Available online at www.sciencedirect.com
ScienceDirect
journal homepage: http://www.elsevier.com/locate/pjnns

Original research article

Minimally invasive decompression in patients with degenerative spondylolisthesis associated with lumbar spinal stenosis. Report of a surgical series and review of the literature

Nicola Montano *, *Vito Stifano, Fabio Papacci, Edoardo Mazzucchi, Eduardo Fernandez*

Institute of Neurosurgery, Catholic University, Rome, Italy

ARTICLE INFO

Article history:
Received 16 October 2017
Accepted 19 June 2018
Available online 2 July 2018

Keywords:
Degenerative spondylolisthesis
Minimally invasive decompression
Lumbar spinal stenosis
Outcome

ABSTRACT

We reported the results of minimally invasive spinal decompression (MISD) in patients with degenerative spondylolisthesis (DS) associated with lumbar spinal stenosis (LSS) and performed a literature review in order to evaluate the clinical and radiological outcomes, the complications and reoperation rate of MISD procedures in these patients.

Data of 28 patients submitted to MISD for DS associated to LSS were reviewed. We evaluated the Visual Analogue Scale (VAS) both for low back pain (LBP) and legs pain, the Oswestry Disability Index (ODI) and the degree of the slippage. A PubMed search of the English literature was conducted. Only papers with more than 10 patients and reporting explicitly data of patients with DS were included in the analysis. We found a statistically significant improvement of LBP, legs pain and ODI in our series. The degree of slippage was stable at follow-up (FU) with no need of reoperation. No major complications occurred. In our literature review, we were able to analyze the differences in ODI in 156 patients and the differences in Japanese Orthopedic Association (JOA) score in 218 patients. We observed a statistically significant improvement of ODI and JOA score at FU compared to pre-operative. The percentage of slippage, evaluated in 283 patients, was unchanged at FU compared to pre-operative. The overall complication rate was 1.6%. The overall reoperation rate was 4.5%.

MISD procedures are safe and effective in patients with DS associated to LSS and are associated to low morbidity and significant improvement of disability without progression of slippage.

* Corresponding author at: Institute of Neurosurgery, Catholic University, Largo Agostino Gemelli, 8, 00168 Rome, Italy.
E-mail address: nicolamontanomd@yahoo.it (N. Montano).
https://doi.org/10.1016/j.pjnns.2018.06.004

1. Introduction

Degenerative spondylolisthesis (DS) associated with lumbar spinal stenosis (LSS) is a common pathology which can cause progressive neurogenic claudication, radicular pain, and legs weakness. Usually when there is evidence of a failure of the conservative management, surgery is indicated [1–4]. The most widely used approach is open lumbar decompression with spinal fusion [5]. This technique has been demonstrated to significantly improve clinical outcome in patients with DS [6–10]. Nonetheless, spinal fusion has been associated with some complications such as fracture of the vertebral body and the pedicle [11–19], pedicle screw loosening and adjacent segment degeneration [20], requiring secondary spine surgery for lumbar adjacent instability [21]. In the last few years minimally invasive spinal decompression (MISD) procedures have been described [22–27] to overcome the problems, such as iatrogenic instability [28], associated with laminectomy. It has been reported that these techniques are as efficacious as laminectomy in terms of good clinical results in non-spondylolisthetic patients [22–27,29–31] with the advantage of a shorter hospital stay and a less postoperative pain compared to laminectomy [29–31]. These procedures seem to be associated to lower incidence of iatrogenic instability [26]. However, only few papers investigating the role of MISD procedures in patients with DS associated to LSS have been reported [16,32–41]. The aim of this study was to report the clinical and radiological outcomes of minimally invasive decompression (obtained by mean of a microsurgical approach) in patients with DS associated to LSS. We also performed a literature review of the pertinent papers in order to evaluate the clinical and radiological outcome, the complications and reoperation rate of MISD procedures in these patients.

2. Materials and methods

2.1. Patients

We retrospectively reviewed clinical and outcome data of 28 consecutive patients (13 M, 15 F) submitted to minimally invasive decompression for the treatment of DS associated to LSS, from July 2013 to July 2016. All patients provided written informed consent according to the research proposals approved by the local ethical committee. The mean age was 67.32 ± 13.01 years. The mean follow-up (FU) was 17.78 ± 9.50 months (range 6–39 months). All patients had no previous lumbar spine operation and complained of lumbar/legs pain and/or neurogenic claudication unresponsive to conservative (physical and medical) treatment for at least 1 year, with a magnetic resonance imaging (MRI), showing a DS associated to LSS. Patients were submitted pre-operatively and at FU to lumbar spine MRI and X-ray (anterior–posterior, lateral neutral and lateral flexion/extension projections). Patients with multilevel LSS were excluded from this study. The changes about pain were assessed using the Visual Analogue Scale (VAS) both for low back pain (LBP) and legs pain pre-operatively, one day post-operatively and at latest FU for each patient. The Oswestry Disability Index (ODI) was used to evaluate the degree of disability of these patients pre-operatively and at latest FU for each patient. The degree of the slippage was evaluated pre-operatively and at FU as previously reported [41]. Statistical comparison of continuous variables and ordinal variables was performed by the *t*-Student test and by Wilcoxon signed rank test, as appropriate.

2.2. Surgical technique

Under general anesthesia and in prone position, the correct level of surgery was confirmed using intraoperative imaging. A midline skin incision was made to expose the fascia. Fascia was incised bilaterally with the supra and interspinous ligaments and the spinous processes preserved. The paraspinous muscles were stripped on both sides from the laminae and the capsules of the facet joints. Under microscopic view, a little rim of bone from the caudal aspect of the cranial lamina and the cranial aspect of the caudal lamina was removed, thereby creating a larger interlaminar space. The ligamentum flavum was removed bilaterally, and the spinal recess subsequently was opened bilaterally by undercutting minimal portions of the medial facet joints. At the end of the procedure, the dural sac and the nerve root were decompressed bilaterally.

2.3. Literature search

A PubMed search of the literature was conducted using combinations of the following terms: "spondylolisthesis" AND "unilateral approach for bilateral decompression" OR "ULBD" OR "muscle-preserving" OR "MILD" OR "interlaminar decompression". Studies until January 2017 were revised. The majority of them were series of LSS including also patients with DS. We included in our review: only articles in English,

Table 1 – Clinical and outcome data of 28 patients submitted to minimally invasive decompression for spondylolisthesis associated to lumbar spinal stenosis, from July 2013 and July 2016.

Patients	28
Sex (M/F)	13/15
Mean age (years)	67.32 ± 13.01
Level	
L3/L4	7
L4/L5	19
L5/S1	2
Low back pain VAS	
Pre-operative	6.53 ± 2.45
Post-operative	3.85 ± 2.12
At follow-up	2.46 ± 2.18
Legs pain VAS	
Pre-operative	7.67 ± 1.41
Post-operative	4.28 ± 2.27
At follow-up	2.60 ± 2.49
Oswestry Disability Index (%)	
Pre-operative	62.39 ± 14.12
At follow-up	19.92 ± 17.38
Degree of slippage (%)	
Pre-operative	13.25 ± 4.61
At follow-up	13.68 ± 4.59
Mean follow-up (months)	17.78 ± 9.50

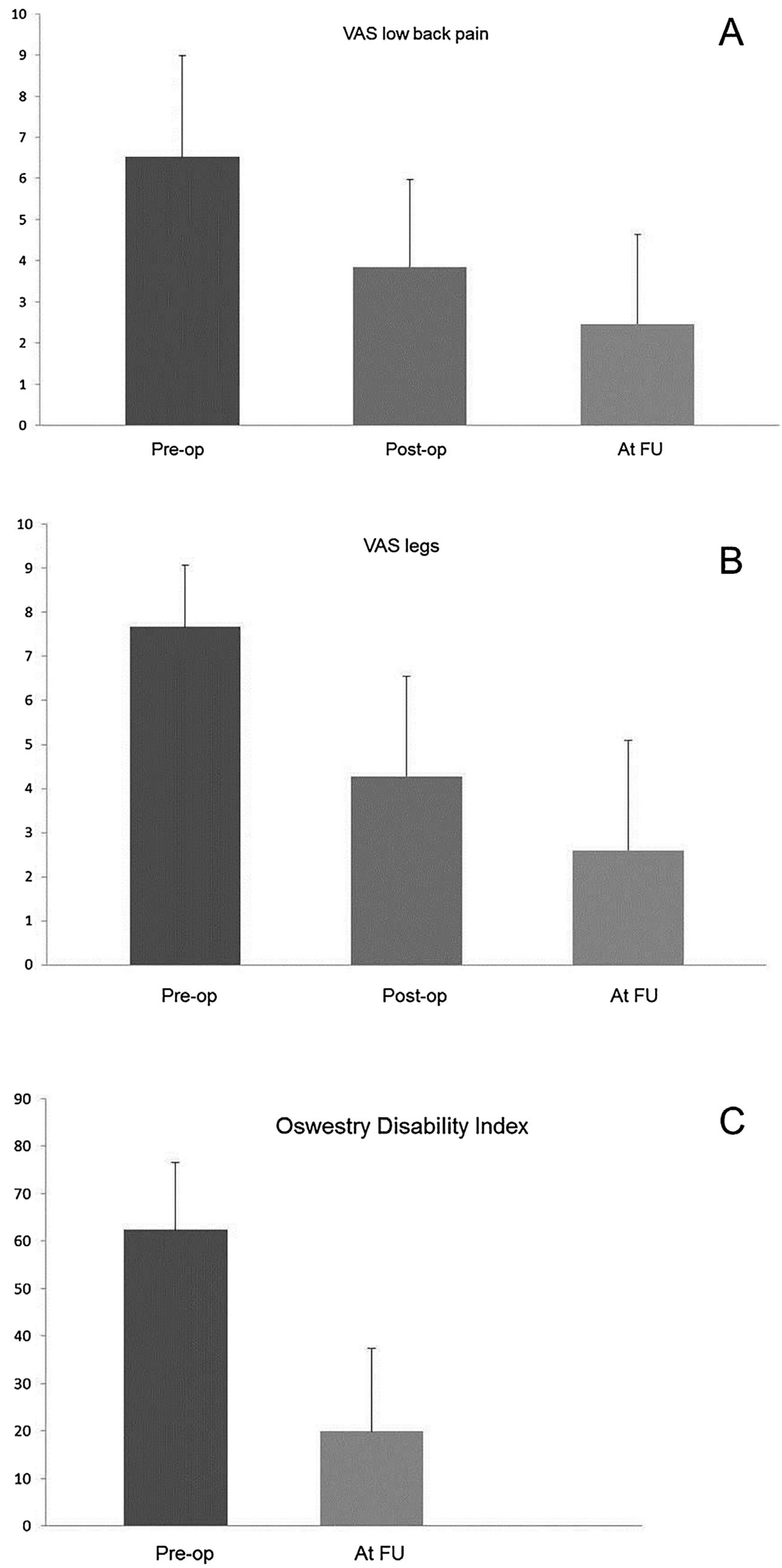

Fig. 1 – (A) Bar graph. Pre-operative, post-operative and follow-up (FU) low back pain VAS of 28 DS patients submitted to MISD showing the statistically significant improvement of VAS at latest FU. (B) Pre-operative, post-operative and FU legs pain VAS showing the statistically significant improvement of VAS at latest FU. (C) Pre-operative and FU ODI showing the statistically significant improvement of ODI at latest FU. Error bars indicate deviation standard.

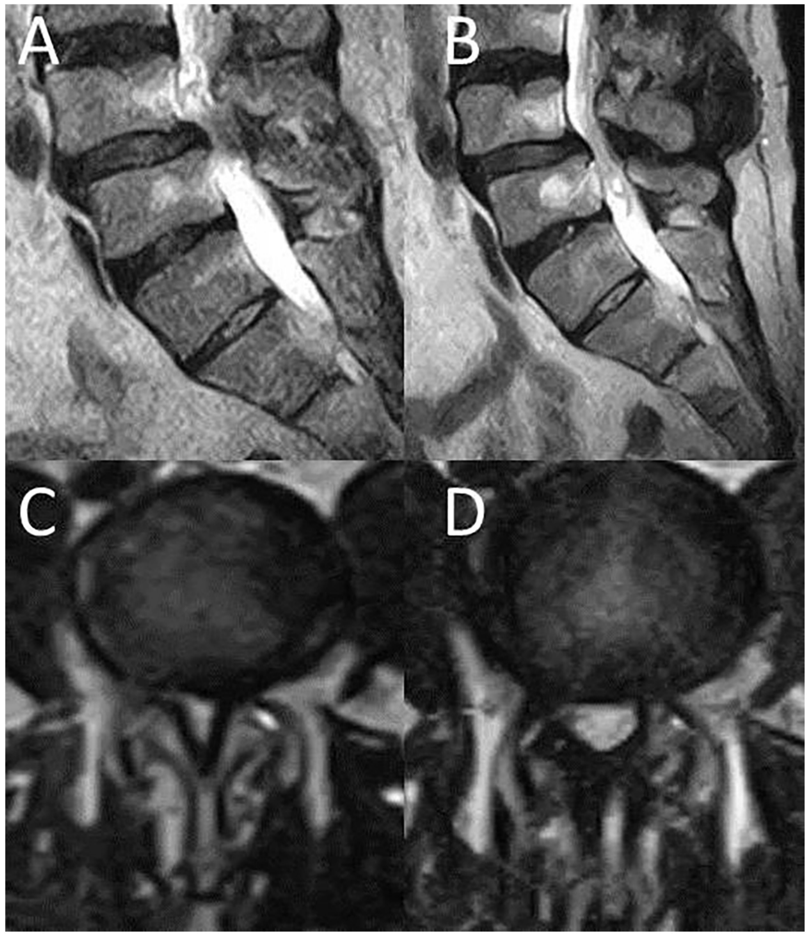

Fig. 2 – Pre-operative T2-weighted (A) sagittal and axial (C) spinal lumbar MRI of a 56-year-old man with a L4–L5 stenosis and spondylolisthesis. The patient was submitted to minimally invasive decompression at this level. One year FU T2-weighted sagittal (B) and axial (D) spinal lumbar MRI showing the optimal decompression of dural sac and nerve roots with no change of the degree of spondylolisthesis.

only papers reporting explicitly data of patients with DS submitted to a MISD and only series with more than 10 patients. We also checked the references of each article looking for further articles to be included. Thus, we were able to evaluate 12 articles in this literature review.

3. Results

3.1. *Results in the present series*

Clinical and outcome data of patients are summarized in Table 1. Although in the post-operative the pain evaluation could be affected by pain medications, we globally found a statistically significant improvement of post-operative and at FU LBP compared to pre-operative (VAS; pre-operative 6.53 ± 2.45, post-operative 3.85 ± 2.12, at FU 2.46 ± 2.18; $p < 0.0001$ and $p < 0.0001$, respectively, Fig. 1A). Post-operative and at FU legs pain was also significantly improved compared to pre-operative (VAS; pre-operative 7.67 ± 1.41, post-operative 4.28 ± 2.27, at FU 2.60 ± 2.49; $p < 0.0001$ and $p < 0.0001$, respectively, Fig. 1B). Considering the degree of disability, we observed a statistically significant improvement of at FU ODI compared to pre-operative (%; pre-operative 62.39 ± 14.12, at FU 19.92 ± 17.38; $p < 0.0001$, Fig. 1C). 7 patients out of 28 had a DS in L3/L4, 19 in L4/L5 and 2 in L5/S1. The degree of slippage at FU was unchanged compared to pre-operative (%; pre-operative 13.25 ± 4.61, at FU 13.68 ± 4.59; $p = 0.28$). The mean operation length was 69.10 ± 12.84 min. During the operation one patient had an incidental durotomy which was repaired with no consequences. No cerebrospinal fluid (CSF) collections were recorded post-operatively and at FU. No wound infection occurred. At latest FU, no reoperation was needed. Two explicative cases are reported in Figs. 2 and 3.

3.2. *Results from the literature review*

Among the articles selected for the literature review, 10 papers reported [16,32–34,36–40,42] the results of a MISD technique in patients with DS (mean FU 46.00 ± 26.50 months; Table 2) and 2 were comparative works [35,41] between a MISD technique and a decompression with fusion in patients with DS (mean FU 60.10 ± 17.50 months; Table 3). All but the study of Musluman

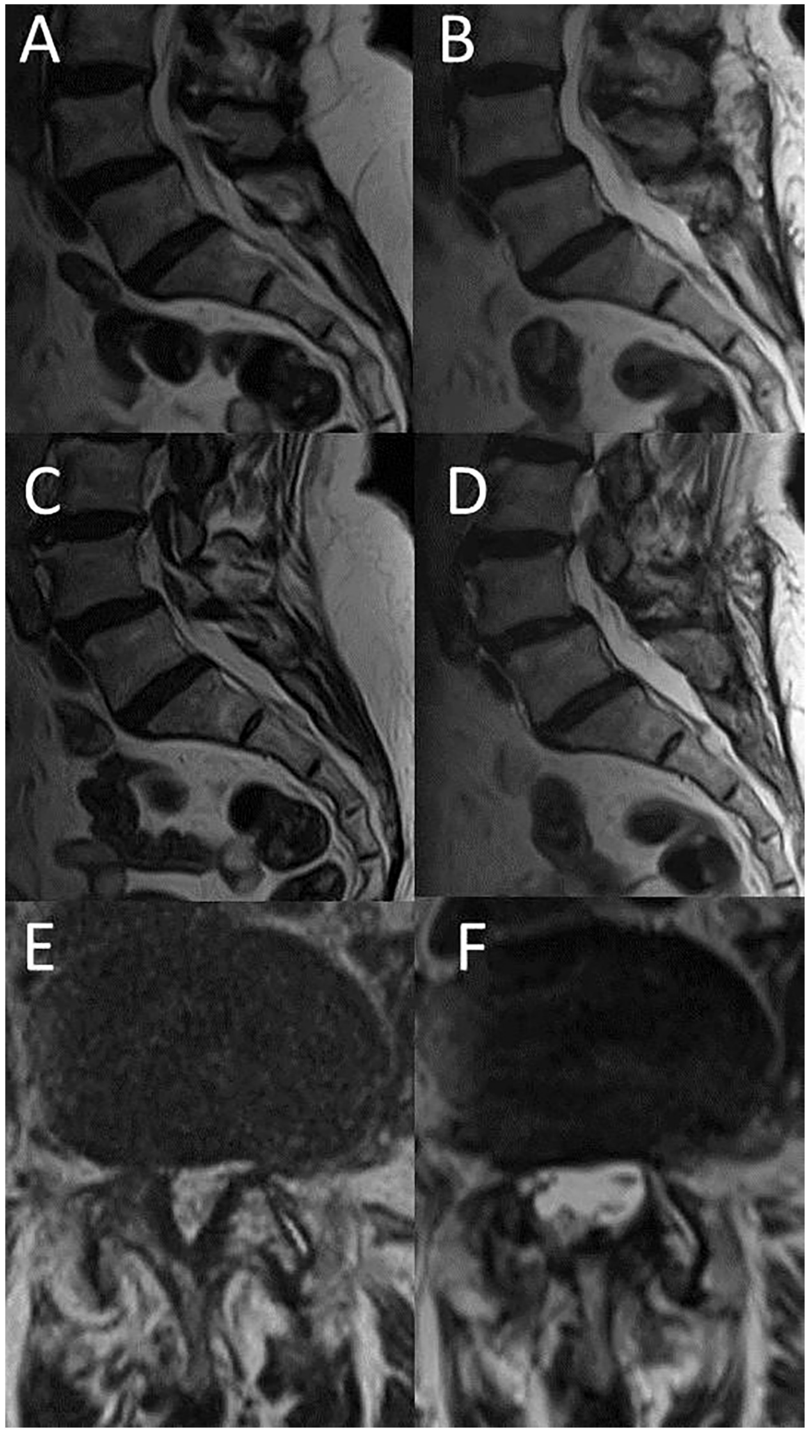

Fig. 3 – Pre-operative T2-weighted (A) sagittal medial cut, (C) sagittal lateral cut and (E) axial spinal lumbar MRI of a 69-year-old woman with a L4–L5 stenosis and spondylolisthesis. The patient was submitted to minimally invasive decompression at this level. One year FU T2-weighted (B) sagittal medial cut, (D) sagittal lateral cut and (F) axial spinal lumbar MRI showing the optimal decompression of dural sac and nerve roots with no change of the degree of spondylolisthesis.

et al. [39] were retrospective papers. 89.55% of cases reported in the literature were operated at one level.

3.2.1. *Non-comparative surgical series (Tables 2 and 4)*

We were able to analyze the differences in ODI in 156 patients and in JOA score in 218 patients (Table 2). We observed a statistically significant improvement of ODI at FU compared with pre-operative (%; pre-operative 41.82 ± 19.34, at FU 18.72 ± 8.72; p = 0.022; mean FU 33.07 ± 18.10 months) as well as a statistically significant improvement of JOA score at FU compared with pre-operative (pre-operative 13.82 ± 0.62, at FU 23.52 ± 1.49; $p < 0.0001$; mean FU 58.25 ± 25.37 months).

Table 2 – Papers reporting the results of a minimal invasive decompression technique in patients with spondylolisthesis.

Authors	Technique	No cases	ODI (%)/JOA pre-operative	ODI (%)/JOA at FU	VAS LBP pre-operative	VAS leg pain pre-operative	VAS LBP at FU	VAS leg pain at FU	Slippage pre-operative (%)	Slippage at FU (%)	Mean FU (mos)
Caralopoulos et al. [32]	ULBD	28	57.00 ± 4.20	26.00 ± 8.80	8.60 ± 0.83[a]		2.30 ± 1.10[a]		NR	NR	12
Dohzono et al. [33]	ULBD	23	12.90 ± 3.40[b]	23.60[b]	NR	NR	NR	NR	10.50 ± 4.60	11.90 ± 5.20	37.7
Ikuta et al. [34]	Endoscopic ULBD	29	14.80 ± 3.50[b]	25.00 ± 2.80[b]	7.10 ± 1.50	7.90 ± 1.40	1.70	1.50	6.80 ± 1.80[c]	7.70 ± 2.10[c]	36.7
		11	13.50 ± 3.80[b]	20.40 ± 3.20[b]	6.70 ± 1.30	7.30 ± 1.80	5.40	1.60	6.10 ± 2.00[c]	7.10 ± 1.50[c]	39.4
Ikuta et al. [16]	endoscopic ULBD	37	14.10 ± 4.10[b]	23.50 ± 3.90[b]	7.30 ± 0.90[a]		3.00 ± 2.10[a]		14.10 ± 5.60	15.70 ± 6.50	38
Jang et al. [36]	ULBD	21	59.52 ± 9.00	26.19 ± 12.42	NR	NR	NR	NR	13.65 ± 4.81	15.87 ± 5.64	49.3
Jasper et al. [37]	TEDF	21	NR	NR	8.48[a]		2.30[a]		NR	NR	12
Mori et al. [38]	Endoscopic MIS	51	14.30[b]	23.60[b]	NR	NR	NR	NR	14.60	17.50	88
Müslüman et al. [39]	ULBD	84	29.76 ± 5.48	13.69 ± 3.38	43.10 ± 12.40	NR	26.80 ± 9.50	NR	22.05 ± 2.78	22.26 ± 2.90	24
Nakanishi et al. [40]	BL	44	13.60 ± 3.80[b]	24.70 ± 3.60[b]	1.50 ± 0.60[d]	0.90 ± 0.30[d]	2.40 ± 0.70[d]	2.30 ± 0.70[d]	15.00 ± 5.10	18.50 ± 6.10	84
	ULBD	23	13.60 ± 3.00[b]	23.90 ± 4.30[b]	1.50 ± 0.70[d]	0.90 ± 0.60[d]	2.20 ± 0.70[d]	2.20 ± 0.80[d]	14.80 ± 4.90	16.20 ± 5.70	84
Sasai et al. [42]	ULBD	23	21.00	9.00	2.20	NR	4.20	NR	NR	NR	47

ODI Oswestry Disability Index; JOA, Japanese orthopaedic score; FU, follow-up; VAS, Visual Analogic Scale; LBP, low back pain; mos, months; ULBD, unilateral approach for bilateral decompression; BL, bilateral laminotomy; TEDF, transforaminal endoscopic discectomy and foraminotomy.
Ikuta et al. [34] divided the population into 2 groups, based on LBP response.
Nakanishi et al. [39] divided the population into 2 groups, based on the used approach.
Mori et al. [41] performed endoscopic MILD in 11 patients and endoscopic ULBD in 40 patients.
[a] Value for both LBP and leg pain.
[b] JOA score.
[c] Value expressed in millimeters.
[d] Pain item of JOA score.

Table 3 – Papers reporting the results of comparative works between a minimally invasive decompression technique and a decompression with fusion in patients with spondylolisthesis.

Author	Technique	No cases	ODI (%)/JOA pre-operative	ODI (%)/JOA at FU	VAS LBP pre-operative	VAS LBP at FU	VAS leg pain pre-operative	VAS leg pain at FU	Slippage pre-operative (%)	Slippage at FU (%)	Mean FU (mos)
Inui et al. [35]	ULBD/BCD	60	11.80 ± 3.70[a]	23.60 ± 4.30[a]	1.30 ± 0.60[b]	2.30 ± 0.80[b]	1.00 ± 0.40[b]	1.90 ± 0.80[b]	5.60 ± 2.60[c]	6.40 ± 2.50[c]	38.00
	PLIF with PS	80	12.50 ± 4.00[a]	23.20 ± 5.20[a]	1.00 ± 0.60[b]	2.20 ± 0.80[b]	1.00 ± 0.50[b]	1.90 ± 0.90[b]	6.50 ± 3.40[c]	2.20 ± 2.10[c]	77.90
Park et al. [41]	ULBD	20	29.80 ± 4.40	15.45 ± 7.06	2.80 ± 3.01	1.20 ± 2.20	7.80 ± 0.91	2.40 ± 2.53	14.10 ± 4.56	14.25 ± 6.14	54.90
	PLIF with PS	25	24.60 ± 5.38	11.00 ± 7.09	6.60 ± 4.70	2.41 ± 2.53	8.00 ± 0.87	2.50 ± 1.80	14.70 ± 4.59	NR	69.40

ODI, Oswestry Disability Index; JOA, Japanese orthopedic association score; FU, follow-up; VAS, Visual Analogic Scale; LBP, low back pain; mos, months; ULBD, unilateral approach for bilateral decompression; PLIF, posterior lumbar interbody fusion; PS, pedicle screws; BCD, bilateral approach for contralateral decompression.

[a] JOA score.

[b] Pain item of JOABPEQ score.

[c] Value expressed in millimetres.

The percentage of slippage (evaluated in 283 patients, mean FU 57.85 ± 26.75 months; Table 2) was substantially unchanged between the pre-operative (%; 14.95 ± 3.48) and FU (%; 16.84 ± 3.15). Although the low back pain and legs pain were statistically significantly improved in all series, we could not make a pooled analysis due to different scales utilized in the different papers (Table 2). The complication rate was evaluated in 300 patients (Table 4). The overall complication rate was 1.6% (5/300 cases). Taking into account also patients with dural tear but without CSF leak the complication rate was 4% (12/300 cases). The overall reoperation rate (Table 4) was 4.5% (16/355 cases).

3.2.2. *Comparative surgical series (Tables 3 and 5)*

There were two comparative papers between a MISD technique and a decompression with fusion in patients with DS. Although a pooled analysis was not possible, a significant improvement of all evaluated scores was reported both for patients submitted to a MISD procedure and patients submitted to decompression and fusion (see Table 3). The overall complication rate (Table 5) was 5% (4/80 cases) for MISD and 8.5% (9/105 cases) for decompression and fusion. The overall reoperation rate (Table 5) was 5% (4/80 cases) for MISD and 5.7% (6/105 cases) for decompression and fusion.

4. Discussion

In this study, we reported the clinical and radiological outcome in patients with DS and LSS submitted to a MISD procedure. Moreover, we performed a literature review of the pertinent papers in order to carefully analyze the clinical and radiological outcomes, the complications and reoperation rate of MISD procedures in these patients. Although various papers reporting the results of MISD procedures in LSS patients have been previously published [22–27], only few works were focused on patients with DS [16,32–41].

In our series, we observed a statistically significant improvement of LBP and legs pain at FU. This finding was strongly confirmed by the literature review. More specifically, four papers evaluated separately LBP and legs pain [34,35,40,41]. Although pain was analyzed with various scales in the different papers, a statistically significant improvement of LBP and legs pain was reported in all works. Notably this improvement was comparable to the one obtained in patients with decompression and fusion [35,41]. We also observed, in our patients, a statistically significant improvement of the degree of disability (evaluated by the ODI score) at FU compared to the pre-operative one. Also this data was strongly confirmed in our literature review. In fact, regardless of the utilized scale (ODI score or JOA score; see Tables 2 and 3) the pooled analysis showed a significant improvement of the degree of disability at FU compared to the pre-operative which was similar to how reported in patients submitted to decompression and fusion [35,41]. Moreover, our results and the literature data evidenced that the percentage of slippage was substantially unchanged between the pre-operative and FU. Although no information has been reported in the considered studies about the sagittal balance which could affect the outcome of these patients, this data is of particular

Table 4 – Complications and reoperations.

Author and year	Technique	No cases	Complication	Dural tear without CSF leak	Reoperation
Caralopoulos et al. [32]	ULBD	28	0	1	0
Dohzono et al. [33]	ULBD	23	0	1	1
Ikuta et al. [34]	Endoscopic ULBD	29	1	0	NR
		11			
Ikuta et al. [16]	Endoscopic ULBD	37	2	0	2
Jang et al. [36]	ULBD	21	0	0	1
Jasper et al. [37]	TEDF	21	NR	NR	3
Mori et al. [38]	Endoscopic MIS*	51	NR	NR	7
Müslüman et al. [39]	ULBD	84	1	4	1
Nakanishi et al. [40]	BL	44	1	1	1
	ULBD	23			
Sasai et al. [42]	ULBD	23	NR	NR	0

CSF, cerebrospinal fluid; ULBD, unilateral approach for bilateral decompression; TEDF, transforaminal endoscopic discectomy and foraminotomy; NR, non-reported; BL, bilateral laminotomy.
These authors [34] divided the population into 2 groups, based on LBP response.
These authors [41] performed endoscopic MILD in 11 patients and endoscopic ULBD in 40 patient.
These authors [39] divided the population into 2 groups, based on the used approach.

Table 5 – Complications and reoperations in comparative papers.

Author and year	Technique	No cases	Complication	Reoperation
Park et al. [41]	ULBD	20	1	1
	PLIF with PS	25	6	0
Inui et al. [35]	ULBD/BCD	60	3	3
	PLIF with PS	80	9	6

ULBD, unilateral approach for bilateral decompression; PLIF, posterior lumbar interbody fusion; PS, pedicle screws; BCD, bilateral approach for contralateral decompression.

interest because it seems to confirm the low incidence of iatrogenic instability associated with a MISD procedure also in DS patients like previously reported in LSS non-spondylolisthetic patients [22–27]. These data rise concerns about the utility of performing a fusion in these patients. It has previously reported that patients with DS may not report ongoing back pain, suggesting that this disorder is unrelated to long-term back pain and physical disability [43]. Moreover, it has recently been evidenced that the decrease of slippage after fusion was not associated to better clinical outcome compared to patients submitted to a MISD procedure [35]. Thus, the recommendation to augment decompression with a fusion procedure in LSS with DS, mainly based on a comparison with laminectomy papers [5,6,9,10] and the relative preservation of spinal stability with MISD procedure may justify the question on the utility of fuse these patients. Two comparative papers tried to address this question [44,45]. Ulrich et al. [45], in a retrospective multicenter study compared decompression alone surgery (standard open or microscopic posterior lumbar decompression) and fusion surgery in patients with LSS and DS, finding that fusion surgery was not associated with a better clinical outcome. Foürsth et al. [44], in a randomized controlled trial, compared decompression alone surgery (laminectomy or bilateral laminotomies) with fusion surgery in patients with LSS (57.9% of patients had also a DS). They found no differences in clinical outcome between the two techniques at 5 years FU.

Recently a systematic review [46] and a meta-analysis [47] have been published with the aim of comparing the outcome of decompression alone (both open laminectomy or MISD techniques included in these two studies) and decompression and fusion in patients with DS. In the study of Dijkerman et al., in which eleven papers were analyzed, the authors found not enough evidence that adding instrumented fusion to a decompression leads to superior outcomes compared to decompression only in patients with LSS and DS. In fact, the most important clinical outcome measures, including the ODI, show comparable results [46]. In the study of Chen et al., including four randomized controlled trials and fourteen nonrandomized controlled studies, these authors found no significant differences in ODI and all quality of life scores between the two treatment groups [47].

Another factor that should be considered when approaching these patients is the complication rate related to these different techniques (MISD and fusion surgery). In our MISD series of DS patients we had no serious complications (only one patient had an incidental durotomy which was repaired with no consequences). Moreover, although to our knowledge, no prospective randomized studies comparing MISD and spinal fusion in DS patients have previously been reported in the literature, our literature review has showed an overall complication rate for MISD procedures of 1.6% (4% taking into account also patients with dural tear but without CSF leak), while the recent meta-analysis of Chen et al. reported that the total complication rate of included studies was 15.3% in the decompression group and 17.0% in the decompression and fusion group [47]. The higher complication rate in decompression group reported in that meta-analysis (15.3%) compared with the lower one observed in our literature review (4%) could be explained by the fact that in the study of Chen et al., also patients submitted to open laminectomy were included in the decompression group while we considered only less invasive MISD procedures in our study. Moreover, the overall reoperation rate (main reasons for reoperation in MISD procedures were: restenosis, stenosis or disc herniation at another level, instability, scoliosis, infection) in our analysis ranged from 4.5% (pooled data from non-comparative surgical series, see Table 4) to 5% (pooled data from comparative surgical series, see Table 5) while recent papers showed an overall reoperation rate for lumbar fusion in DS patients of about 14% [6,48]. Nonetheless, some limits of MISD procedures have previously been reported in the literature. The difficulty of manipulating instruments through a small portal [25,49], the inadequate decompression due to the minimal exposure [50,51] and increased operation time due to the learning curve [52] have been described as the main shortcomings of these minimally invasive approaches.

5. Conclusions

Our study has some limitations such as the small number of patients in our series and the heterogeneous data in the literature review. Obviously further randomized controlled trials are needed to better define the role of MISD procedures, open fusion or percutaneous pedicle screw fixation in patients with DS associated to LSS [53]. Nonetheless MISD procedures seem safe and effective in patients with DS associated to LSS. MISD procedures seem associated with significant improvement of the degree of disability without progression of slippage and low morbidity at FU in these patients.

Conflict of interest

None declared.

Acknowledgement and financial support

None declared.

REFERENCES

[1] Bassewitz H, Herkowitz H. Lumbar stenosis with spondylolisthesis: current concepts of surgical treatment. Clin Orthop Relat Res 2001;54–60.
[2] Herkowitz H. Degenerative lumbar spondylolisthesis. Spine (Phila Pa 1976) 1995;20:1084–90.
[3] Sengupta DK, Herkowitz HN. Degenerative spondylolisthesis: review of current trends and controversies. Spine (Phila Pa 1976) 2005;30:S71–81.
[4] Sigmundsson FG, Kang XP, Jonsson B, Stromqvist B. Prognostic factors in lumbar spinal stenosis surgery. Acta Orthop 2012;83:536–42.
[5] Resnick DK, Watters 3rd WC, Sharan A, Mummaneni PV, Dailey AT, Wang JC, et al. Guideline update for the performance of fusion procedures for degenerative disease of the lumbar spine. Part 9: lumbar fusion for stenosis with spondylolisthesis. J Neurosurg Spine 2014;21:54–61.
[6] Ghogawala Z, Dziura J, Butler WE, Dai F, Terrin N, Magge SN, et al. Laminectomy plus fusion versus laminectomy alone for lumbar spondylolisthesis. N Engl J Med 2016;374:1424–34.
[7] Herkowitz HN, Kurz LT. Degenerative lumbar spondylolisthesis with spinal stenosis. A prospective study comparing decompression with decompression and intertransverse process arthrodesis. J Bone Jt Surg Am 1991;73:802–8.
[8] Kornblum MB, Fischgrund JS, Herkowitz HN, Abraham DA, Berkower DL, Ditkoff JS. Degenerative lumbar spondylolisthesis with spinal stenosis: a prospective long-term study comparing fusion and pseudarthrosis. Spine (Phila Pa 1976) 2004;29:726–33 [discussion 33–4].
[9] Martin CR, Gruszczynski AT, Braunsfurth HA, Fallatah SM, O'Neil J, Wai EK. The surgical management of degenerative lumbar spondylolisthesis: a systematic review. Spine (Phila Pa 1976) 2007;32:1791–8.
[10] Watters 3rd WC, Bono CM, Gilbert TJ, Kreiner DS, Mazanec DJ, Shaffer WO, et al. An evidence-based clinical guideline for the diagnosis and treatment of degenerative lumbar spondylolisthesis. Spine J 2009;9:609–14.
[11] Bhalla A, Schoenfeld AJ, George J, Moghimi M, Bono CM. The influence of subgroup diagnosis on radiographic and clinical outcomes after lumbar fusion for degenerative disc disorders revisited: a systematic review of the literature. Spine J 2017;17:143–9.
[12] Brier-Jones JE, Palmer DK, Inceoglu S, Cheng WK. Vertebral body fractures after transpsoas interbody fusion procedures. Spine J 2011;11:1068–72.
[13] Carreon LY, Puno RM, Dimar 2nd JR, Glassman SD, Johnson JR. Perioperative complications of posterior lumbar decompression and arthrodesis in older adults. J Bone Jt Surg Am 2003;85-A:2089–92.
[14] Chang W, Yuwen P, Zhu Y, Wei N, Feng C, Zhang Y, et al. Effectiveness of decompression alone versus decompression plus fusion for lumbar spinal stenosis: a systematic review and meta-analysis. Arch Orthop Trauma Surg 2017;137:637–50.
[15] Deyo RA, Ciol MA, Cherkin DC, Loeser JD, Bigos SJ. Lumbar spinal fusion. A cohort study of complications, reoperations, and resource use in the Medicare population. Spine (Phila Pa 1976) 1993;18:1463–70.
[16] Ikuta K, Tono O, Oga M. Clinical outcome of microendoscopic posterior decompression for spinal stenosis associated with degenerative spondylolisthesis – minimum 2-year outcome of 37 patients. Minim Invasive Neurosurg 2008;51:267–71.
[17] Phan K, Mobbs RJ. Sacrum fracture following L5-S1 stand-alone interbody fusion for isthmic spondylolisthesis. J Clin Neurosci 2015;22:1837–9.
[18] Ragab AA, Fye MA, Bohlman HH. Surgery of the lumbar spine for spinal stenosis in 118 patients 70 years of age or older. Spine (Phila Pa 1976) 2003;28:348–53.
[19] Shamji MF, Goldstein CL, Wang M, Uribe JS, Fehlings MG. Minimally invasive spinal surgery in the elderly: does it make sense? Neurosurgery 2015;77(Suppl. 4):S108–15.
[20] Shono Y, Kaneda K, Abumi K, McAfee PC, Cunningham BW. Stability of posterior spinal instrumentation and its effects on adjacent motion segments in the lumbosacral spine. Spine (Phila Pa 1976) 1998;23:1550–8.
[21] Chen WJ, Lai PL, Niu CC, Chen LH, Fu TS, Wong CB. Surgical treatment of adjacent instability after lumbar spine fusion. Spine (Phila Pa 1976) 2001;26:E519–24.
[22] Arai Y, Hirai T, Yoshii T, Sakai K, Kato T, Enomoto M, et al. A prospective comparative study of 2 minimally invasive decompression procedures for lumbar spinal canal

stenosis: unilateral laminotomy for bilateral decompression (ULBD) versus muscle-preserving interlaminar decompression (MILD). Spine (Phila Pa 1976) 2014;39:332–40.
[23] den Boogert HF, Keers JC, Marinus Oterdoom DL, Kuijlen JM. Bilateral versus unilateral interlaminar approach for bilateral decompression in patients with single-level degenerative lumbar spinal stenosis: a multicenter retrospective study of 175 patients on postoperative pain, functional disability, and patient satisfaction. J Neurosurg Spine 2015;23:326–35.
[24] Hatta Y, Shiraishi T, Sakamoto A, Yato Y, Harada T, Mikami Y, et al. Muscle-preserving interlaminar decompression for the lumbar spine: a minimally invasive new procedure for lumbar spinal canal stenosis. Spine (Phila Pa 1976) 2009;34: E276–80.
[25] Mobbs RJ, Li J, Sivabalan P, Raley D, Rao PJ. Outcomes after decompressive laminectomy for lumbar spinal stenosis: comparison between minimally invasive unilateral laminectomy for bilateral decompression and open laminectomy: clinical article. J Neurosurg Spine 2014;21:179–86.
[26] Montano NPF, Pignotti P, Fernandez E. Technical nuances of minimal invasive interlaminar decompression in lumbar stenosis: the role of minimal invasive bilateral approach. Open J Mod Neurosurg 2016;06:61–7.
[27] Spetzger U, Bertalanffy H, Reinges MH, Gilsbach JM. Unilateral laminotomy for bilateral decompression of lumbar spinal stenosis. Part II: clinical experiences. Acta Neurochir (Wien) 1997;139:397–403.
[28] Guha D, Heary RF, Shamji MF. Iatrogenic spondylolisthesis following laminectomy for degenerative lumbar stenosis: systematic review and current concepts. Neurosurg Focus 2015;39:E9.
[29] Oertel MF, Ryang YM, Korinth MC, Gilsbach JM, Rohde V. Long-term results of microsurgical treatment of lumbar spinal stenosis by unilateral laminotomy for bilateral decompression. Neurosurgery 2006;59:1264–9 [discussion 9–70].
[30] Palmer S, Davison L. Minimally invasive surgical treatment of lumbar spinal stenosis: two-year follow-up in 54 patients. Surg Neurol Int 2012;3:41.
[31] Podichetty VK, Spears J, Isaacs RE, Booher J, Biscup RS. Complications associated with minimally invasive decompression for lumbar spinal stenosis. J Spinal Disord Tech 2006;19:161–6.
[32] Caralopoulos IN, Bui CJ. Minimally invasive laminectomy in spondylolisthetic lumbar stenosis. Ochsner J 2014;14:38–43.
[33] Dohzono S, Matsumura A, Terai H, Toyoda H, Suzuki A, Nakamura H. Radiographic evaluation of postoperative bone regrowth after microscopic bilateral decompression via a unilateral approach for degenerative lumbar spondylolisthesis. J Neurosurg Spine 2013;18:472–8.
[34] Ikuta K, Masuda K, Tominaga F, Sakuragi T, Kai K, Kitamura T, et al. Clinical and radiological study focused on relief of low back pain after decompression surgery in selected patients with lumbar spinal stenosis associated with grade I degenerative spondylolisthesis. Spine (Phila Pa 1976) 2016;41:E1434–43.
[35] Inui T, Murakami M, Nagao N, Miyazaki K, Matsuda K, Tominaga Y, et al. Lumbar degenerative spondylolisthesis: changes in surgical indications and comparison of instrumented fusion with two surgical decompression procedures. Spine (Phila Pa 1976) 2017;42:E15–24.
[36] Jang JW, Park JH, Hyun SJ, Rhim SC. Clinical outcomes and radiologic changes after microsurgical bilateral decompression by a unilateral approach in patients with lumbar spinal stenosis and grade I degenerative spondylolisthesis with a minimum 3-year follow-up. Clin Spine Surg 2016;29:268–71.
[37] Jasper GP, Francisco GM, Telfeian AE. Transforaminal endoscopic discectomy with foraminoplasty for the treatment of spondylolisthesis. Pain Physician 2014;17: E703–8.
[38] Mori G, Mikami Y, Arai Y, Ikeda T, Nagae M, Tonomura H, et al. Outcomes in cases of lumbar degenerative spondylolisthesis more than 5 years after treatment with minimally invasive decompression: examination of pre- and postoperative slippage, intervertebral disc changes, and clinical results. J Neurosurg Spine 2016;24:367–74.
[39] Musluman AM, Cansever T, Yilmaz A, Cavusoglu H, Yuce I, Aydin Y. Midterm outcome after a microsurgical unilateral approach for bilateral decompression of lumbar degenerative spondylolisthesis. J Neurosurg Spine 2012;16:68–76.
[40] Nakanishi K, Tanaka N, Fujimoto Y, Okuda T, Kamei N, Nakamae T, et al. Medium-term clinical results of microsurgical lumbar flavectomy that preserves facet joints in cases of lumbar degenerative spondylolisthesis: comparison of bilateral laminotomy with bilateral decompression by a unilateral approach. J Spinal Disord Tech 2013;26:351–8.
[41] Park JH, Hyun SJ, Roh SW, Rhim SC. A comparison of unilateral laminectomy with bilateral decompression and fusion surgery in the treatment of grade I lumbar degenerative spondylolisthesis. Acta Neurochir (Wien) 2012;154:1205–12.
[42] Sasai K, Umeda M, Maruyama T, Wakabayashi E, Iida H. Microsurgical bilateral decompression via a unilateral approach for lumbar spinal canal stenosis including degenerative spondylolisthesis. J Neurosurg Spine 2008;9:554–9.
[43] Kauppila LI, Eustace S, Kiel DP, Felson DT, Wright AM. Degenerative displacement of lumbar vertebrae. A 25-year follow-up study in Framingham. Spine (Phila Pa 1976) 1998;23:1868–73 [discussion 73–4].
[44] Forsth P, Olafsson G, Carlsson T, Frost A, Borgstrom F, Fritzell P, et al. A randomized, controlled trial of fusion surgery for lumbar spinal stenosis. N Engl J Med 2016;374:1413–23.
[45] Ulrich NH, Burgstaller JM, Pichierri G, Wertli MM, Farshad M, Porchet F, et al. Decompression surgery alone versus decompression plus fusion in symptomatic lumbar spinal stenosis: a Swiss prospective multi-center cohort study with 3 years of follow-up. Spine (Phila Pa 1976) 2017.
[46] Dijkerman ML, Overdevest GM, Moojen WA, Vleggeert-Lankamp CLA. Decompression with or without concomitant fusion in lumbar stenosis due to degenerative spondylolisthesis: a systematic review. Eur Spine J 2018.
[47] Chen Z, Xie P, Feng F, Chhantyal K, Yang Y, Rong L. decompression alone versus decompression and fusion for lumbar degenerative spondylolisthesis: a meta-analysis. World Neurosurg 2018;111:e165–77.
[48] Sato S, Yagi M, Machida M, Yasuda A, Konomi T, Miyake A, et al. Reoperation rate and risk factors of elective spinal surgery for degenerative spondylolisthesis: minimum 5-year follow-up. Spine J 2015;15:1536–44.
[49] Thome C, Zevgaridis D, Leheta O, Bazner H, Pockler-Schoniger C, Wohrle J, et al. Outcome after less-invasive decompression of lumbar spinal stenosis: a randomized comparison of unilateral laminotomy, bilateral laminotomy, and laminectomy. J Neurosurg Spine 2005;3:129–41.

[50] Oppenheimer JH, DeCastro I, McDonnell DE. Minimally invasive spine technology and minimally invasive spine surgery: a historical review. Neurosurg Focus 2009;27:E9.
[51] Thongtrangan I, Le H, Park J, Kim DH. Minimally invasive spinal surgery: a historical perspective. Neurosurg Focus 2004;16:E13.
[52] Parikh K, Tomasino A, Knopman J, Boockvar J, Hartl R. Operative results and learning curve: microscope-assisted tubular microsurgery for 1- and 2-level discectomies and laminectomies. Neurosurg Focus 2008;25:E14.
[53] Arts MP, Wolfs JF, Kuijlen JM, de Ruiter GC. Minimally invasive surgery versus open surgery in the treatment of lumbar spondylolisthesis: study protocol of a multicentre, randomised controlled trial (MISOS trial). BMJ Open 2017;7:e017882.