



Single Position Prone Lateral Lumbar Interbody Fusion: A Review of the Current Literature

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Abstract

Purpose of Review Spinal fusion, vital for treating various spinal disorders, has evolved since the introduction of the minimally invasive Lateral Lumbar Interbody Fusion (LLIF) by Pimenta in 2001. Traditionally performed in the lateral decubitus position, LLIF faces challenges such as intraoperative repositioning, neurological complications, and lack of access to lower lumbar levels. These challenges lead to long surgery times, increased rates of perioperative complications, and increased costs. The more recently popularized prone lateral approach mitigates these issues primarily by eliminating patient repositioning, thereby enhancing surgical efficiency, and reducing operative times. This review examines the progression of spinal fusion techniques, focusing on the advantages and recent findings of the prone lateral approach compared to the traditional LLIF.

Recent Findings The prone lateral approach has shown improved patient outcomes, including lower blood loss and shorter hospital stays, and has been validated by multiple studies for its safety and efficacy compared to the LLIF approach. Significant enhancements in postoperative metrics, such as the Oswestry Disability Index, Visual Analog Scale, and radiological improvements have been noted. Comparatively, the prone lateral approach offers superior segmental lordosis correction and potentially better subjective outcomes than the lateral decubitus position.

Summary Despite these advances, both techniques present similar risks of neurological complications. Overall, the prone lateral approach has emerged as a promising alternative in lumbar interbody fusion, combining efficiency, safety, and improved clinical outcomes.

Keywords Prone lateral lumbar interbody fusion · Spine surgery · Spine fusion · Orthopaedic surgery

Introduction

Spinal fusion procedures are integral in the management of various spine disorders, including infection, trauma, degenerative pathology, deformity, instability, and neoplasia [1]. The evolution of lumbar interbody fusion techniques, particularly within the realm of minimally invasive surgery (MIS), has revolutionized the field of spine surgery since the advent of the first laparoscopic lumbar discectomy in 1991

[2]. Various novel surgical techniques have been described to address shortcomings of the traditional posterior approach including anterior, lateral, and oblique lumbar interbody fusion (ALIF, LLIF, and OLIF, respectively). These minimally invasive approaches allow for decreased tissue trauma, shorter hospital stays, and less postoperative pain when compared to traditional approaches [3]. The choice of lumbar interbody fusion technique remains a multifaceted decision influenced by the underlying pathology, surgeon expertise, and patient-specific anatomy.

LLIF was first described by Pimenta in 2001, which was followed shortly by the extreme lateral interbody fusion (XLIF) in 2006 [2]. The general principles are the same for all lateral approaches, which achieve fusion rates comparable to ALIF (exceeding 90%) [4–7]. In contrast to ALIF, lateral approaches eliminate the need for access surgeons due to the decreased risk of vascular and gastrointestinal

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complications, as the approach avoids manipulation of these structures. In addition, LLIF allows for the use of hyper-lordotic cages which improve angle correction (cobb, coronal, sagittal) in spinal deformity procedures. However, LLIF is limited because patients require intraoperative repositioning from the lateral decubitus to the prone position to perform posterior instrumentation, decompression, and osteotomies. This leads to increased operative times, healthcare costs, and postoperative complications [8]. Other limitations of this approach include the inability to access L5-S1 pathology due to the anatomy of the iliac crest, iliac vasculature, and anterior lumbar plexus [9]. The lateral approach has been associated with transient neurological symptoms with an incidence rate of 0.7–36.1% [9, 10]. Thus, this approach necessitates neuromonitoring techniques to prevent neurological complications [11].

A variation of this is the OLIF, first described by Mayer in 1997, which allows for access from L1-S1, through a corridor anterior to the psoas muscle (instead of directly through it). Similar to LLIF, the patient must be repositioned from lateral decubitus to prone position in order to attain posterior access. Although OLIF allows access to the lower levels, the procedure has a higher degree of technical difficulty compared to other approaches.

Prone Lateral Approach

A recent novel modification of the lateral approach has been described by Pimenta et al. [12], in which the entirety of the procedure is performed in the prone position. This ameliorates the limitations associated with intraoperative repositioning while achieving the same advantages offered by standard LLIF.

In this approach, the patient is placed in the prone position with a Jackson-type surgical table and a customized bolstering system, that allows bending in the coronal plane if necessary (Fig. 1). Using fluoroscopy, a transverse incision is made from the posterior margin of the foramen at the level of the disc space to the posterior third of the target disc space. The external oblique, internal oblique, and transversus abdominis are dissected in an anterior–posterior direction, toward the quadratus iliac crest border, until access to the retroperitoneal space is achieved. The surgeon then confirms the correct location by palpating the surface of the psoas major muscle, the transverse process, and the iliac crest. Using finger guidance, a dilator is advanced orthogonally to the disc space, through the incision and into the surface of the psoas muscle. The dilator is utilized in conjunction with a neuromonitoring system to separate the psoas muscle between the middle and anterior thirds, ensuring that the operative corridor is posterior to the aorta, inferior vena cava, and common iliac vessels while also being anterior to



Fig. 1 Intraoperative illustration demonstrating patient position and the incision (red line) for the prone lateral lumbar interbody fusion approach. *Original image was digitally processed via Adobe Photoshop CC2021 and Adobe Illustrator 2023 (27.9)*

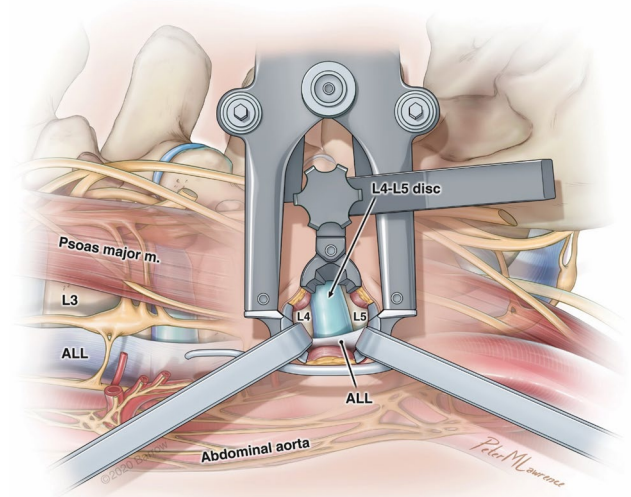


Fig. 2 Illustration of the retractor placement and operative view attained with the prone lateral approach. ALL=anterior longitudinal ligament, m=muscle. *Illustration used with permission from Barrow Neurological Institute, Phoenix, Arizona*

the lumbar plexus. Care should also be taken during separation of the psoas muscle fibers to prevent injury of the genitofemoral nerve. The dilator is then inserted until the surface of the disc is reached (Fig. 2). Sequential dilators are used to create an access corridor, and a specialized access system is placed over the last dilator and attached to the operating table, locking the access system into place [12].

Advantages

The prone lateral approach offers a compelling alternative as it allows for access to both the anterior and posterior spine.

This eliminates the necessity for repositioning and re-draping, making it particularly beneficial for complex surgeries [13, 14]. This efficiency reduces operative times, healthcare costs, decreases morbidity and improves patient outcomes [15].

The prone lateral approach facilitates posterior decompression, posterior column osteotomies, and posterior instrumentation [14]. Additionally, the position may facilitate lateral corpectomy with fixation and fusion [13].

In addition to these advantages, the prone position also provides other unique features. Abdominal contents are drawn away from the spine by gravity, which can provide an unobstructed view for the surgeon. However, while this shift can improve visualization, it does not completely prevent the risk of organ injuries [16]. Ergonomically, the prone lateral approach allows for flexibility to sit or stand during the discectomy, resulting in improved surgeon comfort. Additionally, the surgeon could transition smoothly between posterior fixation and lateral fusion without patient repositioning, allowing for comprehensive treatment strategies. Concurrent anterior and posterior instrumentation can also be performed with multiple surgeons, which further increases procedural efficiency [14].

Safety & Efficacy

Multiple studies have consistently demonstrated the safety and efficacy of the prone lateral approach in lumbar interbody fusion procedures. A systematic review of literature and pooled analysis encompassing 286 patients across 10 different studies, who all underwent a prone lateral approach, found a pooled intraoperative complication rate of just 1.9%. The postoperative complication rate was similarly low at 3.4%, affirming the safety of this approach [17].

Several studies have highlighted the benefits of the prone lateral approach in spinal surgery, noting measurable improvements in patient outcomes. Postoperative scores across various assessments—including the Oswestry Disability Index (ODI), 12-item Short Form Survey, EQ-5D questionnaire, and Visual Analog Scale (VAS) for back and leg pain—show statistically significant enhancements when compared to preoperative scores with this approach. Soliman et al. observed reduced blood loss and shorter hospital stays with the prone lateral approach, findings which were statistically significant ($p > 0.05$), in comparison to transforaminal approaches [18–21].

Additionally, this approach has been associated with benefits in postoperative radiological parameters (Table 1). For instance, increases in lumbar lordosis (LL) and reductions in the discrepancy between pelvic incidence and lumbar lordosis (PI-LL) have been shown to be significant compared to preoperative measurements [18, 19]. This was supported by the findings of Diaz-Aguilar et al., who reported significant improvements in postoperative lumbar lordosis ($p < 0.001$), pelvic incidence ($p = 0.008$), and the pelvic incidence-lumbar lordosis match ($p < 0.001$) [20]. Similarly, Soliman documented enhancements in the lumbar lordosis angle, pelvic tilt, and pelvic incidence minus lumbar lordosis value with the prone lateral approach versus the transforaminal approach [21].

A comprehensive retrospective study involving 365 patients across 11 centers indicated superior outcomes for those undergoing single-position prone LLIF. This study showed a significant reduction in 90-day readmission rates to 1.9%, compared to 24.8% in other approaches ($p < 0.05$), such as XLIF, ALIF, TLIF, and PLIF. The literature consistently supports the prone lateral approach as an effective method for lumbar spine surgery, citing improvements in radiologic parameters, patient outcomes, and procedural safety [22].

Table 1 Summary of Improved Radiological Outcomes from Single Position Prone Lateral Lumbar Interbody Fusion Studies

Authors & Year	Study Design	Level of Evidence	Outcomes	Measurement
Soliman et al. 2022	Case Series	IV	Increased Lumbar Lordosis*	10.3 ± 8.5
			Decreased Pelvic Incidence—Lumbar lordosis*	$12.4 \pm 8.8^\circ$
Diaz-Aguilar et al. 2023	Retrospective Cohort	III	Increased Lumbar Lordosis**	$4.8 \pm 10.8^\circ$
			Pelvic Incidence—lumbar lordosis**	$7.9 \pm 11^\circ$
Wellington. 2023	Retrospective Cohort	III	Increased Lumbar Lordosis**	$4.5 \pm 8.6^\circ$
			Increased Segmental Lordosis**	$6.8 \pm 4.8^\circ$
			Increased Anterior Disc Height**	$8.0 \pm 3.6^\circ$
			Increased Posterior Disc Height**	$3.3 \pm 2.4^\circ$

* $P < 0.05$

** $P < 0.001$

Limitations/Risks

While the prone lateral approach offers many advantages, it also has limitations and risks. Although not unique to this approach, a primary concern is the potential for neurological complications, which may include hip flexor weakness, hip dysesthesia, or femoral neuropathy. This issue was highlighted in a long-term study that investigated neurological outcomes in 29 patients following single prone position lateral interbody fusion. The study reported a 34% incidence of neurological complications, characterized by symptoms such as ipsilateral thigh pain, numbness, or weakness at 6 weeks postoperatively. Notably, one patient (3%) experienced a femoral nerve injury, leading to motor weakness. Most neurological complications were short-term, as only one patient continued to have neurological symptoms at the six-month follow-up. A significant finding of the study was the correlation between the mean duration of trans-psoas surgical access (mean trans-psoas time) and the emergence of new postoperative neurological symptoms. In light of these neurological risks, many surgeons have utilized various intraoperative neuromonitoring methods, including electromyography (EMG), to mitigate potential complications. By providing spatial information about the position of the lumbar plexus relative to the operating field. Specifically, this study recommends using a lower posterior EMG threshold compared to anterior to provide a more sensitive indicator of neurapraxia. A lower threshold signifies detection closer proximity to the which is more critical for the posterior blade. This insight is crucial for the surgeon, as having the plexus posterior to the retractor allows for safer operation on the anterior surgical field, thereby reducing the risk of iatrogenic neurological damage. This consideration is especially important since, as of now, there is no technology available that enables surgeons to measure the extent of neurological damage in real time during a procedure [23].

Surgeons and their teams may require additional training and experience to effectively perform lateral lumbar interbody fusion in the prone position. Patel et al. reported increased complications in a prone lateral naïve surgeon. These included surgery abortion (1.9%), Anterior Longitudinal Ligament ruptures (1.9%), and malpositioned implant requiring revision (0.65%), transient quadriceps palsy (1.3%), and permanent quadriceps palsy (0.6%). They report that as the surgeons increased their repetition, the complication rates decreased, with most of the complications occurring within the first 30 cases. They also report decrease in retractor time as the number of cases performed by the surgeon increased, demonstrating a negative trend in retractor time as surgeon experience increased [24]. Surgeons must also consider the length of the approach corridor, which is typically longer than in the lateral decubitus position. With the patient in the lateral decubitus position, the break of the

table widens the area between the ribs and the iliac crest; as a result, there is less distance between the incision site and the target disc space. This longer corridor may necessitate the use of longer surgical instruments to reach the disc space in the prone position. However, surgeons have the ability to manipulate the coronal plane with pads and a Jackson type table, which can improve accessibility of the disc space and potentially mitigate the corridor discrepancy.

LLIF vs. Prone Lateral Approach

Perioperative Outcomes

The literature indicates that the single-position prone lateral approach is both efficacious and safe, as evidenced by improved radiological parameters and postoperative patient outcomes. Although both positions yield postoperative improvements, the prone lateral approach exhibits greater efficiency due to reduced positioning requirements [14]. A recent study focusing on revision lumbar fusion revealed that the prone lateral approach significantly reduced operative times ($p < 0.004$), with surgeries averaging 151 min compared to 206 min for the lateral decubitus position [25]. This aligns with findings by Lamartina et al., who also reported shorter operative times with the prone lateral approach (133 vs. 183 min) [26]. Additionally, Soliman et al. observed a reduced mean hospital stay of 2.7 days with the prone lateral approach, in contrast to 4.5 days for the lateral decubitus position. The same study noted lower rates of reoperation and subsidence in the prone lateral group compared to the lateral decubitus group [22]. Moreover, there was a statistically significant improvement in subjective patient outcomes, notably in the Oswestry Disability Index ($p < 0.05$), postoperatively in patients treated in the prone position [27].

Radiological Outcomes

Postoperative radiological outcomes differ significantly between the prone lateral and lateral decubitus approaches, an important consideration in multilevel surgeries that often involve deformity corrections. A study focusing on cases of lumbar spondylolisthesis found a significantly greater improvement in segmental lordosis correction— 5.1° compared to 2.5° ($p = 0.02$)—in patients undergoing prone lateral surgery compared to lateral decubitus [28]. Similarly, research by Amaral et al. on segmental lordosis correction across various pathologies underscored the efficacy of the prone lateral approach, significantly enhancing segmental lordosis correction compared to the lateral decubitus position ($P < 0.05$) [29]. These reports are contrasted by Soliman et al. that show no difference in segmental correction

but do report improved lumbar lordosis in the prone lateral approach [27].

One theoretical limitation of the prone lateral approach lies in the challenge of accessing lower vertebral levels, such as L4-L5, attributing to restricted coronal plane manipulation and impedance from the iliac crest. To address this concern, Smith et al. compared radiological parameters in clinically healthy patients across both positions. Employing a Jackson-style surgical frame and a customized bolstering system, the researchers manipulated the coronal planes and lumbar lordosis of the spine while patients were in the prone position and compared them to a lateral decubitus position. It was found that during coronal manipulation in the prone position, the distances between the iliac crest and the superior aspect of L5 were greater than in the lateral decubitus position. Furthermore, a statistically significant difference in accessibility, defined as the caudal positioning of the iliac crest relative to the L5 endplate, favored the coronally bent conditions over the lateral decubitus. The study also revealed that coronal angulation was statistically higher in the lateral decubitus position compared to the prone position [30].

Complications

The most common and persistent complications reported for both the prone lateral and lateral decubitus approach are neurological deficits. Presently, no study directly compares these outcomes between the two procedures. An extensive cohort study found that neurological complications, including hip flexor pain and weakness, were comparable to those seen in patients undergoing LLIF [19]. However, a new neuromonitoring method carried out by one medical center provided 100% sensitivity and 89% specificity to predict femoral nerve deficits in the prone lateral approach. It also had a high negative predictive value, as no alert level changes intraoperatively provided a good prognosis. Thus, early identification of saphSSEP changes may provide surgeons with the opportunity to mitigate neurological complications for both approaches [31]. It is still important to acknowledge the limited studies available, which prevent a direct comparison between the two. Future studies should aim to address this gap in literature.

While the prone lateral approach leads to shorter surgery duration, implying potential cost benefits compared to the lateral position, it is crucial to consider individual patient characteristics when selecting the optimal approach. There is also some literature investigating the differences between the prone lateral approach and LLIF indicating that the prone lateral approach may be superior for patients with certain indications, such as large abdominal girth, transitional or complex anatomy, and revision procedures [32, 33]. Additionally, the greater volume of data and research available on

the lateral decubitus position compared to the single prone position can make it more enticing, as it offers a more established framework for clinical decision-making [34].

Conclusion

There is strong evidence supporting the safety, efficacy, and efficiency of the single prone position for lumbar interbody fusion procedures. Both the traditional LLIF and the single position prone LLIF approaches have distinct advantages and limitations in the context of spine fusion. However, direct comparisons between the prone lateral and LLIF approaches are limited, demonstrating a clear need for further investigation. The prone lateral approach may be superior for deformity correction procedures, specifically those that require improvements in sagittal alignment and lumbar lordosis. Since complex and multilevel surgeries often require both posterior and anterior access along with deformity correction, the prone lateral approach can potentially be indicated for these procedures. This approach results in a significant reduction in operative time, due to decreased repositioning, which results in improved patient outcomes. Future studies should be aimed at trying to understand the nuances between each approach and identifying the most appropriate choice for specific clinical scenarios.

Limitations of the prone lateral approach include post-operative neurological complications, special equipment requirements, and surgeon expertise training. Neurological complications are the most prominent; however, it is essential to note that these complications are often transient, and most studies indicate no long-term effects.

Authors' Contributions Freddy Jacome – Idea generation, manuscript research, writing, and preparation.

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David Hiltzik—Manuscript research and writing.

Sia Cho—Manuscript research and writing.

Manasa Pagadala – Manuscript research and writing.

Dr. Wellington Hsu – Idea generation, manuscript editing.

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Declarations

Competing Interests The authors declare no competing interests.

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