Comparison of minimally invasive fusion and instrumentation versus open surgery for severe stenotic spondylolisthesis with high-grade facet joint osteoarthritis

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Abstract

Purpose The object of this study was to compare minimally invasive surgery (MIS) with open surgery in a severely affected subgroup of degenerative spondylolisthetic patients with severe stenosis (SDS) and high-grade facet osteoarthritis (FJO).

Methods From January 2009 to February 2010, 49 patients with severe SDS and high-grade FJO were treated using either MIS or open TLIF. Intraoperative and diagnostic data, including perioperative complications and length of hospital stay (LOS), were collected, using retrospective chart review. Surgical short- and long-term outcomes were assessed according to the Oswestry disability index (ODI) and visual analog scale (VAS) for back and leg pain.

Results Comparing MIS and open surgery, the MIS group had lesser blood loss, significantly lesser need for transfusion ($p = 0.02$), more rapid improvement of postoperative back pain in the first 6 weeks of follow-up and a shorter LOS. On the other hand, we experienced in the MIS group a longer operative time. The distribution on the postoperative ODI ($p = 0.841$), VAS leg ($p = 0.943$) and back pain ($p = 0.735$) scores after a mean follow-up of 2 years were similar. The overall proportion of complications showed no significant difference between the groups

(29 % in the MIS group vs. 28 % in the open group, $p = 0.999$).

Conclusion Minimally invasive surgery for severe SDS leads to adequate and safe decompression of lumbar stenosis and results in a faster recovery of symptoms and disability in the early postoperative period.

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
LOS	Length of hospital stay
MR	Magnetic resonance
MIS	Minimally invasive surgery
TLIF	Transforaminal interbody fusion
SD	Standard deviation
SDS	Stenotic degenerative spondylolisthesis
VAS	Visual analog scale

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Introduction

Several studies have reported the favorable outcomes of MIS-TLIF accompanied by spinal instrumentation with percutaneous pedicle screw insertion and decompression in degenerative spondylolisthesis [1, 3, 5, 12, 20, 21, 23, 25]. 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 trauma, spinal deformities, and spinal oncology [6]. However, the impact of MIS on outcome for complex degenerative spondylolisthesis is not yet studied. The management of cases with severe SDS remains an area of great controversy [8, 9]. The presence of severe arthritic changes of the facets is characteristic in these patients [13]. Failure surgery and reoperation rates could increase after MIS, especially in the field of lumbar instrumentation [7, 15]. On the other hand, the minimal disturbance of normal anatomy and avoidance of extended muscle dissection could result in a clear advantage of MIS over traditional techniques.

The aim of the present study was to report data pertaining to MIS decompression, TLIF and percutaneous pedicle screw insertion in spondylolisthesis with severe stenosis and high-grade FJO, with particular focus on short and middle-term results, accuracy of pedicle screw insertion and incidence of complications. We compared the findings in this MIS group (24 patients) with a reference group who underwent open surgery (25 patients) in the same period.

Methods

Study design

We conducted a retrospective analysis of prospectively collecting data from consecutive patients with degenerative spondylolisthesis with severe stenosis (SDS) and severe facet joint osteoarthritis (FJO) who were admitted to the neurosurgery department between January 2009 and February 2010.

Patient population

The inclusion criteria were as follows: (1) consecutive patients between January 2009 and February 2010; (2) symptoms of neurogenic claudication or radiculopathy or incapacitating back pain refractory to adequate conservative treatment; (3) degenerative spondylolisthesis Meyerding grades I–II; (4) FJO Pathria Grade 3; (5) spinal stenosis at the affected level grade C and D (Schizas et al.); (6) necessity for decompression and fusion at a single level.

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. The four-point scale that Pathria devised for radiographic grading FJO was used to delineate the severity of facet disease [11]. Radiographically, facets with severe degenerative disease encompassing narrowing, sclerosis, and osteophytes were classified 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. [20], 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.

The exclusion criteria for this study formed simultaneously the contraindications for the minimally invasive approach and were as follows: (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 and were included in this study.

During this period, 85 patients were assessed for eligibility, a total of 49 patients fulfilled the inclusion criteria of our study and all patients completed the follow-up visit. The patients were divided into 2 groups: the MIS group (24 patients) and the open group (25 patients), which constituted the reference group. The baseline characteristics of the 49 patients are shown in Table 1. Sociodemographic characteristics were identical in the groups with regard to the median age and sex ratio. Clinical presentation, VAS for back pain, leg pain, and activity level preoperatively were similar in both groups. The minimum follow-up was 24 months with a mean of 26 months.

The study was based on different policies of treatment represented from two surgeons in the same institute who decided the operative method according to their preference. Allocation to MIS or open surgery was not randomized.

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” [22]. Disability was assessed using the Oswestry low back pain disability questionnaire (ODI), which has been

Table 1 Patient's characteristics

Parameters	MIS group	Open group	<i>p</i> value
No. of cases	24	25	
Age, in years	67 ± 8	68 ± 7	0.937
Sex (female), <i>n</i> (%), no. of cases	14(58)	17(68)	0.917
Body mass index (mean ± SD), kg/m ²	28 ± 6	27 ± 4	0.844
Standard follow-up (range), in months	26(24–29)	26(24–30)	0.923
Spondylolisthesis Meyerding grade, no. of cases			0.599
Grade 1	18	16	
Grade 2	6	9	
Level, no. of cases			0.81
L3–4	2	1	
L4–5	16	17	
L5–S1	6	7	
Duration of symptoms, in months			0.979
LBP	31 ± 27	35 ± 29	
Leg pain	17 ± 9	16 ± 8	
Neurogenic claudication	15 ± 4	16 ± 7	
Symptoms, no. of cases			0.971
LBP	17	15	
Leg pain	19	19	
Neurogenic claudication	20	22	
Neurologic deficit, no. of cases			0.789
Absent	15	12	
Mild	4	6	
Severe	5	7	
Walking distance, no. of cases			0.896
<500 m	12	15	
500–1,000 m	8	6	
>1,000 m	4	4	
Medical history, no. of cases			0.94
Cardiovascular disease	2	1	
Diabetes	4	3	
Thromboembolism	1	2	
Hypertension	6	7	
Asthma or chronic obstructive pulmonary disease	2	1	

Mean values are presented as the mean ± SD

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).

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

A detailed description of the MIS and open procedures is available in the literature [6, 29].

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. The surgical procedures were performed by a consultant neurosurgeon.

Radiological assessment

The accuracy of pedicle screws was estimated with postoperative CT. 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 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) [19].

Radiographic assessment of solid fusion was confirmed by progressive increase in interspace bone density, presence of bridging bone posterolaterally, and no evidence of hardware failure, loosening, or motion on flexion–extension radiographs. Postoperative progression of adjacent-segment degeneration was defined as a condition in which clinical deterioration occurred due to adjacent-segment degeneration.

Outcome assessment and LOS

Pain (VAS score) and walking distance and patient satisfaction were recorded. Functional disability was quantitatively measured using the Oswestry low back pain disability questionnaire (ODI). Both the VAS and ODI were prospectively acquired. 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. [27] (excellent, good, fair and poor).

All outcome parameters were evaluated at 3 days, 1 week, 6 weeks, 6 months, and 24 months postoperatively.

For each patient, we analyzed LOS abstracted through chart review.

Statistical analysis

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

Results

Intraoperative parameters

Regarding the MIS-treated group, the scheduled procedure was adhered to in all patients. In one case we had to change the side of MI-TLIF because of a conjoined nerve root which made the approach to the lumbar disc very difficult with high risk of neurologic deficit. There were no conversions to an open procedure. The following differences between the two groups were observed: (1) the mean surgical time for the MIS group was 220 (SD $\pm$ 48) min and for the open group 190 (SD $\pm$ 65) ($p = 0.535$) (2) the EBL for the MIS group was 185 (SD $\pm$ 140) ml and for the open group 255 (SD $\pm$ 468) ($p = 0.351$). The proportion of blood transfusion increased in patients who had open surgery with significant difference, namely 11 % in the MIS group (1 case) and 35 % in the open group (5 cases) ($p = 0.02$).

Complications

As shown in Table 2, overall complication rates were comparable between the groups. Intraoperative incidental durotomy was observed almost in the same proportion between the groups ($p = 1.0$). 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. Regarding pedicle screw misplacement, we observed frank

penetrations in one patient in the MIS group and in none of the patients in the open group ($p = 0.9$). Regarding wound healing, the proportion of disturbances was higher in the open group but the difference was not considered significant ($p = 0.227$). Regarding postoperative radicular syndrome, two patients in the MIS group were found 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 distribution of patients in the distinct categories of VAS pain scores (leg and back pain) was not different between the groups ($p = 0.836$). As detailed in Table 3, in the MIS group the average preoperative VAS score for back pain of 69, decreased at the third postoperative day to 45, at 1 week to 43, at 6 weeks to 30, at 6 months to 28, and at 24 months mean follow-up to 25. In the open group the average preoperative VAS score for back pain of 66, decreased at the third postoperative day to 52, at 1 week to 49, at 6 weeks to 38, at 6 months to 29, and at 24 months mean follow-up to 28. Both groups resulted in a significant reduction of overall pain ($p < 0.001$), but as far as the back pain is concerned, although not statistically significant due to the small sample numbers, there was a more rapid improvement in the MIS group after 3 days, 1 week and 6 weeks follow-up. In the long term and after a mean follow-up of 26 months, differentiating between low back pain and leg pain revealed no differences in improvement.

The patients in the MIS group had an average preoperative ODI of 46, after 1 week of 45, of 36 after 6 weeks, of 34 after 6 months, and of 23 after a mean follow-up of 24 months. The patients in the open group had an average preoperative ODI of 48, after 1 week of 45, of 37 after 6 weeks, of 34 after 6 months, and of 24 after a mean follow-up of 24 months. The MIS group showed a more rapid improvement in ODI during the first 6 weeks of follow-up. The average clinical improvement in ODI, in this early stage, was 28 versus 23 %, for the MIS and open

Table 2 Complication rates

Complications	MIS group (<i>n</i> :24) No. of patients	Open group (<i>n</i> :25) No. of patients	<i>p</i> value
Incidental durotomy	1	1	1
Wound healing disturbance	0	3	0.227
Radiculopathy contralateral	2	0	0.704
Revision pedicle screw	1	0	0.9
Suspected pseudarthrosis	1	1	1
Adjacent-segment disease	1	2	0.988
Revision surgery	2	2	0.998
Overall complications	7 (29 %)	7 (28 %)	0.999

Table 3 Clinical outcome

Evaluation	MIS group						Open group							
	No.	Median score					No.	Median score						
		Preop	Postop					Preop	Postop					
			3 days	1 week	6 weeks	6 months			24 months	3 days	1 weeks	6 weeks	6 months	24 months
VAS														
VAS leg pain	67	37	33	30	31	27	64	36	32	31	29	26		
VAS back pain	69	45	43	30	28	25	66	52	49	38	29	28		
ODI score	46		38	33	32	23	48		45	37	33	24		
Postop at last follow-up														
Walking distance	250			3,100			300			3,000				
Pat. satisfaction														
Very satisfied and satisf.	17		71 %		19		76 %							
Functional scale														
Excellent and good	19		85 %		20		80 %							

groups, respectively. On the other hand, there were no significant differences between the groups after a minimum of 2 years follow-up ($p = 0.841$) (Fig. 1).

Neurogenic claudication improved in 91 % of the patients in the MIS group and in 88 % of the open group. Walking distance varied greatly among individual patients, but overall ambulation recovered significantly from a mean of 250 (SD $\pm$ 200) to a mean of 3,100 (SD $\pm$ 3,500) in the MIS group and from a mean of 300 (SD $\pm$ 200) to a mean of 3,000 (SD $\pm$ 4,000) in the open group without significant difference between the groups ($p = 0.851$).

The distribution in each category of outcome was similar between the groups (Table 3).

Differences were found with regard to hospital LOS between MIS and open surgery. The mean LOS was 7 and 11 days in the MIS and open groups, respectively

($p = 0.324$) a difference that was not statistically significant due to the small sample numbers. 20 and 35 % of patients undergoing MIS and open surgery, respectively, were discharged to inpatient rehabilitation.

Radiology

In the axial and coronal images, one screw out of 96 in the MIS group 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 in the MIS group (3 medially, 4 laterally, 1 cranially) and nine in the open group (3 medially, 4 laterally, 2 cranially) encroached the pedicular cortex without frank penetration.

The patient with frank penetration in the MIS group made an uneventful recovery. This case was not encountered in the beginning of our learning curve but on our 13th procedure.

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

Radiographic fusion was thought to be present in 22 of 24 of the patients in the MIS group and 24 of 25 of the patients in the open group based on the presence of obliteration of the disc space anterior and/or posterior to the cage as well as continuous trabecular bone throughout the intertransverse fusion mass, no loosening or breakage of implants, and no demonstrable motion on flexion–extension radiographs. None of the patients had a confirmed pseudarthrosis, two patients in the MIS group and one patient in the open group had radiographic evidence suggestive of pseudarthrosis, but were not symptomatic to a level of considering further surgery. This yielded a total suspected pseudarthrosis rate of 8 % in the MIS group and

Fig. 1 Change in ODI score at 6 weeks and 2 years postoperatively in the MIS and open group. There was a more rapid improvement during the first 6 weeks of follow-up in the MIS group

4 % in the open group demonstrating no statistical significant difference.

Postoperative progression of adjacent-segment degeneration was observed in one patient in the MIS group and in two patients in the open group. The progression of adjacent-segment degeneration was observed at the cranial segment in all cases. The following conditions were identified as progressive adjacent-segment degeneration: spinal canal stenosis in one patient, disc herniation in two patients and degenerative spondylolisthesis in one patient. None of these patients underwent surgery because of the absence of persisting neurological symptoms such as radicular pain, sensory disturbance, and motor weakness. These patients' symptoms improved after conservative treatment.

Revision rate

The revision rate for the MIS group at a mean of 26 months (range, 24–29 months) from surgery was 8 %, 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 were made responsible for the contralateral foraminal encroachment. We performed repeat decompression in one patient (Fig. 2) 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. For these patients the mean ODI preoperative was 42. Following revision, these patients had a mean ODI of 34 at their latest follow-up.

The revision rate for the open group at the same period was also 8 %, which included deep wound infection ($n = 1$) and CSF leakage ($n = 1$). These results yielded no statistical difference in revision rate between the two groups.

Discussion

There is controversy concerning the necessity of MIS procedures in order to achieve fusion and adequate decompression [2, 9, 15, 20, 28]. 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 [4, 5, 10, 12, 16, 23]. 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 [6]. 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 [13]. Moreover, the severity of the central spinal stenosis, facet osteoarthritis and foraminal narrowing can significantly differ between patients [21]. 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 [2, 29]. The authors of previous studies of MIS and especially MIS-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 [5, 12, 18, 20, 23, 26]. 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 [17]. 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 this more complex patient population.

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. We performed the current analysis to evaluate feasibility, short-term and 2-year outcome results and to provide data for complication rates in this group of patients.

Intraoperative parameters

Open TLIF is considered a simple and fast fusion technique, whereas MIS-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) min. Others have reported longer operative times for TLIF. In our study, the duration of surgery in the MIS group was proved to be 220 (SD $\pm$ 48) min which was on average 30 min longer in comparison with the open group ($p = 0.535$) but comparable with the time described in the literature. 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 %) [24]. In our study, blood loss in the MIS group was clinically insignificant (185 ± 210), requiring transfusion in only one case compared to the open group where blood transfusion was required in 5 cases

Fig. 2 A 64-year-old woman with severe SDS and FJO and ischiadic pain on the *left side*. The preoperative CT (**a**) demonstrates foraminal stenosis on both sides. The postoperative CT demonstrates sufficient decompression of the central stenosis but an osteophytic spur that

impinges the contralateral right foramen (**b**). Repeat decompression from the *right side* led to complete resolution of symptoms (**c**). Two years after surgery, radiographic control depicted fusion of the disc space (**d**)

($p = 0.02$). Because of longer duration of surgery in the MIS group, it could be anticipated that the MIS procedure is less cost effective. However, during the acute hospitalization, the advantages of MIS include less muscle traumatization which could lead in faster resolution of pain and disability and result in short-term cost saving as will be analyzed in the following section. The longer operative time in complex cases could also be neutralized as a result of cost saving due to less EBL and necessity of blood transfusion.

Overall, our results are comparable with those reported in literature. Although all cases included in this study were demanding because of the high grade of stenosis and FJO, this, however, did not translate in increased EBL or perioperative morbidity compared with open surgery.

Complications, reoperations and radiographic outcome

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 [1, 3, 7, 8, 14]. In some studies of less invasive techniques, however, investigators revealed an increase in perioperative morbidity, namely neurological sequelae [4]. Therefore, our main concern in view of MIS-TLIF in this complex and surgically demanding cohort of patients has been the possibility of neural injury. In the series reported by Schwender et al. [21], a postoperative increased radicular deficit was observed in 2/49 cases (4 %) of MIS decompression and interbody fusion cases (one from graft dislodgement, the other from contralateral neuroforaminal stenosis). According to our data, actual injury to a nerve root did not occur. We observed in two patients of the MIS group, postoperatively, a contralateral foraminal encroachment syndrome due to osteophytic spurs arising from the facet joint and impinging the nerve root. Although not statistically significant ($p = 0.704$), this makes 8 % of this patient group. This impingement caused radicular pain in lower limbs and numbness or tingling sensations in the

feet without motor deficits (Fig. 2). We think that these patients with severe stenosis and 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, where an adequate decompression of the contralateral exiting nerve root cannot be achieved through the unilateral approach.

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 %. The results of the present study, namely 4 % for both the MIS and the open control group are in accordance with those in the literature, underscoring that MIS-TLIF and MIS decompression through a unilateral approach although technically demanding, carry a low risk of unintended durotomy ($p = 1.0$).

The wound infection rate is approximately 2 % of all spinal surgery cases in the literature. We had no cases of wound healing disturbance or infection in the MIS group. The complication rate of the open group was 12 % and although not statistically significant ($p = 0.227$), it may demonstrate that the limited soft tissue disruption of the MIS procedure could have a positive influence on the wound healing process.

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. [19] 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 coronal images. 13 % of the patients (2/15) had severe frank penetration from the screws, while 80 % of them (12/15) had some perforation. In the present study, we found a severe frank pedicle penetration of 1 % (1/96) of all pedicle screws in the MIS group and no frank penetration in the open group. MIS-TLIF in complex cases although technically demanding, was not associated with an increase of pedicle screw misplacement.

The radiographic fusion rate of 90 % in the MIS group compares favorably with the results in the open control group and with the reports in the literature. This may be partly because of the meticulous removal of disc material using angled curettes. This allows the largest surface area possible for fusion and aids in proper cage and bone graft placement [6].

Conflicting results have been reported in the literature with respect to the relationship between symptomatic ASD and spinal fusion. The follow-up period in our study of 26 months was long enough to assess the consequences of spinal fusion and short enough to minimize the influence of the aging process at the adjacent segments. There was a

low incidence of symptomatic ASD in our patient cohort and no statistical significance between the groups. However, our results partly underscore the importance of our operative strategy which was to avoid overdistraction of the fused disc height and to minimize the risk of irritation of the adjacent upper level facets during pedicle screw insertion and decompression.

In summary, the MIS-TLIF in complex and surgically demanding cases was neither associated with an increased rate of complications nor a higher surgical revision rate compared with the open procedure (29 vs. 28 %, $p = 0.999$).

Outcome assessment

In the present study, analysis of outcome was based on the VAS for pain and satisfaction and the ODI for disability [1, 2, 18, 26]. Both MIS-TLIF and open surgery resulted in a significant reduction of overall pain ($p < 0.001$) in the long term. But, one of the advantages of MIS was the rapid relief of postoperative back pain in the first 6 weeks postoperatively. The ODI showed also a more rapid functional recovery in the same period after surgery in the MIS group. It is obvious that due to lessening of the approach-related morbidity; minimally invasive techniques offer a quicker recovery. On the long term, MIS achieves the same objectives as open surgery even in this complex and surgically demanding patient population.

This study identified a trend for reduction of LOS and lower rates of discharge to inpatient rehabilitation after MIS. It should, however, be noted that the LOS for both groups was longer than seen at many previous studies. This may be due to the fact that we did not try to speed discharge with either group and patients were discharged home after they were able to ambulate independently and had acceptable pain control with oral medication. The higher LOS may also reflect the fact that in this study, we included a more complex subgroup of stenotic spondylolisthesis with severe degenerative changes.

Patient outcomes and costs associated with the benefits of MIS are critical factors for determining the value of these interventions. The study of Wang et al. [24] investigated the relative costs and benefits of MIS and founded these interventions to be meaningful. With regard to acute care hospital costs, more investigation is necessary to explore the effectiveness of MIS through cost comparisons with open surgery.

Overall, this study demonstrates that in selected patients with severely stenotic degenerative spondylolisthesis accompanied by high-grade FJO, MIS decompression and MIS-TLIF can not only achieve significant improvement in functional outcome, but also may have advantages in the early postoperative stage.

Weaknesses

The main weaknesses of this study are inherent to its retrospective nature (i.e., selection bias and limited cohort). The patients were not randomly selected and the cohort size of this study was not large enough to have a sufficient statistical power for drawing complete conclusions. In addition it should be noted that the fact that we compared two different methods by two different surgeons leaves some room for questions of whether there is enough power in the study for equality. However, this series represents consecutive patients, with prospective data collection and 100 % follow-up. Selection bias, such as the use of MIS techniques in healthier, younger patients remains paramount in comparative studies of MIS versus open surgery. However, randomized trials in this area are difficult, largely due to patient's desire for what might be perceived as a potentially less morbid procedure.

Another potential limitation of this study is that our average period of follow-up was not long enough to sufficiently validate the effect of MIS or open surgery on adjacent-segment degeneration. This study presents short and middle-term results and continued follow-up is mandatory and will be pursued in order to assess the long-term results.

Conclusions

Minimally invasive surgery 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 might have benefits in the early postoperative phase for this demanding patient population. Middle-term outcome and radiologic result after MIS-TLIF and percutaneous pedicle screw insertion was comparable with that after conventional techniques and showed acceptable complication rates.

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

References

1. Dhall SS, Wang MY, Mummaneni PV (2008) Clinical and radiographic comparison of mini-open transforaminal lumbar interbody fusion with open transforaminal lumbar interbody fusion in 42 patients with long-term follow-up. *J Neurosurg Spine* 9(6):560–565
2. Gelalis ID, Arnaoutoglou C, Christoforou G, Lykissas MG, Batsilas I, Xenakis T (2010) Prospective analysis of surgical outcomes in patients undergoing decompressive laminectomy and posterior instrumentation for degenerative lumbar spinal stenosis. *Acta Orthop Traumatol Turc* 44(3):235–240
3. Holly LT, Schwender JD, Rouben DP, Foley KT (2006) Minimally invasive transforaminal lumbar interbody fusion: indications, technique, and complications. *Neurosurg Focus* 20(3):E6
4. Hsieh PC, Koski TR, Sciubba DM, Moller DJ, O'Shaughnessy BA, Li KW, Gokaslan ZL, Ondra SL, Fessler RG, Liu JC (2008) Maximizing the potential of minimally invasive spine surgery in complex spinal disorders. *Neurosurg Focus* 25(2):E19
5. Logroscino CA, Proietti L, Pola E, Scaramuzza L, Tamburrelli FC (2011) A minimally invasive posterior lumbar interbody fusion for degenerative lumbar spine instabilities. *Eur Spine J* 20(Suppl 1):S41–S45
6. Lowe TG, Tahernia AD, O'Brien MF, Smith DA (2002) Unilateral transforaminal posterior lumbar interbody fusion (TLIF): indications, technique, and 2-year results. *J Spinal Disord Tech* 15(1):31–38
7. Mummaneni PV, Rodts GE Jr (2005) The mini-open transforaminal lumbar interbody fusion. *Neurosurgery* 57(4 Suppl): 256–261
8. Oppenheimer JH, De Castro I, McDonnell DE (2009) Minimally invasive spine technology and minimally invasive spine surgery: a historical review. *Neurosurg Focus* 27(3):E9
9. Park P, Foley KT (2008) Minimally invasive transforaminal lumbar interbody fusion with reduction of spondylolisthesis: technique and outcomes after a minimum of 2 years' follow-up. *Neurosurg Focus* 25(2):E16
10. Park Y, Ha JW, Lee YT, Oh HC, Yoo JH, Kim HB (2011) Surgical outcomes of minimally invasive transforaminal lumbar interbody fusion for the treatment of spondylolisthesis and degenerative segmental instability. *Asian Spine J* 5(4):228–236
11. Pathria M, Sartoris DJ, Resnick D (1987) Osteoarthritis of the facet joints: accuracy of oblique radiographic assessment. *Radiology* 164(1):227–230
12. Peng CW, Yue WM, Poh SY, Yeo W, Tan SB (2009) Clinical and radiological outcomes of minimally invasive versus open transforaminal lumbar interbody fusion. *Spine* 34(13):1385–1389
13. Potter BK, Freedman BA, Verwiebe EG, Hall JM, Polly DW Jr, Kuklo TR (2005) Transforaminal lumbar interbody fusion: clinical and radiographic results and complications in 100 consecutive patients. *J Spinal Disord Tech* 18:337–346
14. Quante M, Kesten H, Richter A, Halm H (2012) Transforaminal lumbar interbody fusion for the treatment of degenerative spondylolisthesis. *Orthopade* 41(2):153–162
15. Rosenberg WS, Mummaneni PV (2001) TLIF: technique, complications, and early results. *Neurosurgery* 48:569–574
16. Ryang YM, Oertel MF, Mayfrank L, Gilsbach JM, Rohde V (2008) Standard open microdiscectomy versus minimal access trocar microdiscectomy: results of a prospective randomized study. *Neurosurgery* 62(1):174–181
17. Salehi SA, Tawak R, Ganju A, LaMarca F, Liu JC, Ondra SL (2004) Transforaminal lumbar interbody fusion: surgical technique and results in 24 patients. *Neurosurgery* 54:368–374
18. Scheufler KM, Dohmen H, Vougioukas VI (2007) Percutaneous transforaminal lumbar interbody fusion for the treatment of degenerative lumbar instability. *Neurosurgery* 60(4 Suppl 2): 203–212
19. Schizas C, Michel J, Kosmopoulos V, Theumann N (2007) Computer tomography assessment of pedicle screw insertion in percutaneous posterior transpedicular stabilization. *Eur Spine J* 16(5):613–617
20. Schizas C, Theumann N, Burn A, Tansey R, Wardlaw D, Smith FW, Kulik G (2010) Qualitative grading of severity of lumbar spinal stenosis based on the morphology of the dural sac on magnetic resonance images. *Spine (Phila Pa 1976)* 35(21): 1919–1924
21. Schwender JD, Holly LT, Rouben DP, Foley KT (2005) Minimally invasive transforaminal lumbar interbody fusion (TLIF):

- technical feasibility and initial results. *J Spinal Disord Tech* 18(Suppl):S1–S6
22. Scott J, Huskisson EC (1976) Graphic representation of pain. *Pain* 2(2):175–184
 23. Wang J, Zhou Y, Zhang ZF, Li CQ, Zheng WJ, Liu J (2010) Comparison of one-level minimally invasive and open transforaminal lumbar interbody fusion in degenerative and isthmic spondylolisthesis grades 1 and 2. *Eur Spine J* 19(10):1780–1784
 24. Wang MY, Cummock MD, Yu Y, Trivedi RA (2010) An analysis of the differences in the acute hospitalization charges following minimally invasive versus open posterior lumbar interbody fusion. *J Neurosurg Spine* 12(6):694–699
 25. Weiner BK, Nguyen HV, Hazard SW (2006) Transforaminal lumbar interbody fusion: an independent assessment of outcomes in a difficult patient population. *Med Sci Monit* 12:CR99–CR102
 26. Weinstein JN, Lurie JD, Tosteson TD, Zhao W, Blood EA, Tosteson AN, Birkmeyer N, Herkowitz H, Longley M, Lenke L, Emery S, Hu SS (2009) Surgical compared with non operative treatment for lumbar degenerative spondylolisthesis. Four-year results in the Spine Patient Outcomes Research Trial (SPORT) randomized and observational cohorts. *J Bone Joint Surg Am* 91(6):1295–1304
 27. Whitecloud TS 3rd, Davis JM, Olive PM (1994) Operative treatment of the degenerated segment adjacent to a lumbar fusion. *Spine (Phila Pa 1976)* 19(5):531–536
 28. Whitecloud TS 3rd, Roesch WW, Ricciardi JE (2001) Transforaminal interbody fusion versus anterior-posterior interbody fusion of the lumbar spine: a financial analysis. *J Spinal Disord* 14(2):100–103
 29. Wood MJ, Mannion RJ (2010) Improving accuracy and reducing radiation exposure in minimally invasive lumbar interbody fusion. *J Neurosurg Spine* 12(5):533–539