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IDEAS AND TECHNICAL INNOVATIONS

Prone single-position extreme lateral interbody fusion (Pro-XLIF): preliminary results

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Abstract

Background Single-position options for combined anterior and posterior fusion in the lumbar spine have been suggested to reduce the surgical time and improve the efficiency of operating room. Previous reports have focused on lateral decubitus single-position surgery. The goal of this study is to describe and evaluate the feasibility and safety of prone single-position extreme lateral interbody fusion (XLIF) with posterior fixation.

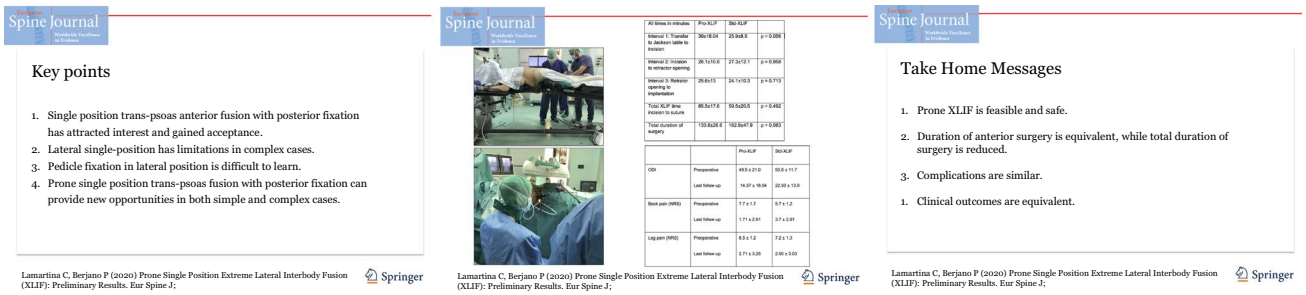
Methods *Design* Pilot prospective non-randomized controlled study. Seven patients who underwent prone single-position XLIF and posterior fixation were evaluated (Pro-XLIF). A control group (Std-XLIF) was composed of ten patients who underwent XLIF in lateral decubitus and posterior fixation in prone position. All patients underwent interbody XLIF fusion at one level and posterior procedures at one or more levels. Duration of surgery, blood loss, complications, X-ray use and clinical outcomes were recorded.

Results No major complications were observed in either group. Oswestry Disability Index, back pain and leg pain were improved in the Pro-XLIF group from 48.5, 7.7 and 8.5 to 14.5, 1.71 and 2.71, respectively, and in the Std-XLIF group from 50.8, 5.7 and 7.2 to 22.5, 3.7 and 2.5. The Pro-XLIF group had a longer time of preparation before incision (39 vs 26 min, ns), equal duration of the anterior procedure (65 vs 59 min, ns), shorter duration of surgery (133 vs 182 min, ns) and longer X-ray exposure time (102 vs 92 s, ns). The surgical technique is described.

Conclusions Prone single-position XLIF is feasible and safe. In this preliminary report, the results are comparable to the standard technique.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.



Keywords Prone LLIF · Direct lumbar lateral fusion · Minimally invasive spine surgery · Revision surgery

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Extended author information available on the last page of the article

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Introduction

Since it was first described by Ozgur et al. in [1], extreme lateral interbody fusion (XLIF) has become a standard surgical technique for the treatment of degenerative spine conditions.

The advantages of this technique include: (1) the indirect decompression of the neural elements, leaving the anterior and posterior longitudinal ligaments intact, (2) the restoration of the sagittal and coronal alignment of the spine, (3) a lower subsidence rate because of the implant of larger cages and (4) no damage caused to the paravertebral muscles compared to the conventional posterior arthrodesis and direct decompression techniques [2–9].

Compared to traditional posterior techniques, this approach is also advantageous in revision surgery cases as it allows to reach the vertebral bodies avoiding the scar tissue from previous interventions [3, 4, 10, 11].

This technique makes it possible to implant stand-alone cages and add an anterior fixation plate or, more commonly, posterior pedicle screw instrumentation, which provides major stability to the segment affected [6, 12, 13]. Should the latter option be chosen, surgery is normally performed in two stages: (a) the patient is placed in a lateral decubitus position and the cage is implanted via a retroperitoneal transpsoas approach; (b) with the patient in the same position, or after having turned the patient into the prone position, posterior pedicle screw fixation is performed [14].

The aim of our study is to report on the technique and to preliminarily assess the feasibility and safety of extreme lateral interbody fusion (XLIF) with the patient in prone position.

Materials and methods

Design Pilot prospective non-randomized controlled study.

Inclusion criteria Patients undergoing single-level XLIF and posterior fixation due to degenerative conditions or adjacent disc disease at a spine reference centre, operated on by one of the senior authors between April 2018 and April 2019, were included. Inclusion criteria were age 18 to 75, primary or revision surgery at the index XLIF level. Exclusion criteria were interbody fusion present at the index level, need for release of the anterior longitudinal ligament, infection, severe osteoporosis (T score < -3, 5), chronic inflammatory conditions, vascular, visceral or neural anatomy not compatible with transpsoas approach.

Patient allocation Patients were divided into two groups: prone position XLIF (Pro-XLIF) and standard, lateral decubitus position XLIF (Std-XLIF). Patients in the Pro-XLIF group first underwent interbody fusion in prone position and then a posterior procedure without changing the patient's position. Patients in the Std-XLIF group had the XLIF procedure in lateral decubitus position, followed by percutaneous pedicle screw posterior fixation in the same position or in prone position after shifting the patient. The allocation of patients to groups was based on surgeon's decision.

Data collection pre-operative and post-operative patient-reported outcome measures (PROMs), intraoperative data and complications were collected with the use of the institutional registry of spinal procedures, which was incepted in 2015. Data regarding C-arm usage were recorded from the C-arm software at the end of the procedure. One research assistant recorded the timing of the procedure and notes regarding difficulties found or intraoperative events and complications.

Data analysis Quantitative variables were compared with the Mann–Whitney (MW) nonparametric test, and statistical significance was set at the threshold of $p < 0.05$.

Ethics The study was approved by the local ethics committee.

Outcome variables Safety was evaluated by computation of complications and adverse events. Clinical outcomes were evaluated by pre-operative and post-operative Oswestry Disability Index and pain intensity (back and leg) with numeric rating scales from 0 (no pain) to 10 (maximum imaginable pain). Patients were scheduled to follow-up evaluations (FU) at 3, 6 and 12 months.

Surgical technique All patients received general anaesthesia. When possible, muscle relaxants were avoided. When they were needed, short-action ones were preferred. Quantitative train-of-four stimuli test was performed before incision in order to confirm the restoration of conduction through the neuromuscular plate. Directional triggered EMG stimulation (NV5^{TM}, Nuvasive Inc., San Diego, CA, USA) was used to map the position of the plexus during trans-psoas passage. Surgeons aimed to reproduce the same surgical steps and technique that have been described previously [14, 15]. The most relevant steps are as follows: patient positioning with the index disc transversal and sagittal axes in a clearly identifiable orientation (vertical and horizontal, respectively), 4-cm incision parallel to the disc on the lateral side of the patient, splitting of the three muscular layers of the abdominal wall, finger dissection to develop the retroperitoneal space to the lateral aspect of the psoas, dilatation through the psoas fibres with C-arm guidance and triggered EMG neuromapping, use of a standard retractor (Maxcess, Nuvasive Inc.), fixed with a shim to the disc space, discectomy, endplate preparation, trialing, and final implantation. Surgeons attempted to maintain retraction time into the psoas below 30 min in order to decrease the risk of neurapraxia of the lumbar plexus. Angled instruments were used when required to approach the L4–L5 disc space when the iliac crest position precluded a straight approach with standard straight instruments. Specificities of each group were as follows:

Fig. 1 Patient's position for Pro-XLIF

Fig. 2 Surgeon's position and operating room setting

Std-XLIF Patients were placed in strict lateral decubitus on an articulated Jackson table. Jackknife table break was reduced to the minimum that allowed clearance of the space between the ribs and the iliac crest. The interbody fusion was performed with a single lateral incision, with the surgeon standing on the back of the patient. Depending on the needs of the specific case, the posterior step of the procedure was performed in the same lateral decubitus position (percutaneous pedicle screw instrumentation) after changing the patient into prone position.

Pro-XLIF After general anaesthesia, patients were placed in prone position on a Jackson table with pelvic and chest supports, leaving the abdomen to hang freely (Fig. 1).

In some patients, in order to clear the area of the incision from the table, one additional silicone pad was placed between the anterior iliac spines and the iliac support of the table. The side of the transpsoas approach was decided on the basis of the width of the neurovascular window and/or the coronal inclination of the disc space, especially for the L4–L5 disc. In order to avoid displacement of the patient towards the opposite side during impaction of instruments and trials in the disc space (which would result in pulling back of the retractor), a bolster used for hip surgery was placed on the lateral side of the pelvis or greater trochanter, opposite to the side of the XLIF approach. In addition, for the same reason, the patient was taped to the table at the pelvis and at the thorax. The patient was prepared and draped in such a way to allow access to both the lateral and posterior incisions. For the interbody XLIF approach, the surgeon was standing or sitting on a stool on the side of the lateral incision (Fig. 2).

The C-arm was placed opposite to the surgeon with the X-ray source under the patient for anterior–posterior view. For the lateral view, the C-arm was rotated under the surgical table. After the incision, all the surgical steps were identical to the standard procedure: muscle splitting approach, finger dissection of the retroperitoneal space and dilatation of the psoas muscle with triggered EMG through the dilators. The retractor (Maxcess, Nuvasive Inc.) was fixed with an intradiscal shim anterior to the lumbar plexus and to the table with an articulating arm, paying attention to place it parallel to the floor. After the retractor was secured to the table and lateral and AP views were obtained with C-arm, the patient was tilted laterally towards the side opposite to the surgeon approximately 15°, in order to allow the surgeon for a more comfortable position. The angle was recorded, and the AP view of the C-arm was tilted accordingly in order to keep a true AP view. An anterior blade was placed anterior to the anterior longitudinal ligament, and the standard disc preparation and implantation were performed. All the Pro-XLIF operations in this series were performed with standard XLIF™ instruments and implants (Nuvasive Inc.).

Results

Seventeen patients were included in the study, 5 males and 12 females. Baseline characteristics of the patients are presented in Table 1. Average follow-up was 6 months (3–12).

We compared the two groups, placing a particular focus on the differences in duration of the surgical phases (Table 2) and the corresponding X-ray exposure in terms of number of spots and seconds of radiation (Table 3). Blood loss, complications and clinical outcomes are also reported (Tables 4 and 5). Examples of pre- and post-operative radiographs are shown in Figs. 3 and 4.

Table 1 Baseline characteristics of the patients

	Pro-XLIF	Std-XLIF
n	7	10
Age (years)	54.14 ± 15.16	53.53 ± 12.88
BMI (Kg/m^2)	27.14 ± 4.49	25.7 ± 4.02
Levels		
L3–L4	4	2
L4–L5	3	8
Diagnosis		
Degenerative spondylolisthesis	2	4
Isthmic spondylolisthesis	1	2
Adjacent segment	2	1
Degenerative disc disease (DDD)	1	3
Canal stenosis with DDD	1	

We registered 2 intraoperative complications, both in the prone group: one case of partial cage (Fig. 3) and the other case of rupture of the anterior ligament, which required the insertion of a cage with screw fixation to prevent migration. None of those complications had clinical consequences.

Regarding neurological events, 3 cases in each group had psoas weakness (grade 4/5) in post-operative day 1, and all resolved by post-operative day 4. At last follow-up, no patient had motor deficits. Four cases in Pro-XLIF had thigh hypoesthesia in postop day 1, one of them resolved by post-operative day 4 and 2 more resolved by post-operative month 3. One thigh hypoesthesia was not resolved at the time of this report. In the Std-XLIF group, 1 patient had

Table 2 Duration of surgical steps

	Pro-XLIF	Std-XLIF	
Interval 1: transfer to Jackson table to incision	39 ± 18.04	25.9 ± 8.5	$p = 0.056$
Interval 2: incision to retractor opening	26.1 ± 10.8	27.3 ± 12.1	$p = 0.958$
Interval 3: retractor opening to implantation	25.6 ± 13	24.1 ± 10.3	$p = 0.713$
Total XLIF time incision to suture	65.5 ± 17.6	59.5 ± 20.5	$p = 0.492$
Total duration of surgery	133.8 ± 26.6	182.8 ± 47.9	$p = 0.083$

Table 3 X-ray exposure

	Pro-XLIF	Std-XLIF	
Interval 1: pre-incision (level identification and patient positioning)	13 ± 7.1 shots 12.8 ± 6.4 s	22.5 ± 10 shots 20.6 ± 12.3 s	$p = 0.055$ $p = 0.181$
Interval 2: incision to retractor opening	85 ± 70.55 shots 49 ± 35 s	60.5 ± 30.9 shots 49.13 ± 31.8 s	$p = 0.933$ $p = 0.833$
Total X-ray incision to suture*	151.4 ± 99.8 shots 102.33 ± 41.9 s	108.25 ± 56.7 shots 92.13 ± 25 s	$p = 0.354$ $p = 0.755$

*After removal of one outlier in each group (325 shots in Pro-XLIF and 226 in Std-XLIF), the average total number of shots was 108 (Pro-XLIF) and 91 (Std-XLIF)

Table 4 Blood loss and complications

	Pro-XLIF	Std-XLIF
Estimated blood loss	105 ± 109.3	92.86 ± 67.2 ml
Transfusions	0	0
Intraoperative complications	1 cage subsidence 1 anterior ligament rupture and intraoperative cage displacement (resolved intraoperatively without consequences)	0
Post-operative complications		
Psoas grade 4/5 weakness postop day 1	3	3
Psoas weakness postop day 4	0	0
Thigh hypoesthesia postop day 1	4	1
Thigh hypoesthesia postop day 4	3 (2 resolved by month 3)	1 (resolved by postop month 3)

Table 5 Clinical outcomes

	Pro-XLIF	Std-XLIF
ODI		
Pre-operative	48.5 ± 21.0	50.8 ± 11.7
Last follow-up	14.57 ± 18.54	22.50 ± 13.9
Back pain (NRS)		
Pre-operative	7.7 ± 1.7	5.7 ± 1.2
Last follow-up	1.71 ± 2.91	3.7 ± 2.91
Leg pain (NRS)		
Pre-operative	8.5 ± 1.2	7.2 ± 1.3
Last follow-up	2.71 ± 3.25	2.50 ± 3.03

resolved at post-operative month 3.

Patient-reported outcomes were improved in both groups, and the improvement included intensity of back pain, intensity of leg pain and Oswestry Disability Index score (Table 5).

Discussion

This is the first report describing and assessing the feasibility and efficacy of single-position XLIF with pedicle screw fixation in prone.

Though single-position XLIF with pedicle screw fixation in the lateral decubitus position has gained some

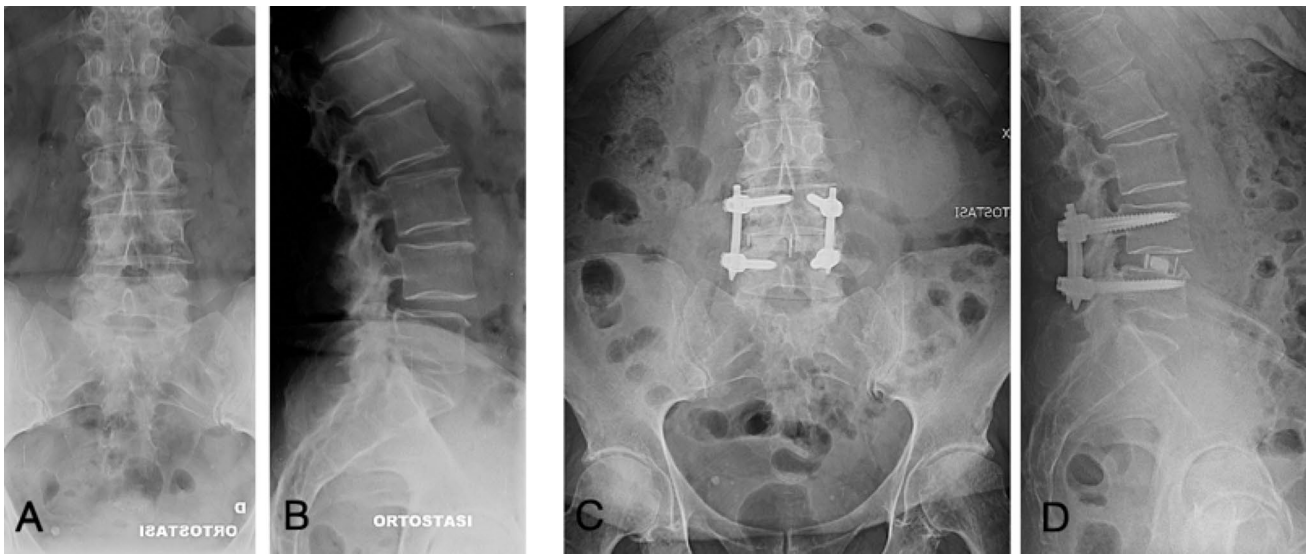

Fig. 3 A case of L4 degenerative spondylolisthesis (Pro-XLIF group). Slight cage subsidence was observed after insertion due to improper sagittal rotation of the cage. The construct was stable during follow-up without clinical consequences

thigh hypoesthesia at post-operative days 1 and 4, which

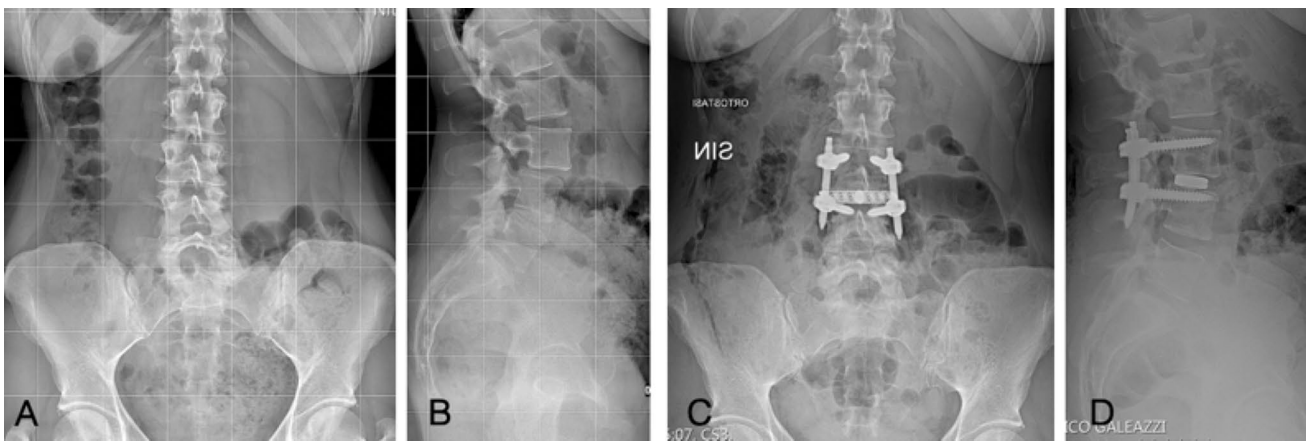

Fig. 4 A case of L3 degenerative spondylolisthesis (Pro-XLIF group)

acceptance and is being used for years now, few studies have been published on the topic [16, 17]. Single-position anterior interbody fusion and posterior fixation combine the advantages of both options (excellent anterior support, restoration of the lordosis and minimally invasive placement of the cage and solid pedicle screw fixation with percutaneous technique) while reducing the total time of anaesthesia, the number of manipulations of the patient to change position and the total surgical time and operating room occupation, which translates into improved surgical flow efficiency. Though attractive, this option has some disadvantages: percutaneous screw fixation in lateral decubitus does not belong to the standard surgeon's abilities and needs learning, its technical difficulty increases with longer constructs or constructs including the sacrum (not to speak about iliac screws), the position does not assist in promoting increase in lordosis, and control of the coronal plane is difficult. In addition, most surgeons practicing single-position lateral decubitus anterior and posterior procedures would consider just percutaneous pedicle screw fixation in the posterior approach.

Years of single-position lateral decubitus procedures has led the authors to believe that a single-position option for trans-psoas interbody fusion and posterior single- or multilevel procedures (including percutaneous or open screw fixation, implant removal, implant extension, decompression, posterior column or three-column osteotomies) might be a substantial contribution to more effective and efficient procedures. This is specially important in revision cases.

The results of this study show the feasibility of the XLIF procedure in prone position. The seven patients included in the study underwent successfully the interbody fusion without relevant complications and with clinical results and duration of surgery comparable to the standard lateral position group.

Though this result has been observed, it is important to remark that some peculiarities of the Pro-XLIF procedure have to be taken into account. First, the position of the patient cannot be easily modified into lateral flexion. This limitation is partly compensated by the fact that in prone position the spine is not flexed laterally versus the side of the approach (which is the main mechanism that reduces the space between the ribs and the iliac crest when the procedure is performed in lateral decubitus, making it necessary to provide jackknife adjustment). In addition, placing the spine into gentle lordosis further increases the rib–iliac crest distance, making easier the approach in neutral side bending. In case of high iliac crest, we have used angled instruments in order to approach properly the L4–L5 space. Second, movement of the patient towards the side opposite to the approach must be limited with a contralateral bolster. In this series, we introduced after case #3 a hip bolster on the contralateral greater trochanter in order to prevent the patient to move during impaction of instruments and implants (which in cases #1 and #2 caused the retractor to "mysteriously" back out in the wound). Third, standard instruments have been used for all the patients in this series. Though this means that what we achieved can be reproduced by other authors, it cannot be denied that development of some specific instruments may improve the reproducibility of the procedure.

Interestingly, in this series, we did not find that prone position caused additional difficulties to dissect the retroperitoneal plane or caused anterior migration of the lumbar plexus (especially at L4–L5), and the position of the retractor was considered satisfactory in all cases.

The finding of a longer pre-incision time in the Pro-XLIF procedure was unexpected. In fact, one of our hypotheses was that placing the patient in prone position would make the time to incision shorter compared to lateral decubitus placing, taping, jackknife bending, etc. We found that pre-incision time was nearly 15 min longer in Pro-XLIF. We believe that this might be due to the comparison of a well-defined procedure (positioning and targeting for Std-XLIF) with more than 400 cases performed by the team against a new procedure (needing to find out the right combinations of table supports, bolsters, patient's supports and OR setting in the first cases). Interestingly, after incision, all the steps of the anterior procedures had similar duration. (Average incision-to-suture time was 59 min in the Std-XLIF and 65 min in the Pro-XLIF group.) Blood loss and transfusions were equivalents, and there were no gross differences in complications, exception made of two minor events regarding cage placement. On the other side, the total duration of the procedure in the Pro-XLIF group was on average 50 min shorter than in the Std-XLIF group, confirming the improvement in duration of surgery provided by single-position surgery.

The effect of the learning curve in Pro-XLIF translated as well into higher number of C-arm shots and X-ray total time compared to the Std-XLIF group. Whether this difference will be reduced with increased experience must be evaluated with further studies.

In a recent literature review on 39 articles treating XLIF, Walker et al. [18] reported a mean surgical XLIF time, inclusive of the posterior pedicle screw fixation, of 203.6 ± 64.8 min. In our study, we registered an overall surgical time in the STD-XLIF of 182.8 ± 47.9 min, which was approximately 50 min longer than the prone group (133.8 ± 26.6 min).

Walker et al. [18] highlighted the main neurological complications of XLIF and found a mean rate of transient hip flexion weakness of 19.7% (range 0 to 54.9%), transient anterior thigh sensory symptoms of 21.7% (range 0 to 50%) and lasting motor neurological weakness of 2.8%. Our results on the 17 patients analysed were quite similar to those reported in this recent review: 6 patients (35.2%; 3

in the STD-XLIF and 3 in the PRO-XLIF) had hip flexion weakness in the immediate post-operative period, but all those cases regressed spontaneously *by post-operative day 4*. Considering only the PRO-XLIF, we had no cases of permanent hip flexion weakness nor lower limb strength loss and only 1 patient (14.2%) had anterior thigh hypoesthesia 3 months after surgery.

Average improvements in back pain, leg pain and ODI score were large and similar across groups. We do not present statistical comparisons because the heterogeneity of the samples and the small numbers make difficult to draw any conclusions regarding clinical outcomes. Furthermore, this feasibility study did not hypothesize a superior clinical outcome of Pro-XLIF compared to Std-XLIF. Such comparisons must wait for larger studies conceived ad hoc to test a hypothesis of superiority.

However, our study showed clinical outcomes comparable to other studies evaluating XLIF. Khajavi et al. [19] reported their clinical results on a cohort of 160 patients and described improvements in VAS back, leg and ODI scores of, respectively, 59% (from 6.9 to 2.8), 56% (from 7.1 to 3.1) and 47% (from 44.1 to 23.5). The same encouraging outcomes following XLIF surgery were reported by Tohmeh et Al on 140 patients with the following results: VAS back went from 7.5 to 3.8 (49% improvement), VAS leg went from 6 to 3.1 (48% improvement), and ODI score lowered from 46.1 to 25.6 (44% difference) [5].

Mechanical complications were observed in the Pro-XLIF group, and both instances were related to disc preparation and cage placement. We registered one case of intraoperative subsidence in the prone group. Cage subsidence is a well-known possible complication of interbody fusion that prevents the surgical goals of sagittal realignment, neural indirect decompression and interbody fusion to be reached; however, the subsidence observed in one of our cases did not seem to affect the clinical outcome. Actually, our case of subsidence was followed by a good clinical outcome with the patient's VAS back, leg and ODI scores improving, respectively, from 6 to 4, 10 to 1 and 60 to 28 at the last FU.

In this study, we learned that XLIF in prone position is feasible. Some technical refinements and specific instruments may improve the efficiency and reproducibility of the procedure. Potentially, Pro-XLIF provides a new opportunity to use the advantages of trans-psoas interbody fusion in simple degenerative cases but also in complex degenerative or deformity cases, long fusions, patients with posterior implants, adjacent segment disease, other instances of revision surgery, and subjects who need osteotomies of the spine in combination with anterior procedures. Not least, it opens an opportunity for simultaneous anterior and posterior manipulation.

This study has some limitations. The number of cases is small, allocation was not randomized nor concealed, and the authors involved in data analysis were not blinded to the arm of treatment. For these reasons, comparisons between groups must be made cautiously, taking into account the risk of bias. Moreover, the results presented are not representative of the potentialities of Pro-XLIF but of its earliest stage of evolution.

Conclusion

XLIF in single prone position (Pro-XLIF) is a feasible technique. Major complications have not been observed in this preliminary study. Single-position prone XLIF reduced the overall surgical time with similar clinical results.

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Compliance with ethical standards

Conflict of interest Dr Claudio Lamartina has received honorarium as consultant from Nuvasive, DePuySynthes, Medacta, K2M and Royalties from Nuvasive and Medacta. Dr Pedro Berjano has received honorarium as consultant from Nuvasive, DePuySynthes, Medacta, K2M and Royalties from Nuvasive.

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