Infarct	1
Post-operative Hypotension	1
Hypomagnasaemia	1
Airway swelling	1
Spinal and Surgical Complications	
Pseudomeningocoele	1
Wound haematoma requiring drainage	1
Wound Infection	1
Total Number of Complications	**19**
Systemic complications here refers to complications either not directly attributable to the surgical procedure or which caused systemic problems. Spinal and surgical complications refer to complications that directly affected the area which had been operated on.	

Table 2: Post-operative complications in our series of 57 patients who underwent extended TLIF.

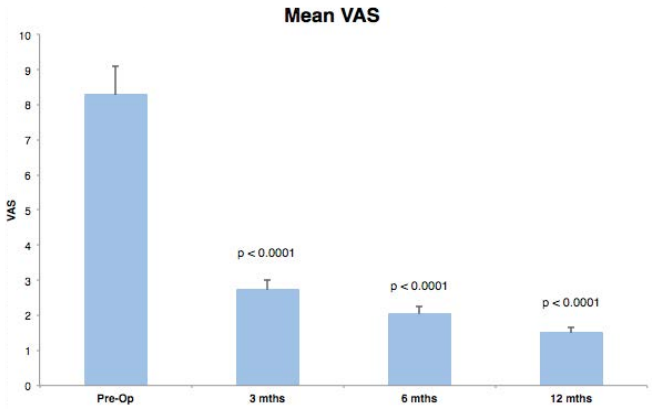

Figure 2: Mean Visual analogue scale (VAS) scores taken from the patients pre-operatively, at 3 months, 6 months and 12 months post-operatively. Compared with the pre-operative score, the reduction in pain score was significant at each of the review intervals. Of the 57 patients included in this study, 42 had their VAS score recorded at the 12 month follow up interval at the time of writing.

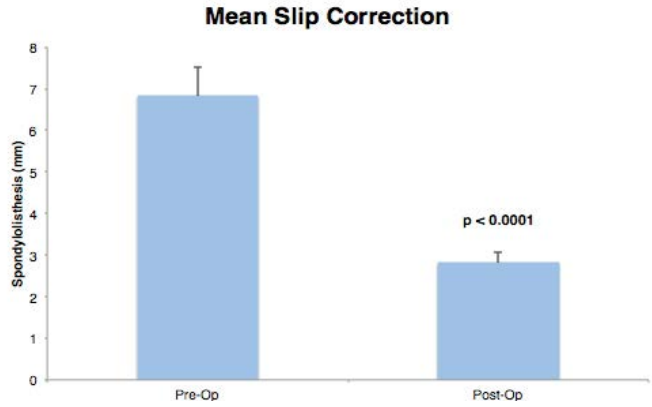

Figure 3: Mean Slip correction, as measured from the patient's pre-operative and post-operative midsaggital CT scans. The reduction in slip is significant comparing pre-operative to post-operative radiography.

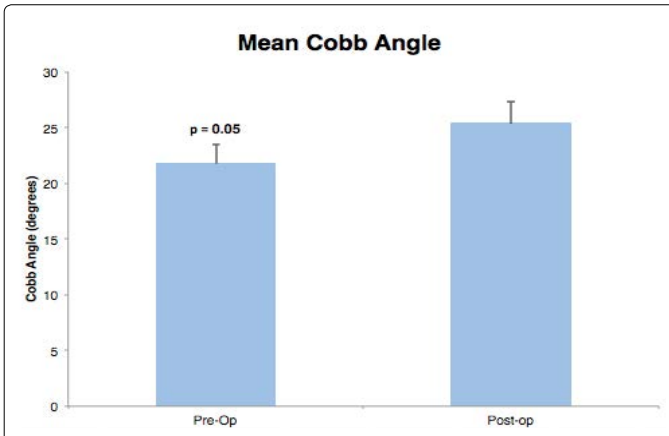

Figure 4: Mean Cobb angle, as measured from the patient's pre-operative and post-operative midsaggital CT scans. Whilst there is an increase in Cobb angle, and hence some restoration of lumbar lordosis, this change did not reach statistical significance.

with open TLIF [16,22], mini-open TLIF [23] and minimally invasive TLIF [24].

Rosenberg's initial series evaluating TLIF, a 22 patient cohort who underwent single or two-level TLIF was the first series since Harms in 1998 to establish the safety of the TLIF procedure [16]. In this series the back pain completely resolved in 16 of 22 patients (72%). One patient required re-operation for a CSF leak, two patients encountered wound infections but neither required re-operation [16]. Humphreys et al. [22] compared TLIF to PLIF in a 74 patient series (40 TLIFs). In this series the average operative time was 144.4 min for a single-level and 174.5 min for a two-level TLIF. The average hospital stay was the same for both groups at 4.8 days. Importantly in this series the TLIF cohort encountered no post-operative complications, whereas the PLIF group had 10 complications, a rate of 29.4% [22].

Dhall et al. [23] published a 42 patient series comparing open and mini-open TLIF, with 21 patients in each cohort. In this series the mini-open TLIF utilised a expandable and progressively wider dilator tubes rather than a larger open incision. This series showed no difference in long-term outcomes between mini-open and open TLIF and as expected the blood loss, length of stay (LOS) and operative time were all decreased with the mini-open group. The open TLIF group in this series had a mean operative time of 199 min and a mean LOS of 5 days. There were 2 complications requiring re-operation in the open group (4.8%) and 3 (9.5%) in the mini-open group, with one patient requiring a revision ALIF. The indication for surgery in this series is the same as in our cohort, namely spondylosis and degenerative disc disease (DDD). Importantly, the authors noted that there is greater potential for complications with tubular dilator retractors. These include nerve injury, inadequate decompression, problems with cage sizing and placement and misplaced screws [23].

Scheufler et al. [24] evaluated percutaneous TLIF in a 53 patient series and compared them with a concurrent 67 patient series of open TLIFs. The operative time was equivalent and blood loss was reduced in the percutaneous group. Post-operative pain was reduced after day 2 post-op in the percutaneous group compared to the open group. The overall clinical outcome was the same between groups at 8 and 16 months. One patient developed adjacent segment disease 16 months after a percutaneous TLIF, there were no such complications in the open group.

A more recent series from Terman et al. [25] compared minimally invasive and open TLIF, 53 and 21 patients in each respective cohort. These patients were specifically studied because of their obesity (mean BMI >30 kg/m^2). The open TLIF cohort had a mean pre-operative VAS of 7.1, and a post-operative VAS of 4.3. This was not significantly different from the minimally invasive group, which had a VAS 7.1 pre-operatively and VAS 4.7 post-operatively. Interestingly they stratified these patients by BMI, either above or below 35 kg/m^2, however they found that there was no significant difference between cohorts. The median LOS for the open group was 3 days and 2 days for the MI group. As expected, estimated blood loss was significantly less for the MI group, 100 mL compared with 450 mL (p=0.009). In this series the complication rate was higher for the open group (n=11) compared with the MI-TLIF group (n=9) however 5 of these were listed as "excessive blood loss" [25].

TLIF has also been recently evaluated in comparison to posterolateral fusion in a randomised clinical trial. This work carried out by Høy et al. [26] was a 100 patient trial, which included 51 TLIF cases. There was a reduction in VAS score from 6.1 pre-operatively to 3.6 at 12 months post-operatively and 3.5 at 24-month follow up.

Patient ID	Gender	Age (years)	BMI (kg/m²)	Indication for surgery	Date of Operation	Operation	Operating time (mins)	LOS (days)
7	F	53	22.309	Spondylolisthesis, radiculopathy	8/06/2011	L4/5 TLIF	515	4
58	F	63	27.916	Spondylolisthesis	21/01/2014	L4/5 TLIF	210	3
Abbreviations: BMI: Body Mass Index; LOS: Length of Stay								

Table 3: Comparison of two cases of single level, L4/5 extended TLIFs from the beginning and end of case series.

The TLIF group did not show a higher complication rate than the posterolateral fusion (control) group, despite all patients in the TLIF group receiving decompression, whereas the control group were only decompressed if clinically indicated (e.g. had radicular pain or sciatica symptoms) [26]. At the longest follow up interval, there was no difference in clinical outcome, as measured by VAS, between the control and TLIF group. This is consistent with the outcomes from a large multicentre RCT, the Swedish spine patient outcomes research trial (SPORT), which compared pedicle screw, posterolateral fusion and interbody fusion and found that after 4 years there was no difference in clinical outcomes [27].

In a traditional TLIF, as previously described by Harms [12] and Salehi [15], the spinal canal is entered from one side via a unilateral laminectomy and inferior facetectomy on the side of radicular pain or the side of entry is chosen arbitrarily. The extended TLIF described herein and that we are evaluating differs in that bilateral decompression is performed. To our knowledge this is the first description and evaluation of this technique in the literature. Otherwise the technique is essentially the same as the TLIF, using the same banana shaped cages and transpedicular screw construct. An important point to make is that the operation described in the present study is an open TLIF, not an MIS approach.

The demographic and clinical data from our series correlates with what has been published to date. The indications for surgery in our series, namely degenerative disease is the most common indication for TLIF reported in the literature. Although the operative time in our cohort seems to be greater than what has been reported recently for open TLIF, this is likely due to the bilateral decompression undertaken in our series. Length of stay is comparable to other retrospective series on open, or even minimally invasive TLIF. Improvement, and lack of regression in ASIA scores validates the safety of our technique. The placement of PEEK cages and transpedicular screw-rod construct ensured correction of antero- or retrolisthesis and may contribute to long-term pain relief and improvement of neurological symptoms. After 12 months of follow up no patients have displayed adjacent segment disease, which is always a concern especially in a rigid construct such as TLIF. Reported rates of ASD requiring revision surgery has recently been reported at 7.8% for interbody fusion procedures [28], this rate is higher in pateints greater than 60 years [29].

Our study shows an improvement in pain scores, which to our knowledge has not been achieved to this degree with a traditional TLIF. Hackenberg et al. [30] have a 52 patient case series that closely resembles ours, using traditional TLIF. Their pre-operative mean VAS was approximately 7.9 and their 3 month post-operative VAS approximately 4. Interestingly the VAS scores reported by these patients slowly increased (albeit non-significantly) after the 6 month follow up period [30]. The reduction in the current cohort from VAS 8.28 to VAS 2.73 at just 3 months post-operatively and there is a gradual, but not significant, further reduction in pain to VAS 1.50 at 12 months. This result is very encouraging, and suggests that although in the short-term a bilateral decompression by facet joint removal as part of a TLIF will increase operating time and probably immediate post-operative pain compared with a traditional TLIF. However it may provide additional long-term benefits, specifically better pain relief. This may be due to removal of pain causing structures such as the facet joints [31]. Further study and ideally prospective or randomised control trials comparing this technique to traditional open TLIF with unilateral decompression is needed to validate the outcomes that are suggested by our data.

Learning Curve

It is accepted that there is a substantial learning curve for any surgical procedure, as an example Regan et al. have reported a learning curve of 5-10 cases for laparoscopic ALIF [32]. Considering only the single level TLIFs from our series (n=47), the overall mean operating time for this subset of the current cohort was 275.32 ± 15.12 min. Table 3 compares two operations occuring in our series, one from the start of the series and one from the end. Both single level extended TLIFs occuring at L4/5. As can be seen, the operating time for patient 7 was 515 minutes, this took place in June 2011. In January 2014, patient 58 underwent the same operation and this only took 210 minutes. This is representative of the entire series. The shorter operating time can be seen as a marker for technical proficiency of the operation [33].

This is consistent with data published by Villavicencio et al. [34] and Lee et al. [35] on the learning curve related to MI-TLIF. A more recent study on MI-TLIF claims that it takes a surgeon 44 cases to achieve technical proficiency in this technique, and the patients operated on after this number of cases not only have shorter operations with less blood loss, but have better clinical outcomes [36]. Whilst we don't have the numbers to reproduce these data, and our surgical technique is not MI-TLIF, but rather an open approach. We did see a significant difference in operative time from the first 23 to the second 24 single-level extended TLIFs, if it is accepted to use operative time as a proxy for surgical proficiency. This is an area for further research.

Limitations

Limitations to our present study include its retrospective nature, the relatively small patient numbers, and lack of follow up greater than 12 months, we acknowledge that this limits the evaluation of pain, neurological deficits and fusion. Additional data which could be collected from this patient set include time to radiographic bony fusion, intervertebral disc height pre- and post-operatively. Additional Perioperative data that could be collected include estimated blood loss for a greater number of patients, duration of opiod analgesia, time to ambulation and VAS scores for lower back pain during the inpatient period. Prospective studies should include comparisons to other methods of interbody fusion such as PLIF or LLIF, or compare to standard TLIF with unilateral decompression.

Conclusions

The present study is limited by its retrospective nature and relatively small patient population. Nevertheless it demonstrated that bilateral decompression as part of a TLIF procedure is a safe and effective alternative to the traditional TLIF that utilises a unilateral window through the facet joint to access the disc space. Pain, neurological

status and spinal deformity were likely to improve after surgery. Future prospective and randomised study should further define the long term outcomes of this approach.

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