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Clinical Case Studies

Prone Transpsoas Lateral Interbody Fusion (PTP LIF) with Anterior Docking: Preliminary functional and radiographic outcomes

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ABSTRACT

Background: Disadvantages of lateral interbody fusion (LIF) through a direct, transpsoas approach include difficulties associated with lateral decubitus positioning and limited sagittal correction without anterior longitudinal ligament release or posterior osteotomy. Prior technical descriptions advocate anchoring or docking the retractor into the posterior to middle aspect of the disc space.

Methods: 72 patients who underwent 116 total levels of Prone Transpsoas (PTP) LIF with anterior docking with a single surgeon between December 2021 and May 2023 were included. Patient characteristics, perioperative data, as well as postoperative functional and radiographic outcomes were recorded. Subgroup analysis was performed for patients who underwent single-level PTP LIF with single-level percutaneous fixation (SLP). Patients in the SLP subgroup did not undergo direct decompression, release, or osteotomy.

Results: N=41 (56.9%) of cases included the L4–5 level. No vascular, bowel, or other visceral complications occurred. No patients developed a permanent motor deficit. Both the total cohort and the SLP group demonstrated statistically significant improvements in functional outcomes including Oswestry Disability Index (ODI) and Visual Analog Scale (VAS) as well as all radiographic parameters measured. Mean total operative time (incision to completion of closure for lateral and posterior fusion) in the SLP group was 104.3 minutes with a significant downward trend with increasing surgeon experience. The SLP group demonstrated a **9.9**° increase in segmental lordosis (SL), a **7.5**° increase in lumbar lordosis (LL), **5.3**° reduction in pelvic tilt (PT), and a decrease in pelvic incidence – lumbar lordosis mismatch (PI-LL) from **11.0**° preoperatively to **3.9**°, postoperatively ($p<.01$).

Conclusions: PTP LIF with anterior docking may address shortcomings associated with traditional lateral interbody fusion by producing safe and reproducible access with improved restoration of segmental lordosis and optimization of spinopelvic parameters.

Background

The advantages of lateral interbody fusion (LIF) through a direct, transpsoas approach are well documented [1,2]. LIF creates an optimized fusion environment through the placement of a large, mechanically stable graft under physiologic compressive forces and ligamentotaxis. The size of the lateral interbody cage as well as its ability to span the dense cortical bone of the apophyseal ring contribute to increased construct stiffness and decreased rates of subsidence [3,4]. A wide release of the lateral annulus allows for substantial indirect decompression of the neural foramen, lateral recess and central canal [5]. Traditionally, LIF has provided excellent coronal correction and mild to moderate sagittal correction [6–8]. Additional sagittal correction may be achieved through release of the anterior longitudinal ligament or posterior based osteotomies [9].

LIF is able to achieve excellent radiographic fusion [10], decompression [11], and coronal alignment correction [12] with relative preservation of the posterior musculoligamentous complex compared to posterior based techniques. These favorable characteristics have led to significant surgeon interest in the technique. A review article ranking the top 50 articles on minimally invasive spine surgery recognized the original description of extreme lateral interbody fusion (XLIF) by Ozgur et al. in 2006 as the number one most cited article [1,13]. Despite significant surgeon interest in harnessing this powerful technique, relatively few surgeons perform lateral interbody fusion.

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Historically, LIF has been performed in the lateral decubitus position. This position presents several difficulties which may contribute to the limited adoption of the technique. Lateral decubitus is an unfamiliar setup with labor-intensive initial positioning [14] as well as repositioning to the prone position for the vast majority of posterior work [14,15]. Although surgeons are certainly able to perform single-position lateral decubitus surgery, this can be logistically cumbersome, compromising the accuracy of screw placement [15] and making direct decompression very difficult to perform [16]. Additionally, lordosis is not maximized in the lateral decubitus position compared to the prone position [17,18]. Other challenges include either direct or traction-related lumbar plexus injury and difficulty with access at L4–5 due to iliac crest and upper lumbar levels due to rib cage [19,20].

As a response to these difficulties associated with LIF in the lateral decubitus position, a novel prone transpsoas (PTP) approach to lateral interbody fusion was initially described by Pimenta et al in 2020 [18,21]. Performing LLIF in the prone position presents several advantages compared to lateral decubitus. The surgeon has simultaneous access to the anterior and posterior columns of the spine. No repositioning is required for direct decompression or other posterior work. Prone positioning uses gravity to induce greater positional lordosis than lateral decubitus [22]. Hip extension draws the psoas and with it the lumbar plexus posteriorly for an increased safe zone anterior to the lumbar plexus [23,24].

Lamartina and Berjano presented an initial case series of seven patients who underwent prone extreme lateral interbody fusion (Pro-XLIF) [25]. Their technique describes performing the transpsoas XLIF procedure [1] in the prone position without equipment specifically designed for the unique demands of the prone position. Specifically, the authors anchored their retractor to the posterior aspect of the spine by inserting a rigid shim through the posterior blade of their 3-bladed retractor into the posterior aspect of the disc space. The authors were able to avoid major complications but noted difficulties related to patient and retractor stability

Pimenta et al. [18] and Smith et al. [26] described multicenter experiences demonstrating feasibility and safety with equipment designed specifically for prone transpsoas lumbar interbody fusion (PTP LIF) including a patient positioner with lateral bolster and a rigid 2-bladed retractor designed to enhance patient and retractor stability in the prone position. This retractor allowed for shim insertion through both the posterior and anterior blades of the retractor (Fig. 1).

Initial case series of prone LIF have demonstrated safety and efficacy with potentially shorter surgical times and improved segmental lordosis [18,25–30]. Patel et al. [31] recently presented a single surgeon experience describing the learning curve associated with LIF performed in the prone position. These case series have been presented by surgeons with extensive experience with lateral decubitus LIF and many include recommendations that surgeons have extensive experience and training in the lateral decubitus position before learning LIF in the prone position [31,32].

The purpose of this study is to describe a single surgeon's experience with PTP LIF including technique, learning curve, and perioperative and short term clinical and radiographic data.

Materials and methods

Study design

This is a retrospective, observational study. All patients who underwent single or multi-level PTP LIF by a single surgeon from December 2021 to May 2023 were included. PTP LIF was either performed exclusively or combined with additional anterior or posterior based procedures. Exclusion criteria were patients with contraindication to LIF including neurovascular anatomy prohibitive to a lateral transpsoas approach or other decompensated medical comorbidities preventing preoperative surgical clearance.

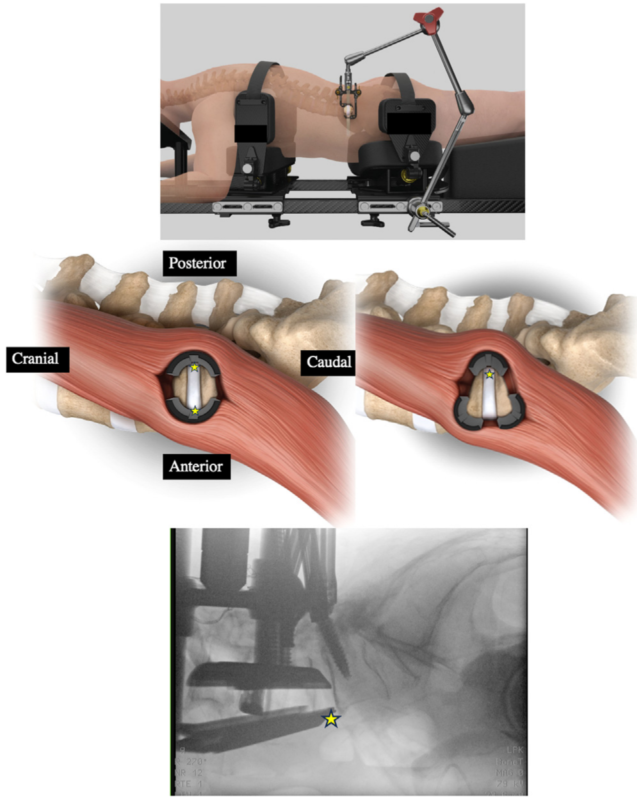

Fig. 1. PTP specific positioner and retractor. Top: Patient positioner with retractor. Left: PTP specific 2 bladed retractor with anterior and posterior blades. Both blades allow for retractor docking through rigid intradiscal shim placement. Star denotes potential docking site. Right: Traditional 3 bladed retractor designed for lateral decubitus LIF. This retractor is only able to dock through posterior retractor blade. Bottom: Intraoperative fluoroscopy of anterior docking technique with rigid intradiscal shim fixation through anterior retractor blade of a 2 bladed retractor.

Surgical technique

The author's surgical technique is based on techniques described previously [21,26]. Briefly, the patient is positioned in the prone position on a patient positioner specific for PTP LLIF (Atec Spine). This positioner features ventral and lateral bolsters with circumferential strapping and the ability to bend in the coronal plane to reduce scoliosis and facilitate cranial and caudal access. The patient is draped widely with split sheets to enable lateral and posterior access. Ipsilateral retroperitoneal access is established through a 2 cm accessory incision overlying the Wiltse interval. Depending on the nature of the posterior portion of the operation a midline incision or percutaneous pedicle screw incision may be used instead of a dedicated accessory incision. Blunt dissection is carried with the fingertip, palpating transverse processes and entering the retroperitoneal space.

A direct lateral incision is then made over the disc space of interest and blunt dissection is carried through the abdominal wall and into the retroperitoneal space. Abdominal contents are pushed ventrally and retroperitoneal space is established through palpation of the inner surface of the 12th rib and the inner table of the ilium. Safe access to the disc space and sequential dilation are performed under triggered electromyography (EMG) and the retractor is opened. The retractor is a lightweight, rigid, 2-bladed retractor capable of independent anterior and posterior motion (Atec Spine). Each retractor blade has a channel for insertion of a 6 or 8mm, rigid, serrated shim that fixes the retractor into the intradiscal space.

Fig. 2. Case example of L4–5 PTP LIF with percutaneous PSF for spondylolisthesis . Anterior docking was utilized to place interbody cage at the anterior aspect of L5 vertebral body prior to percutaneous placement of pedicle screws with reduction of spondylolisthesis.

The first shim is inserted through the anterior blade of the retractor into the anterior aspect of the disc space and the position is confirmed with fluoroscopy. This technique is known as anterior docking.

The retractor is opened posteriorly to the minimum width possible to allow the passage of an 18 mm instrument. A posterior shim is then inserted under fluoroscopy and triggered EMG to establish a rigid working corridor. Standard discectomy, endplate preparation, and sequential trialing are performed under continuous saphenous somatosensory evoked potential (SSEP) monitoring. Depending on trial placement, either the anterior or posterior shim is removed to facilitate desired placement of a 22 mm cage, whose position is confirmed on fluoroscopy. Hemostasis is achieved and the retractor is removed.

Attention is then turned to the posterior portion of the operation. Most frequently percutaneous placement of pedicle screws was performed under fluoroscopy (Figs. 2 and 3).

Data collection

Patient demographic information, including age, body mass index (BMI), and gender were recorded. Intraoperative data were collected, including estimated blood loss (EBL), operative time, in room time, setup time, time to final insertion of hardware, and complications. Preoperative and postoperative patient-reported functional outcomes including Oswestry Disability Index (ODI) and Visual Analog Scale (VAS) were recorded. Preoperative and postoperative upright x-rays were assessed for the following sagittal parameters: Pelvic Incidence (PI), Lumbar Lordosis (LL) measured from superior endplate of L1 to superior endplate of S1, Pelvic Tilt (PT), and segmental lordosis (SL) measured from superior endplate of upper instrumented vertebrae with LIF and inferior endplate of lower instrumented vertebrae with LIF. For example, in an L4–5 LIF construct the segmental lordosis was be measured as the angle between the superior endplate of L4 and the inferior endplate of L5. Postoperative data including length of stay and complications were recorded. Postoperative motor weakness was defined as a decrease in strength of 1 or more points out of 5 on the manual muscle testing scale between preoperative and postoperative examination.

Statistical analysis

Data were analyzed using SPSS software (SPSS version 23.0 by International Business Machines) with significance set at p<.05. Paired sample T test was used to compare pre and post operative functional and radiographic outcomes. Pearson correlation coefficient was applied to detect relationship between operative time and surgeon experience.

Results

Demographics

This study included 72 patients with 116 levels of PTP LIF performed. Mean follow up was 9.19 months with a range of 1.5 to 19 months. Mean age was 66.9 with a range from 35–88. Mean BMI was 29.4 kg/m^2 with a range of 18.2 to 46.9. There were 44 (61.1%) single level, 14 (19.4%) 2-level, 11 (15.3%) 3 level and 3 (4.2%) 4 level surgeries performed. The most frequently operated level was L4–5 (n=41, 56.9% of cases) Table 1. Four patients and 7 levels were treated with a prone retropleural approach and 1 patient and 1 level was treated with a prone, retrodiaphragmatic approach. The most common diagnoses were spondylolisthesis (n=44, 61.1% of cases), degenerative scoliosis (n=19, 26.4%), and adjacent segment degeneration (n=15, 20.1%).

Of the 44 single-level PTP LIF surgeries performed, 26 included only 1 level PTP LLIF and 1 level of percutaneous posterior spinal fusion

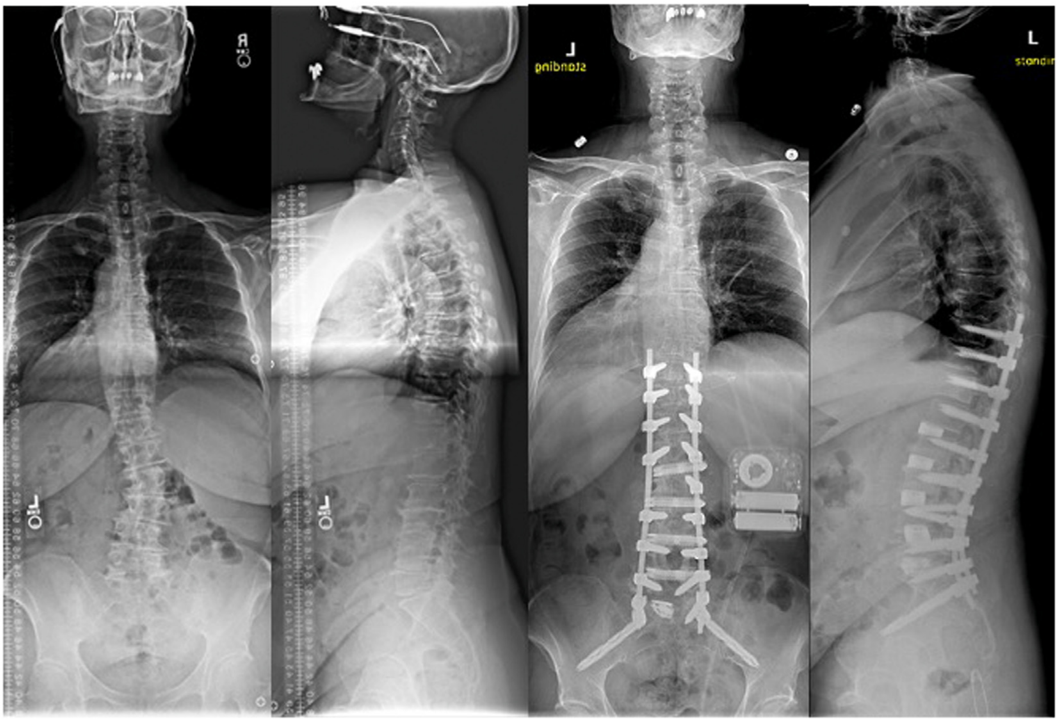

Fig. 3. Case example of L1–5 PTP LLIF for degenerative scoliosis.

Table 1
Case Distribution by operative level and number of levels per case

Operative Level	Frequency (n)	Percentage (%) (N = 116) levels
T11–12	1	0.9%
T12–L1	2	1.7%
L1–L2	8	6.9%
L2–L3	28	24.1%
L3–L4	36	31.0%
L4–L5	41	35.3%
Number of Operative Levels	**Frequency (n)**	**Percentage (%) (N=72 cases)**
Single level	44	61.1%
2 Levels	14	19.4%
3 Levels	11	15.3%
4 Levels	3	4.2%

(SLP). This SLP subgroup did not include open posterior decompression, release, or osteotomy.

Perioperative data

For the SLP patients, the duration of surgery from skin incision to final skin closure was 104.3 minutes with a range of 60 to 163 and a standard deviation of 28.0. The average EBL was 12.4 mL and length of stay was 2.1 days.

In regard to complications, there were no vascular, bowel, or other visceral injuries. No patients developed quadriceps or hip flexor weakness as measured by manual motor testing at the 6-week and all subsequent follow-up appointments. There were no revisions of implants due to malposition. There were no instances of aborted surgery due to inaccessibility of disc space.

Three (n=3/116 levels, 2.59%) unintentional anterior longitudinal ligament (ALL) ruptures were encountered, which were recognized intraoperatively and plated in situ with antimigration plate with no untoward sequelae. One (n=1/116 levels, 0.862%) case of intraoperative air leak was noted. This was treated prophylactically with a chest tube placement, which was removed uneventfully without development of pneumothorax or other related complication.

Functional outcomes

In regard to functional outcomes, statistically significant differences were demonstrated on ODI and VAS scales for all study participants as well as SLP subgroup Table 2.

Table 2
Functional outcomes of all study participants

Parameter	Mean ± SD	p - value
Oswestry Disability Index (ODI)		
Preoperative	48.9 ± 19.1	**<.001**
Postoperative	31.1 ± 21.2	
ΔODI	**15.7 ± 16.7**	
Visual Analogue Scale (VAS)		
Preoperative	6.2 ± 2.1	**<.001**
Postoperative	2.8 ± 2.4	
ΔVAS	**3.4 ± 2.8**	
Functional outcomes of study participants with single level percutaneous PSF (SLP)		
Parameter	Mean ± SD	p - value
Oswestry Disability Index (ODI)		
Preoperative	49.2 ± 20.0	**.001**
Postoperative	34.8 ± 22.0	
ΔODI	**14.3 ± 15.9**	
Visual Analog Scale (VAS)		
Preoperative	6.0 ± 2.3	**<.001**
Postoperative	3.2 ± 2.5	
ΔVAS	**2.8 ± 2.2**	

Table 3
Radiographic outcomes of all study participants

Parameter	Mean ± SD	p - value
Pelvic Incidence (PI)		
Preoperative	54.7 ± 7.7	.312
Postoperative	55.0 ± 7.1	
ΔPI	0.4 ± 3.1	
Lumbar Lordosis (LL)		
Preoperative	43.2 ± 13.4	**<.01**
Postoperative	52.5 ± 10.6	
ΔLL	**9.2 ± 8.1**	
Pelvic Tilt (PT)		
Preoperative	21.6 ± 5.8	**<.01**
Postoperative	16.9 ± 6.1	
ΔPT	**-4.7 ± 4.1**	
Segmental Lordosis (SL)		
Preoperative	11.6 ± 12.3	**<.01**
Postoperative	24.2 ± 11.1	
ΔSL	**12.6 ± 6.2**	
Pelvic Incidence (PI) - Lumbar Lordosis (LL)		
Preoperative	11.8 ± 11.5	**<.01**
Postoperative	3.0 ± 8.9	
ΔPI-LL	**-8.7 ± 8.2**	

Radiographic outcomes of study participants with single level PTP LIF with percutaneous PSF (SLP)

Parameter	Mean ± S.D	p - value
Pelvic Incidence (PI)		
Preoperative	57.8 ± 7.4	1.000
Postoperative	57.8 ± 7.3	
ΔPI	0.0 ± 0.6	
Lumbar Lordosis (LL)		
Preoperative	46.4 ± 12.3	**<.01**
Postoperative	53.9 ± 12.1	
ΔLL	**7.5 ± 5.5**	
Pelvic Tilt (PT)		
Preoperative	22.8 ± 7.4	**<.01**
Postoperative	17.5 ± 8.1	
ΔPT	**-5.3 ± 3.5**	
Segmental Lordosis (SL)		
Preoperative	12.4 ± 7.3	**<.01**
Postoperative	22.3 ± 8.1	
Change (Post op – Pre op)	**9.9 ± 3.7**	
Pelvic Incidence (PI) - Lumbar Lordosis (LL)		
Preoperative	11.0 ± 9.7	**<.01**
Postoperative	3.9 ± 10.3	
ΔPI-LL	**-7.1 ± 4.5**	

Paired sample T-Test was applied.
Boldface type indicates statistically significant results.

Radiographic outcomes

There were statistically significant differences in LL, PT, SL and PI-LL between preoperative and postoperative groups in all study groups including the single level percutaneous cohort Table 3.

Discussion

Technical considerations

The fundamental difference between LIF in the prone versus lateral position is the effect of gravity. In the lateral decubitus position the advantage of gravity is that it keeps the retractor fixed rigidly to the spine and the patient fixed to the bed and shortens the working distance as abdominal girth tends to pancake outward.

In the prone position the advantage of gravity is that it induces greater lordosis and improves lateral access to the spine at cranial and caudal levels while allowing simultaneous circumferential access to the anterior and posterior columns without repositioning. The major disadvantage of the prone position is that gravity is no longer working to keep the retractor fixed to the spine and the patient fixed to the table during lateral percussive maneuvers associated with disc preparation and implantation. Additionally, abdominal girth tends to gather peripherally resulting in an increased working length, which also decreases retractor stability.

Equipment that facilitates enhanced retractor and patient stability should allow the surgeon to enjoy the advantages of the prone position while mitigating the disadvantages. For this reason the author uses a positioner and retractor specifically designed for prone transpsoas lateral interbody fusion (Atec Spine). The positioner features ventral and lateral bolsters with circumferential strapping and coronal bending capability. The lateral bolsters are spring-loaded and affixed snugly to the lateral aspect of the patients buttock to minimize recoil throughout the operation. The coronal bending feature increases the size of the retroperitoneal working corridor at cephalad and caudal levels.

The retractor features 2 blades capable of independent anterior and posterior motion. Each blade features a channel that allows for insertion of a shim that provides rigid intradiscal fixation. It is the authors preference to dock anteriorly by inserting an anterior shim and establishing a fixed boundary between the operative field and the great vessels. The retractor is opened minimally in the posterior direction to allow the passage of disc prep instruments prior to placement of a posterior shim. At this point the discectomy may be performed through a rigid and strictly bound operative corridor resistant to displacement or migration.

The 2-bladed retractor is much lighter and more rigid than the 3-bladed retractor typically used in the lateral decubitus approach. The 3-bladed retractor only allows for one shim to be inserted into the disc space through the posterior blade. As the discectomy is performed the fixation of this posterior shim weakens, increasing the tendency of the retractor to drift anteriorly toward the vessels. Furthermore, in order to establish an anterior boundary with a 3-bladed retractor the plane anterior to the spine must be developed and an ALL retractor must be inserted. The ALL retractor does not provide any additional intradiscal fixation. Many papers describe retractor instability as the major issue with LIF performed in the prone position [25,31]. This instability may be due to insufficient intradiscal fixation.

An additional benefit of anterior docking with a 2-bladed retractor is increased distance from the lumbar plexus, which resides in the posterior aspect of the disc space. Frequently in the prone position the author will obtain triggered EMG values greater than 20 mA in all 4 quadrants, even at the L4–5 level. Anterior docking, combined with a limited exposure, may reduce traction on the lumbar plexus and allow for more anterior cage placement, which has been shown to result in increased segmental lordosis values [12,33].

Perioperative outcomes

A mean operative time of 104.3 minutes compares favorably with established operative times for lateral interbody fusion combined with posterior spinal fusion. A recent systematic review of 39 studies on transpsoas fusion techniques reported a mean surgical time of 203.6±64.8 minutes [34]. Lamartina et al reported a surgical time of 133.8±26.6 minutes in their initial case series of single-level prone XLIF [25]. Over the course of the author's initial 72 case experience the author demonstrated increased procedural efficiency with surgeon experience (Fig. 4).

The complication profile was comparable to that described in existing literature regarding LIF in both lateral decubitus and prone positions [25,31,34,35]. No vascular, bowel, visceral complications were encountered. Due to the increased working length in the prone position, the author advocates strongly for the use of an accessory incision in order to establish and develop a clean retroperitoneal plane for dissection. This may be easier in the prone position as the peritoneal contents drift forward with gravity. In smaller patients the psoas and spine are directly palpable through the lateral incision, but in larger patients this is not possible. In this situation using the accessory incision to touch fingertips and guide the initial dilator to the surface of the psoas provides

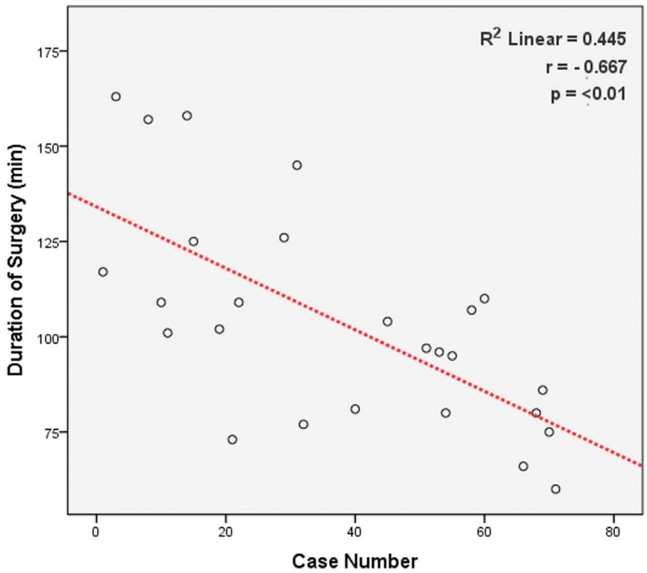

Fig. 4. Correlation of total surgery duration (incision to completion of closure for lateral and posterior incisions) to increasing surgeon experience in single level PTP LIF with percutaneous PSF (SLP) cases.

reassurance to the surgeon that no viscera or abdominal contents are interposed.

Three (n=3, 2.59%) incidental ALL ruptures were encountered, which is consistent with existing literature [25,26,31]. They were identified during trialing or implant insertion when a loss of resistance was encountered. Since no prior evidence of ALL incompetence was noted, these ruptures were likely caused by the procedure. They were not associated with anterior retractor or cage migration and were treated with in situ anti-migration plate fixation. In all cases an anterior and posterior shim were in place at the time of rupture and the posterior shim remained fixed rigidly, preventing anterior migration of the retractor. In the prone position there appears to be increased tension on the ALL and the surgeon should have a heightened awareness for signs of ALL disruption. In the future expandable cage and trial technology may allow for more gentle expansion of the disc space and fewer cases of ALL rupture.

Air leak (n=1, 0.862%) is a known complication of retropleural approaches. In this particular case the patient had friable parietal pleura, which was damaged during the approach. At the end of the case, a red rubber catheter was inserted into the retropleural space and persistent, occult air leak was noted. A chest tube was placed prophylactically and removed uneventfully without development of pneumothorax or other sequelae.

In regard to neurologic complications, there were no cases of quadriceps or hip flexor motor deficit in this series despite 57% of cases addressing the L4-5 level. In a systematic review of transpsoas literature the reported incidence of permanent motor deficit was 1.9% to 4.0% [34], with a greater incidence of neurologic complications early in a surgeon's learning curve and at the L4–5 level [36]. The absence of motor weakness in this series may be due to a small number of cases or possibly technical factors related to anterior docking such as a more anterior position in the disc space. This anterior position maintains a greater distance from the lumbar plexus than traditional docking techniques in the posterior or middle third of the vertebral body and may reduce the likelihood of direct or traction-related injury. In all cases, continuous saphenous sensory evoked potentials were used. As the terminal branch of the femoral nerve the saphenous SSEP may provide insight into an evolving motor deficit. In 5 cases an alert was triggered by a decrease in SSEP amplitude by a >50% drop in amplitude and >10% increase in latency. The author reacted by either closing the retractor and waiting for signals to return or by expediting cage insertion and retractor removal.

Radiographic outcomes

Restoration of segmental lordosis and optimization of spinopelvic parameters have been associated with improved functional outcomes [37] and decreased rates of adjacent segment degeneration [38,39]. Roussouly et al. noted that patients with degenerative spondylolisthesis were characterized by a greater Pelvic Incidence than the asymptomatic population [40]. High pelvic incidence patients require greater values of lumbar lordosis to achieve sagittal balance than low pelvic incidence patients, highlighting the importance of restoration of segmental lordosis even in the treatment of single level degenerative pathology

Acosta et al. [6] demonstrated a 2.9° increase in segmental lordosis with a lateral transpsoas approach in the lateral decubitus position and Sembrano demonstrated a statistically significant increase of 3.2° [41]. Kepler reviewed 67 levels in 29 patients and found an average increase in segmental lordosis of 3.7°. Anterior cage placement was associated with the largest lordosis gain of 7.4° per level while posterior cage placement resulted in 1.2° of kyphosis per level. Lordosis restoration was also inversely correlated with preoperative lordosis [12]. These findings were corroborated by Otsuki et al. [42] who concluded that lordosis gains are optimized by maximizing anterior disc space expansion.

Using the prone LIF technique, Uribe, Walker et al. [30] demonstrated a 6.3° increase in segmental lordosis in single-level fusion for spondylolisthesis. The authors also found that compared to lateral decubitus position, the cages were placed more anteriorly in the prone group. Despite a significant increase in segmental lordosis, they did not find a significant increase in overall lumbar lordosis or significant improvement in other spinopelvic parameters. Pimenta et al demonstrated a 6.1° segmental lordosis correction with the PTP technique [18]. More recently in 2023 Amaral, Pimenta et al. [43][demonstrated a 6.6° segmental lordosis correction with PTP.

Radiographic analysis of all study participants and the single-level subgroup demonstrated statistically significant improvements in SL, LL, PT, and PI-LL.

In the subgroup of single-level PTP LIF with percutaneous PSF the average change in segmental lordosis was 9.9°. In this group, no direct posterior decompression, facetectomy, or other osteotomy or release was performed. This increase in lumbar lordosis is likely due to multiple factors relating to patient and cage positioning. The prone position has been shown to result in a more anterior cage position [30]. The anterior docking technique utilized allows for more anterior cage position. Expandable cages were used for 9 of the last 10 cases in this series. An anteriorly placed expandable cage may facilitate the appropriate maximum physiologic expansion of the anterior aspect of the disc space. Furthermore, the vast majority of these cases were performed for degenerative conditions featuring loss of segmental lordosis. As preoperative segmental lordosis is inversely correlated to changes in segmental lordosis [12], these levels were able to gain significant lordosis by reconstituting the native disc height with an anteriorly positioned cage.

Functional outcomes

Patients demonstrated statistically significant improvements in VAS and ODI despite relatively short term follow up (Table 2).

Strengths

To the author's knowledge this is the largest case series of prone LIF presented by a single author with functional and radiographic outcomes. This study demonstrates statistically significant improvement in all functional and radiographic parameters measured. The anterior docking technique is proposed as a possible means of enhancing segmental lordosis.

Limitations

The primary limitations of this study are its retrospective and observational nature as well as relatively short follow up. Due to significant overlap of radicular, axial and postural symptoms in initial presentation, clinical outcomes were not stratified by predominant symptom. Given the enthusiasm for adoption and implementation of this operation, the author felt that it was important to publish this data expediently in order to contribute to the growing body of knowledge regarding this procedure and to help surgeons with technique acquisition and preoperative planning. Additional studies are forthcoming and will feature long term functional and radiographic outcomes.

Conclusions

The 2 major drawbacks of traditional LIF are difficulties associated with lateral decubitus positioning and limited sagittal correction without anterior longitudinal ligament release or posterior osteotomy. Preliminary results indicate that PTP LIF with anterior docking may address these shortcomings by producing safe and reproducible access with improvement in segmental lordosis and other spinopelvic parameters. Additional, long-term studies are required to elucidate the strengths, weaknesses, and applications of this exciting and powerful technique.

Declaration of Competing Interests

The author declares potential competing financial interests or personal relationships as specified on required ICMJE-NASSJ Disclosure Forms.

Patient informed consent

The author declares that informed patient consent was not provided for the following reason: This study focused solely on observable procedural data, and did not include patient-identifiable data, and as-such is not considered human subjects research and is therefore exempt from informed consent requirements per FDA 45 CFR 46.104(d).

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References

[1] Ozgur BM, Aryan HE, Pimenta L, Taylor WR. Extreme Lateral Interbody Fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. Spine J 2006;6(4):435–43. doi:10.1016/j.spinee.2005.08.012.

[2] Goyal A, Kerezoudis P, Alvi MA, Goncalves S, Bydon M. Outcomes following minimally invasive lateral transpsoas interbody fusion for degenerative low grade lumbar spondylolisthesis: a systematic review. Clin Neurol Neurosurg 2018;167:122–8. doi:10.1016/j.clineuro.2018.02.020.

[3] Pimenta L, Turner AWL, Dooley ZA, Parikh RD, Peterson MD. Biomechanics of lateral interbody spacers: going wider for going stiffer. ScientificWorldJournal 2012;2012:381814. doi:10.1100/2012/381814.

[4] Yuan W, Kaliya-Perumal AK, Chou SM, Oh JYL. Does lumbar interbody cage size influence subsidence? A biomechanical study. Spine 2020;45(2):88–95. doi:10.1097/BRS.0000000000003194.

[5] Elowitz EH, Yanni DS, Chwajol M, Starke RM, Perin NI. Evaluation of indirect decompression of the lumbar spinal canal following minimally invasive lateral transpsoas interbody fusion: radiographic and outcome analysis. Minim Invasive Neurosurg 2011;54(5-6):201–6. doi:10.1055/s-0031-1286334.

[6] Acosta FL, Liu J, Slimack N, Moller D, Fessler R, Koski T. Changes in coronal and sagittal plane alignment following minimally invasive direct lateral interbody fusion for the treatment of degenerative lumbar disease in adults: a radiographic study. J Neurosurg Spine 2011;15(1):92–6.

[7] Saadeh YS, Joseph JR, Smith BW, Kirsch MJ, Sabbagh AM, Park P. Comparison of segmental lordosis and global spinopelvic alignment after single-level lateral lumbar interbody fusion or transforaminal lumbar interbody fusion. World Neurosurg 2019;126:e1374–8. doi:10.1016/j.wneu.2019.03.106.

[8] Nakashima H, Kanemura T, Satake K, et al. Comparative radiographic outcomes of lateral and posterior lumbar interbody fusion in the treatment of degenerative lumbar kyphosis. Asian Spine J 2019;13(3):395–402. doi:10.31616/asj.2018.0204.

[9] Akbarnia BA, Mundis GM Jr, Moazzaz P, et al. Anterior column realignment (ACR) for focal kyphotic spinal deformity using a lateral transpsoas approach and ALL release. J Spinal Disord Tech 2014;27(1):29–39. doi:10.1097/BSD.0b013e318287bdc1.

[10] Malone H, Mundis GM, Collier M, et al. Can a bioactive interbody device reduce the cost burden of achieving lateral lumbar fusion? J Neurosurg Spine 2022;37:646–53. doi:10.3171/2022.4.SPINE211070.

[11] Kepler CK, Sharma AK, Huang RC, et al. Indirect foraminal decompression after lateral transpsoas interbody fusion. J Neurosurg Spine 2012;16(4):329–33. doi:10.3171/2012.1.SPINE11528.

[12] Kepler CK, Huang RC, Sharma AK, et al. Factors influencing segmental lumbar lordosis after lateral transpsoas interbody fusion. Orthop Surg 2012;4(2):71–5. doi:10.1111/j.1757-7861.2012.00175.x.

[13] Virk SS, Yu E. The top 50 articles on minimally invasive spine surgery. Spine 2017;42(7):513–19. doi:10.1097/BRS.0000000000001797.

[14] Tohmeh AG, Watson B, Tohmeh M, Zielinski XJ. Allograft cellular bone matrix in extreme lateral interbody fusion: preliminary radiographic and clinical outcomes. ScientificWorldJournal 2012;2012:263637. doi:10.1100/2012/263637.

[15] Drazin D, Kim TT, Johnson JP. Simultaneous lateral interbody fusion and posterior percutaneous instrumentation: early experience and technical considerations. Biomed Res Int 2015;2015:458284. doi:10.1155/2015/458284.

[16] Blizzard DJ, Thomas JA. MIS single-position lateral and oblique lateral lumbar interbody fusion and bilateral pedicle screw fixation: feasibility and perioperative results. Spine 2018;43(6):440–6. doi:10.1097/BRS.0000000000002330.

[17] Siljander B, Thomas JAA, Sembrano JN, Dick NR. 67. Lateral lumbar interbody fusion with percutaneous pedicle screw fixation (LLIF-PPS): are we getting the sagittal alignment right? Spine J 2019;19(9):S33 Supplement. doi:10.1016/j.spinee.2019.05.080.

[18] Pimenta L, Amaral R, Taylor W, et al. The prone transpsoas technique: preliminary radiographic results of a multicenter experience. Eur Spine J 2021;30(1):108–13. doi:10.1007/s00586-020-06471-y.

[19] Tohmeh AG, Rodgers WB, Peterson MD. Dynamically evoked, discrete-threshold electromyography in the extreme lateral interbody fusion approach. J Neurosurg Spine 2011;14(1):31–7. doi:10.3171/2010.9.SPINE09871.

[20] Cheng I, Briseño MR, Arrigo RT, Bains N, Ravi S, Tran A. Outcomes of two different techniques using the lateral approach for lumbar interbody arthrodesis. Global Spine J 2015;5(4):308–14. doi:10.1055/s-0035-1546816.

[21] Pimenta L, Taylor WR, Stone LE, Wali AR, Santiago-Dieppa DR. Prone transpsoas technique for simultaneous single-position access to the anterior and posterior lumbar spine. Oper Neurosurg (Hagerstown) 2020;20(1):E5–E12. doi:10.1093/ons/opaa328.

[22] Smith TG, Pollina J, Joseph SA Jr, Howell KM. Effects of surgical positioning on L4-L5 accessibility and lumbar lordosis in lateral transpsoas lumbar interbody fusion: A comparison of prone and lateral decubitus in asymptomatic adults. World Neurosurg 2021;149:e705–13. doi:10.1016/j.wneu.2021.01.113.

[23] Alluri R, Clark N, Sheha E, et al. Location of the femoral nerve in the lateral decubitus versus Prone position. Global Spine J 2021;13(7):1765–70. doi:10.1177/21925682211049170.

[24] Amaral R, Daher MT, Pratali R, et al. The effect of patient position on Psoas morphology and in lumbar lordosis. World Neurosurg 2021;153:e131–40. doi:10.1016/j.wneu.2021.06.067.

[25] Lamartina C, Berjano P. Prone single-position extreme lateral interbody fusion (Pro-XLIF): preliminary results. Eur Spine J 2020;29(1):6–13 Suppl. doi:10.1007/s00586-020-06303-z.

[26] Smith TG, Joseph SA Jr, Ditty B, et al. Initial multi-centre clinical experience with prone transpsoas lateral interbody fusion: feasibility, perioperative outcomes, and lessons learned. Spine J 2021;6:100056. doi:10.1016/j.xnsj.2021.100056.

[27] Pimenta L, Pokorny G, Amaral R, et al. Single-position prone transpsoas lateral interbody fusion including L4L5: early postoperative outcomes. World Neurosurg 2021;149:e664–8. doi:10.1016/j.wneu.2021.01.118.

[28] Diaz-Aguilar L, Stone LE, Soliman MAR, et al. Radiographic alignment outcomes after the single-position prone transpsoas approach: a multi-institutional retrospective review of 363 cases. Neurosurg Focus 2023;54(1):E3. doi:10.3171/2022.10.FOCUS22603.

[29] Godzik J, Ohiorhenuan IE, Xu DS, et al. Single-position prone lateral approach: cadaveric feasibility study and early clinical experience. Neurosurg Focus 2020;49(3):E15. doi:10.3171/2020.6.FOCUS20359.

[30] Walker CT, Farber SH, Gandhi S, Godzik J, Turner JD, Uribe JS. Single-position prone lateral interbody fusion improves segmental lordosis in lumbar spondylolisthesis. World Neurosurg 2021;151:e786–92. doi:10.1016/j.wneu.2021.04.128.

[31] Patel A, Rogers M, Michna R. A retrospective review of single-position prone lateral lumbar interbody fusion cases: early learning curve and perioperative outcomes. Eur Spine J 2023;32(6):1992–2002. doi:10.1007/s00586-023-07689-2.

[32] Tamburrelli FC, Perna A, Proietti L. Letter to the editor concerning "Prone single-position extreme lateral interbody fusion (Pro-XLIF): preliminary results" by Lamartina C and Berjano P. Eur Spine J; 2020: 10.1007/s00586-020-06303-z. Eur Spine J 2020;29(7):1771–2. doi:10.1007/s00586-020-06456-x.

[33] Park SJ, Lee CS, Chung SS, Kang SS, Park HJ, Kim SH. The ideal cage position for achieving both indirect neural decompression and segmental angle restoration

in lateral lumbar interbody fusion (LLIF). Clin Spine Surg 2017;30(6):E784–90. doi:10.1097/BSD.0000000000000406.

[34] Walker CT, Farber SH, Cole TS, et al. Complications for minimally invasive lateral interbody arthrodesis: a systematic review and meta-analysis comparing prepsoas and transpsoas approaches. J Neurosurg Spine 2019;25:1–15. doi:10.3171/2018.9.SPINE18800.

[35] Uribe JS, Deukmedjian AR. Visceral, vascular, and wound complications following over 13,000 lateral interbody fusions: a survey study and literature review. Eur Spine J 2015;24(3):386–96 Suppl. doi:10.1007/s00586-015-3806-4.

[36] Lee YP, Regev GJ, Chan J, et al. Evaluation of hip flexion strength following lateral lumbar interbody fusion. Spine J 2013;13(10):1259–62. doi:10.1016/j.spinee.2013.05.031.

[37] Serratrice N, Gennari A, Yuh SJ, et al. Segmental lordosis gain is a prognostic radiological factor of good functional outcome after the implantation of a single-level prosthesis or a hybrid construct for lumbar disc degeneration. World Neurosurg 2021;152:e597–602. doi:10.1016/j.wneu.2021.06.005.

[38] Tian H, Wu A, Guo M, et al. Adequate restoration of disc height and segmental lordosis by lumbar interbody fusion decreases adjacent segment degeneration. World Neurosurg 2018;118:e856–64. doi:10.1016/j.wneu.2018.07.075.

[39] Rothenfluh DA, Mueller DA, Rothenfluh E, Min K. Pelvic incidence-lumbar lordosis mismatch predisposes to adjacent segment disease after lumbar spinal fusion. Eur Spine J 2015;24(6):1251–8. doi:10.1007/s00586-014-3454-0.

[40] Barrey C, Jund J, Perrin G, Roussouly P. Spinopelvic alignment of patients with degenerative spondylolisthesis. Neurosurgery 2007;61(5):981–6 discussion 986. doi:10.1227/01.neu.0000303194.02921.30.

[41] Sembrano JN, Tohmeh A, Isaacs RSOLAS Degenerative Study Group. Two-year comparative outcomes of MIS lateral and MIS transforaminal interbody fusion in the treatment of degenerative spondylolisthesis: part I: clinical findings. Spine 2016;41(8):S123–32 Suppl. doi:10.1097/BRS.0000000000001471.

[42] Otsuki B, Fujibayashi S, Takemoto M, et al. Analysis of the factors affecting lumbar segmental lordosis after lateral lumbar interbody fusion. Spine 2020;45(14):E839–46. doi:10.1097/BRS.0000000000003432.

[43] Amaral R, Moriguchi R, Pokorny G, Arnoni D, Barreira I, Marcelino F, et al. Comparison of segmental lordosis gain of prone transpsoas (PTP) vs. lateral lumbar interbody fusion. Archives of Orthopaedic and Trauma Surgery 2023;18:1–6. doi:10.1007/s00402-023-04821-1.