

# Preliminary Results of Minimally Invasive Decompression, TLIF and Percutaneous Pedicle Screw Insertion in Stenotic Spondylolisthesis with Severe Facet Joint Osteoarthritis

Eleftherios Archavlis<sup>1\*</sup>, Mario Carvi Y Nievas<sup>2</sup> and Peter Ulrich<sup>1</sup>

<sup>1</sup>Department of Neurosurgery, Sana Klinikum Offenbach, Akademisches Lehrkrankenhaus der Universität Frankfurt, Germany

<sup>2</sup>Department of Neurosurgery, Klinikum Frankfurt Hoechst, Akademisches Lehrkrankenhaus der Universität Frankfurt, Germany

## Abstract

**Object:** Minimally invasive spine (MIS) procedures are increasingly being recognized as equivalent to open procedures with regard to clinical and radiographic outcomes. These techniques are also believed to result in less pain and disability in the immediate postoperative period. There are, however, little data to assess whether these procedures in combination with minimally invasive transforaminal interbody fusion (MI-TLIF) and percutaneous pedicle screw insertion are effective in complex cases of stenotic degenerative spondylolisthesis with severe facet joint osteoarthritis (FJO).

**Methods:** This study retrospectively reviewed all patients who underwent lumbar instrumentation, fusion and decompression for degenerative spondylolisthesis with severe stenosis and facet joint osteoarthritis (FJO) between June 2010 and June 2011. Blood loss, operative time and intraoperative complications were assessed in all surgically treated patients who were treated with MIS decompression, MI-TLIF and percutaneous transpedicular instrumentation. Clinical outcome was measured using the Oswestry Disability Index (ODI) and Visual Analogue Scale (VAS) for back pain, leg pain, and activity level. Satisfaction was assessed with VAS for satisfaction. Radiological follow-up includes x-ray films, computed tomography and in some cases magnetic tomography scan.

**Results:** Twenty four cases with severe stenotic changes accompanied by severe FJO were treated with minimally invasive procedure. The minimum follow-up was 6 months with a mean of 8 months. The mean preoperative ODI score was 46.8, decreasing to a mean of 23 postoperatively. The mean VAS leg and back pain scores were 67.5 improving to means of 25.8. Twenty one out of 24 cases experienced a clinical benefit according to VAS for satisfaction and ODI. Complications included wound healing disturbance (4%), CSF fistula (4%) and contralateral radiculopathy due to articular bone spurs (8%). The accuracy of pedicle screws was high and only one revision surgery was performed.

**Conclusion:** MIS for severe stenotic spondylolisthesis leads to adequate and safe decompression of lumbar stenosis and results in a highly significant reduction of symptoms and disability. MIS-TLIF and percutaneous pedicle screw insertion constitute a promising treatment alternative for patients with severe stenosis and facet joint osteoarthritis.

**Keywords:** Minimally invasive transforaminal interbody fusion; Spondylolisthesis; Lumbar stenosis; Facet joint osteoarthritis

**Abbreviations:** CSF: Cerebrospinal Fluid; CT: Computerized Tomography; EBL: Estimated Blood Loss; FJO: Facet Joint Osteoarthritis; LBP: Low Back Pain; MR: Magnetic Resonance; MIS: Minimally Invasive Surgery; MI-TLIF: Minimally Invasive Transforaminal Interbody Fusion; SD: Standard Deviation; VAS: Visual Analog Scale

## Introduction

A basic principle of minimally invasive spine surgery (MIS) is to effectively treat pathology with minimal disturbance of normal anatomy, although some reports suggest that the limited exposure that results from these techniques can result in incomplete treatment of pathology with no clear-cut advantage over traditional techniques [1,2]. The avoidance of complications is more challenging through limited surgical portals [1]. Failure surgery and reoperation rates can increase, especially in the field of lumbar instrumentation [3,4]. In spite of these challenges, the evolution of MIS has exceeded that of traditional spine procedures over the past 2 decades [5-10].

The area of greatest controversy, however, is the handling of cases with degenerative spondylolisthesis with severe stenosis of the spinal canal [11]. The presence of severe arthritic changes of the facets is characteristic in many of these patients [12]. Some authors prefer to perform a laminectomy without fusion. It is argued that fusion after laminectomy is necessary to prevent instability and postoperative complications [13]. Some authors prefer the open interbody fusion and

instrumentation in cases of spondylolisthesis with severe stenosis and spondylarthrosis [13-15]. There is growing evidence that circumferential support through TLIF offers the advantage of avoiding the cost and morbidity of an anterior approach while providing equivalent clinical results with a lower rate of perioperative complications than PLIF [16]. Several studies have reported the favorable outcomes of MI-TLIF accompanied by spinal instrumentation with percutaneous pedicle screw insertion and decompression in degenerative spondylolisthesis [9,10,14,17]. In the presence of severe spinal canal stenosis and distorted facet anatomy due to severe FJO, MIS techniques however could limit direct visualization of neural elements and pedicle screws relative to key anatomical structures and could increase the rate of complications and pedicle screw misplacement. Hsieh et al. reported the feasibility of MIS in several cases of complex spinal disorders such as spinal

\*Corresponding author: Eleftherios Archavlis, Department of Neurosurgery, Sana Klinikum Offenbach, Akademisches Lehrkrankenhaus der Universität Frankfurt, Starkenburgring 66, 63069 Offenbach, Germany; Tel: 0049 178 9160743; Fax: 0049 69 8405 3143; E-mail: [neurosurgery@t-online.de](mailto:neurosurgery@t-online.de)

Received August 26, 2013; Accepted September 27, 2013; Published September 30, 2013

**Citation:** Archavlis E, Carvi y Nievas M, Ulrich P (2013) Preliminary Results of Minimally Invasive Decompression, TLIF and Percutaneous Pedicle Screw Insertion in Stenotic Spondylolisthesis with Severe Facet Joint Osteoarthritis. J Spine S5: 004. doi:10.4172/2165-7939.S5-004

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trauma, spinal deformities, and spinal oncology [18]. Some previous studies report that MIS techniques may achieve superior clinical results with reduced postoperative pain, narcotic use, and hospital length of stay, however, the impact of MIS on outcome for the more complex degenerative spondylolisthesis cases is not yet well studied [19,20].

The aim of the present study was to report data pertaining to MIS decompression, MI-TLIF and percutaneous pedicle screw insertion in spondylolisthesis with severe stenosis and FJO, with particular focus on short term results, accuracy of pedicle screw insertion and incidence of complications.

## Methods

### Patient population

We conducted a retrospective analysis of prospectively collecting data from consecutive patients at a single center (Sana Klinikum Offenbach, University of Frankfurt) who underwent single-level percutaneous pedicle screw insertion, MIS-decompression and TLIF, between June 2010 and June 2011, with the following inclusion criteria: 1) symptoms of neurogenic claudication or radiculopathy or incapacitating back pain refractory to adequate conservative treatment; 2) degenerative spondylolisthesis Meyerding grades I-II (Meyerding classification [21]); 3) FJO Pathria Grade 3 (Pathria et al. [8]); 4) spinal stenosis at the affected level grade C and D (Schizas et al. [9]).

A total of 24 patients fulfilled the inclusion criteria of our study and all patients completed the follow-up visit. Symptoms were considered refractory to non surgical management if conservative measures, particularly non-steroidal anti-inflammatory drug and physical therapies, had been administered for at least 2 months without sufficient improvement. The severity of vertebral displacement was estimated according to the grading criteria of Meyerding [21]. The four-point scale that Pathria devised for radiographic grading FJO was used to delineate the severity of facet disease [8]. Radiographically, normal facets were classified as grade 0. Facets with joint space narrowing were classified as grade 1, facets with narrowing plus sclerosis or hypertrophy as grade 2, and facets with severe degenerative disease encompassing narrowing, sclerosis, and osteophytes as grade 3. The severity of lumbar spinal stenosis at the affected level was based on the morphology of the dural sac on magnetic resonance images according to Schizas et al., who described a 7-grade classification based on the morphology of the dural sac as observed on T2 axial magnetic resonance images based on the rootlet/cerebrospinal fluid ratio. Grades A and B show cerebrospinal fluid presence while grades C and D show none at all [9].

Contraindications for the minimally invasive approach (and the patients with these contraindications were treated by traditional open surgery) included 1) the patients with high-grade (grade III/IV) spondylolisthesis, 2) the patients who needed multi-level decompression and fusion, 3) the patients with combined coronal and/or sagittal deformities (kyphoscoliosis) that needed a correction, and 4) the patients who had back disease involving trauma, infection or other pathologic causes.

Neither lateral and foraminal stenosis nor segmental instability were considered as contraindications for MIS.

### Preoperative assessment

All patients underwent a standardized neurological and clinical assessment to evaluate walking distance, pain was measured separately for the low back and the legs according to a self-assessment on a 100-mm horizontal line with 0 equal to "no pain," and 100 equal to "very

severe pain" [10]. Disability was assessed using the Oswestry Low Back Pain Disability Questionnaire (ODI), which has been validated and reported on for German-language speakers. The ODI was scored on a 0–100 scale, 0–20 equates to minimal disability, 20–40 moderate disability, 40–60 severe disability, 60–80 crippled, and 80–100 bed-bound or exaggerating.

To evaluate neurologic deficit, we analyzed this parameter on a 3-point scale, absent (without motor or sensory deficit), mild (motor deficit grade 4 or sensory deficit) and severe (motor deficit grade 0–3).

Radiological/neuroimaging work-up included MR imaging, myelography, and postmyelography CT scanning for identification of the involved segments.

### Assessment of intraoperative parameters

Intraoperative parameters such as duration of the procedure, Estimated Blood Loss (EBL), and intraoperative complications (for instance, incidental durotomy) were analyzed on the basis of operative records.

### Surgical Technique of percutaneous instrumentation, MAST-decompression and TLIF

Surgical access for interbody fusion was obtained using a tubular retraction system (Quadrant, Medtronic Sofamor Danek). Pedicle screws and rods were placed percutaneously (CD Horizon Sextant, Medtronic Sofamor Danek). In cases that spondylolisthesis could not be reduced through distraction of the disc space, a reduction screw extender allowed for reduction. In each case the patient was positioned prone on a spinal surgery table. In some cases, positioning alone resulted in some degree of postural reduction. Intra-operative 2D C-arm guidance was integrated with navigation software (2D Fluoro navigation, Brainlab) and enabled the surgeon to navigate relative to preoperative CT data after registration and matching with intraoperative two plane fluoroscopy. For that purpose, a reference pin kit was placed at the spinal process of the affected vertebra, through a 1 cm midline skin incision on the dorsal skin surface. A detailed description of the procedure is available in the literature [16].

The site of MI-TLIF was determined according to the side of main symptomatology, the central and contralateral decompression was performed by bending the tubular retractor medially. After discectomy, the empty disc space was filled initially with Tri-Ca-Phosphate as well as local autograft, leaving a channel for an interbody implant. An appropriately sized polyetheretherketone (PEEK) interbody implant was selected and filled with autograft from the resected lamina. The implant is convex-shaped to allow reduction (Capstone, Medtronic). Of note, even in patients with Grade II spondylolisthesis, an attempt was made to fully reduce the slippage after adequate disc space distraction had been achieved. All procedures were done in a strictly standardized step-by-step fashion. All surgical procedures were performed by the same consultant neurosurgeon (EA).

All patients received a single intravenous dose of an antibiotic agent and a wound drain placed subfascial.

### Radiological assessment

The accuracy of pedicle screws was estimated with postoperative CT. Evaluation of screw placement was performed according to the criteria published by Learch [22] modified to include assessment in the coronal and sagittal reformat images [23]. A screw was classified as cortical encroachment if the pedicle cortex could not be visualized and if bone in excess of 2-mm was visible on the opposite direction.

Frank penetration was defined when not only the cortex was invisible but also when the screw trajectory was obviously outside the pedicular boundaries. Frank penetration was further subdivided and defined as minor (less than half of the screw thread), moderate (less than the full screw thread) and severe (more than one screw diameter) [23].

Radiographic assessment of solid fusion was not performed because of the short term follow-up.

### Outcome assessment

Pain (VAS score) and walking distance were recorded. Patient satisfaction was also assessed according to a self-assessment on a 100-mm horizontal line with 0 to 49 equivalent to “not satisfied”, 50 equal

to “neither satisfied nor dissatisfied”, 51-75 “satisfied”, and 76 to 100 equivalent to “very satisfied”. Functional disability was quantitatively measured using the Oswestry Low Back Pain Disability Questionnaire (ODI). Both the VAS and ODI were prospectively acquired. The subjective postoperative symptoms documented at each postoperative visit were divided into 4 categories: symptom free, back pain only, leg pain only and both back and leg pain. Patients presenting with significant residual or recurrent symptoms underwent postoperative MR imaging. Perioperative morbidity included reoperations within 30 days and the presence of an increased postoperative radicular deficit. In order to assess the functional outcome, we used a functional scale as described by Whitecloud et al. (excellent, good, fair and poor) [24].

Radiological and outcome assessment were performed by a single author (EA).

### Statistical analysis

Statistical analysis was performed using an unpaired t-test for parametric variables. Categorical variables were analyzed in contingency tables using the Fisher exact test. Results with  $p < 0.05$  were considered significant. All calculations were made with standard commercial software (BiAs)

### Results

#### Patient characteristics

The minimal invasive procedure was performed in 24 patients. Patient characteristics, including age, sex and presence of neurologic deficits according to the primary admission diagnosis are shown in Table 1.

All patients underwent decompression at a single level. 58 percent had a left-sided and 42% had a right-sided approach. 2 patients had concomitant synovial cyst excision. 62.5% of patients (n = 15 of 24) in the study had at least 1 significant medical comorbidity. Follow-up was obtained in all patients. The overall preoperative ODI score was 46.8.

#### Intraoperative parameters

The scheduled procedure was adhered to in all patients. In one case we had to change the side of MI-TLIF because of a con-joined nerve root which made the approach to the lumbar disc very difficult with high risk of neurologic deficit. The mean surgical time for the minimal invasive procedure was 230 (SD ± 48) minutes. The EBL was 185 (SD ± 140) ml. One patient required a blood transfusion due to prolonged surgery. There were no conversions to an open procedure.

#### Complications of MIS

Complications after MAST are shown in Table 2. An intraoperative incidental durotomy occurred in 1 (4%) patient. This occurred at the beginning of the authors experience with this technique. Self-closing nitinol U-clips (Medtronic, Inc., Minneapolis) were used for closing the dural tear through the MIS approach that could make a conventional microsuturing technique very difficult. Postoperative complications included 1 patient with pedicle screw misplacement with no neurologic sequelae, 1 patient with wound healing disturbance and 2 patients with contralateral foraminal encroachment syndromes due to osteophytic spurs arising from the facet joint and impinging the nerve root. There were no perioperative deaths.

#### Outcome

The mean VAS leg and back pain scores improved from a mean of 67.5 to 25.8, thus, MI-TLIF resulted in a significant reduction of

| Parameters                                      |                   | Value    |
|---|-------------------|----------|
| no. of cases                                    |                   | 24       |
| Age (mean ± SD)                                 | in years          | 67 ± 8   |
| Sex (female), n (%)                             | no. of cases      | 14(58.3) |
| Body mass index (mean ± SD)                     | kg/m <sup>2</sup> | 28 ± 6   |
| Standard follow up (range)                      | in months         | 8 (6-12) |
| Spondylolisthesis Meyerding Grade               | no. of cases      |          |
| Grade 1   |                   | 18       |
| Grade 2   |                   | 6        |
| Level   | no. of cases      |          |
| L3-4  |                   | 2        |
| L4-5  |                   | 16       |
| L5-S1   |                   | 6        |
| Duration of symptoms                            | in months         |          |
| LBP   |                   | 31 ± 27  |
| Leg pain  |                   | 17 ± 9   |
| neurogenic claudication                         |                   | 15 ± 4   |
| Symptoms  | no. of cases      |          |
| LBP   |                   | 17       |
| Leg pain  |                   | 19       |
| neurogenic claudication                         |                   | 20       |
| Neurologic deficit                              | no. of cases      |          |
| absent  |                   | 15       |
| mild  |                   | 4        |
| severe  |                   | 5        |
| Walking distance                                | no. of cases      |          |
| <500 meters                                     |                   | 12       |
| 500-1000 meters                                 |                   | 8        |
| >1000 meters                                    |                   | 4        |
| Medical history                                 | no. of cases      |          |
| Cardiovascular disease                          |                   | 2        |
| Diabetes  |                   | 4        |
| Thromboembolism                                 |                   | 1        |
| Hypertension                                    |                   | 6        |
| Asthma or chronic obstructive pulmonary disease |                   | 2        |

Table 1: Patient’s characteristics.

| Pt. | Initial Meyerding Grade | postoperative Meyerding grade | initial VAS back/leg | VAS back/leg at last F/U | Complications                         | VAS satisfaction | ODI initial | ODI at last F/U |
|-----|-------------------------|-------------------------------|----------------------|--------------------------|---------------------------------------|------------------|-------------|-----------------|
| 1   | 1                       | 0                             | 80                   | 40                       | no                                    | 60               | 50          | 28              |
| 2   | 1                       | 0                             | 60                   | 10                       | CSF fistula                           | 60               | 40          | 10              |
| 3   | 2                       | 0                             | 60                   | 20                       | no                                    | 90               | 45          | 20              |
| 4   | 1                       | 0                             | 70                   | 30                       | no                                    | 70               | 40          | 24              |
| 5   | 2                       | 1                             | 70                   | 30                       | no                                    | 80               | 50          | 30              |
| 6   | 1                       | 0                             | 60                   | 10                       | wound healing disturbance             | 60               | 40          | 10              |
| 7   | 1                       | 1                             | 70                   | 40                       | radiculopathy contralateral           | 50               | 50          | 24              |
| 8   | 1                       | 0                             | 60                   | 10                       | no                                    | 90               | 40          | 16              |
| 9   | 1                       | 0                             | 70                   | 50                       | revision contralateral redcompression | 50               | 55          | 26              |
| 10  | 1                       | 0                             | 80                   | 10                       | no                                    | 90               | 48          | 12              |
| 11  | 2                       | 0                             | 60                   | 20                       | no                                    | 80               | 40          | 20              |
| 12  | 1                       | 0                             | 60                   | 0                        | no                                    | 90               | 44          | 24              |
| 13  | 1                       | 0                             | 70                   | 50                       | revision pedicle screw                | 40               | 60          | 42              |
| 14  | 1                       | 0                             | 80                   | 40                       | no                                    | 60               | 50          | 28              |
| 15  | 2                       | 0                             | 60                   | 20                       | no                                    | 90               | 45          | 20              |
| 16  | 1                       | 0                             | 70                   | 30                       | no                                    | 70               | 40          | 24              |
| 17  | 2                       | 1                             | 70                   | 30                       | no                                    | 80               | 50          | 30              |
| 18  | 1                       | 1                             | 70                   | 40                       | no                                    | 50               | 50          | 24              |
| 19  | 1                       | 0                             | 60                   | 10                       | no                                    | 90               | 40          | 16              |
| 20  | 1                       | 0                             | 70                   | 50                       | no                                    | 50               | 55          | 26              |
| 21  | 1                       | 0                             | 80                   | 10                       | no                                    | 90               | 48          | 12              |
| 22  | 2                       | 0                             | 60                   | 20                       | no                                    | 80               | 40          | 20              |
| 23  | 1                       | 0                             | 60                   | 0                        | no                                    | 90               | 44          | 24              |
| 24  | 1                       | 0                             | 70                   | 50                       | no                                    | 40               | 60          | 42              |

**Table 2:** Initial and Follow-up Radiographic/Clinical Data.

overall pain ( $p < 0.001$ ). Differentiating between low back pain and leg pain revealed no differences in improvement. Neurogenic claudication improved in 91% of the patients ( $p < 0.001$ ). Walking distance varied greatly among individual patients, but overall ambulation recovered significantly from a mean of 250 (SD  $\pm$  200) to a mean of 3100 (SD  $\pm$  3540) ( $p < 0.001$ ).

Average clinical improvement in ODI was 50.8% for the entire cohort (46.8% before surgery to 23% after surgery) at a mean of 8 months follow-up (range 6 –12), demonstrating a marked and significant improvement ( $p < 0.001$ ).

Overall, 79.8% patients were satisfied (60.7% very satisfied, 9% satisfied) with their treatment; 12.7% were dissatisfied and 9.5% were neither satisfied nor dissatisfied. Twelve out of 24 showed no symptoms at the final follow-up. Additionally, 19 patients (85%) showed excellent or good results according to the functional scale.

### Radiology

There were 18 patients who had a grade I spondylolisthesis and 6 with grade II. The slip was anatomically reduced in grade I patients by 100% in 15 patients and between 90% and 95% in 3. In grade II, 100% anatomical reduction was achieved in 4 patients and between 90% and 95% in 2 patients.

In the axial and coronar images, one screw showed frank pedicle penetration laterally, classified as severe and produced clinical symptoms of progressive low back pain. Revision surgery was performed 2 weeks later. Eight screws encroached the pedicular cortex without frank penetration (3 medially, 4laterally, 1 cranially).

The patient with franc penetration made an uneventful recovery. This case was not encountered in the beginning of our learning curve but on our thirteenth procedure.

No evidence for loss of correction was observed in the follow-up.

As mentioned above we avoid intentionally to report about radiographic solid fusion rates because of the short term follow up.

### Revision rate

The revision rate at a mean of 6 months (range, 3 – 8 months) from surgery was 10%, which included either repeat decompression alone ( $n=1$ ) or pedicle screw revision ( $n=1$ ).

Two patients complained about contralateral neuropathic pain after surgery. Postoperative CT scanning demonstrated sufficient decompression of the central stenosis, however, newly emerged osteophytic spurs arising from the facet joint and impinging the nerve root was made responsible for the contralateral foraminal encroachment. We performed repeat decompression in one patient, and percutaneous periradicular nerve root infiltration therapy in the other, both of which had complete permanent resolution of symptoms.

Before revision, the revised patients ( $n=2$ ) had an ODI that was 57.5%. For these patients the mean ODI preoperative was 42.5%. Following revision, these patients had a mean ODI of 34% at their latest follow-up.

### Discussion

Decompression, stabilization and fusion are known to be effective in degenerative spondylolisthesis [13]. In current surgical practice, the majority of patients with degenerative spondylolisthesis undergo an instrumented fusion [15]. In the recently reported spine patient outcomes research trial (SPORT) on degenerative spondylolisthesis only 5% of patients underwent decompression alone [15]. Based on the available literature, fusion in this population is supported, however, not absolute [11]. There is controversy concerning the surgical approach in

order to achieve fusion and the necessity of MIS procedures [4,9,11]. Because of a reduced destruction of the soft tissues, proponents of these MIS techniques claim to achieve superior clinical results with reduced postoperative pain, narcotic use, and hospital length of stay [1]. On the other hand, performing percutaneous instrumentation, fusion and decompression in complex cases with severe arthritic and stenotic changes could increase the complication rate and lower the accuracy of pedicle screw insertion [18]. We performed the current analysis to evaluate feasibility and to provide data for complication rates in these patients.

Degenerative spondylolisthesis often coincides with other consequences of spinal degeneration such as spinal stenosis, disc prolapse and instability, facet joint arthritic changes, resulting in a heterogeneous patient population [12]. Moreover the severity of the central spinal stenosis, facet osteoarthritis and foraminal narrowing can significantly differ between patients [17]. Consequently, it has been suggested that the procedure should be tailored to each patient depending on imaging findings and symptoms-for example, ventral approaches in cases of high grade spondylolisthesis or unilateral approaches in cases of unilateral symptoms [13,16]. The authors of previous studies of MIS and especially MI-TLIF have commonly neglected the heterogeneity of the patient population by including such complex cases in the patient population without differentiating the efficacy of the surgery on these patients [9,15,25]. Other authors either a priori excluded such complex cases from performing MIS techniques or recommended that MIS should be performed at the discretion of the surgeon [2]. This may, of course, reflect the patient's individual situation, but it prevents the drawing of solid conclusions regarding the efficacy of MIS techniques in comparison to open procedures.

In order to minimize the heterogeneity of the patient population, only high grade FJO (Pathria grade 3) and high grade spinal stenosis (grade C and D according to Schizas et al.) were included in this study. High grade spondylolisthesis was excluded in the present study.

### **Intraoperative parameters**

Open TLIF is considered a simple and fast fusion technique, whereas MI-TLIF, especially in spondylolisthesis with severe FJO could be associated with technical challenges and longer operative duration. Weinstein et al reported by the SPORT study an operative duration of 210.4 (SD  $\pm$  81.1) minutes. In our study, the duration of surgery was proved to be 230 (SD  $\pm$  48) minutes which was comparable with the time described in the SPORT study. Concerning blood loss in open TLIF, Weinstein et al reported 569.2 (SD  $\pm$  425.4) ml, requiring transfusion in 62 of the 178 cases in the randomized cohort (35 %). It is of note that 27% of the randomized control group of the SPORT study received a multilevel fusion [15]. While in this study we evaluated only a single level fusion, all cases included were demanding because of the high grade of stenosis and FJO. This, however, did not translate in excessive operative time, EBL or perioperative morbidity. Blood loss was clinically insignificant ( $185 \pm 210$ ), requiring transfusion in only one case.

### **Complications and reoperations**

The authors of comparative studies involving open and MIS techniques for interbody fusion have reported complication rates that were comparable but the sizes of populations have been small and the studies were mostly retrospective or lacked a control group [3,5,7,14,26]. A quantitative meta-analysis of Wu et al. revealed similar fusion and complication rates [27] but in some studies of less invasive techniques, however, investigators revealed an increase in perioperative morbidity,

namely neurological sequelae [6] or contralateral radiculopathy although the proportion of complications was comparable. Therefore, the main concern of spine surgeons in view of MIS techniques has been an increased rate of neural injury. In the series reported by Schwender et al., a postoperative increased radicular deficit was observed in 2/49 cases (4.1%) of MIS decompression and interbody fusion cases (one from graft dislodgement, the other from contralateral neuroforaminal stenosis) [17]. According to our data, actual injury to a nerve root did not occur. Intraoperative manipulation and/or compression of nerve roots, however, may provoke radicular deficit postoperatively. Weinstein et al. [15] reported nerve-root injury as postoperative complication in 1% of cases. We observed in two patients, postoperatively, a contralateral foraminal encroachment syndrome due to osteophytic spurs arising from the facet joint and impinging the nerve root. We think that these patients with high grade FJO might have a higher risk of postoperative foraminal encroachment contralateral to the decompression entry. Larger series are needed to further evaluate this matter. In our opinion, a bilateral facetectomy through a MIS approach should be done in selected cases.

Unintended durotomy is another concern during spinal decompressive procedures, although no association with long-term sequelae has been found. Overall, durotomy rates for laminectomy have been shown to range from 5 to 15%. This rate is reported (1%) by SPORT study for spinal stenosis and degenerative spondylolisthesis where conventional open techniques were performed for the majority of patients [15]. The results of the present study, namely 4% are underscoring that MI-TLIF and MIS decompression through a unilateral approach although technically demanding, carry a low risk of unintended durotomy.

Potter et al. demonstrated a wound infection rate of approximately 2% in open TLIF cases [12], and this complication was also rare in our study with 4%. As far as the accuracy of pedicle screws is concerned, in a study of computer tomography assessment of percutaneous pedicle screw insertion, Schizas et al. reported an overall rate of screw perforation of 30 % with an incidence of severe frank pedicle penetration of 3.3% as seen on axial and coronar images. 13% of the patients (2/15) had severe frank penetration from the screws, while 80% of them (12/15) had some perforation [22]. Schwender et al. reported screw malposition requiring repositioning in 2/49 (4.1%) [17]. In the present study, we found a severe frank pedicle penetration of 1% (1/96) of all pedicle screws. 4% of our patients (1/24) had severe frank penetration from the screws, while 50% of them (12/24) had some perforation. The low frank penetration rate in our study may be partly due to the use of cannulated pedicle screws and computer-assisted image guidance. We used in particular, the more recent ability to fuse preoperative CT scans with intraoperative fluoroscopic imaging.

In the recently reported SPORT study on surgical versus nonsurgical treatment of degenerative spondylolisthesis, Weinstein et al. reported an overall revision rate of 12% of the surgically treated group at 2 years [15]. Within the methodological limitations of historical comparisons, and the fact that we demonstrate preliminary results after 8 months, the surgical revision rate in our study of 8% seems comparable to the SPORT study.

In summary, the MI-TLIF in complex and surgically demanding cases was neither associated with an increased rate of postoperative nerve deficits nor a high rate of other complications.

### **Outcome assessment**

Literature analysis of open interbody fusions by using metaanalysis

or Cochrane Review proved very challenging because measuring outcomes in musculoskeletal disorders is extremely problematic [13] and outcome variables as well as definition of (good/bad) outcome varied considerably among studies [14,15,25]. In the present study, analysis of outcome was based on the VAS for pain and satisfaction and the ODI for disability. MI-TLIF resulted in a significant reduction of overall pain ( $p < 0.001$ ).

In the recently reported SPORT study, Weinstein et al. reported absolute improvements of 30% in scores of back pain and 43% in scores for leg pain (on 7-point scale) which remained for 4 years after surgery [15]. These results are similar to the improvements of 61.4% and 61.5% (on VAS scale), respectively seen in our study at 8 months.

In a retrospective study, Park et al., found excellent or good outcomes after 36.1 months in 88% of their 24 patients [1]. In the present study, the rate of patient satisfaction, and improvement of neurogenic claudication after MI-TLIF was 79.8%, and the rate of excellent or good functional outcome was 85% which are in accordance with that reported from the above authors.

The SPORT study reported significant clinical improvements in the ODI scores, in the randomized and observational cohorts combined, from 42.6 preoperatively to 20.7 in the last follow-up. These results were stable and maintained over the period of 4 years [15]. When compared with our study group similar ODI scores both before and after surgery were found (46.8 –23).

This study demonstrates that in selected patients with low- and mid-grade degenerative spondylolisthesis accompanied by severe stenosis and FJO, MIS decompression and MI-TLIF can achieve significant improvement in functional outcome and excellent patient satisfaction in the majority of patients, in the short term.

## Weaknesses

The main weaknesses of this study are inherent to its retrospective nature (*i.e.*, selection bias and limited cohort with no control group). However, this series represents consecutive patients, with prospective data collection and 100% follow-up. The follow-up from the time of surgery was short (8 months), thus, no conclusions can be drawn about fusion rates and adjacent level disease. This study presents preliminary results and continued follow-up is mandatory and will be pursued in order to assess the long-term results. Prospective randomized trials could better address these issues.

## Conclusions

MIS for severe stenotic spondylolisthesis leads to adequate and safe decompression of lumbar stenosis and results in a highly significant reduction of symptoms and disability. Early outcome and radiologic result after MI-TLIF and percutaneous pedicle screw insertion was comparable with that after conventional techniques and showed acceptable complication rates. Long term results and randomized studies could help in verifying our findings.

## Disclosure

The authors report no conflict of interest concerning the materials and methods used in this study or the findings specified in this paper.

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This article was originally published in a special issue, [Minimally Invasive Spine Surgery](#) handled by Editor. Dr. Christopher Duntsch, Texas Neurosurgical Institute, USA