Minimally invasive anterior lumbar interbody fusion for adult degenerative scoliosis with 1 or 2 dislocated levels

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OBJECT Frequent complications of posterolateral instrumented fusion have been reported after treatment of degenerative scoliosis in elderly patients. Considering that in some cases, most of the symptomatology of adult degenerative scoliosis (ADS) is a consequence of the segmental instability at the dislocated level, the use of minimally invasive anterior lumbar interbody fusion (ALIF) to manage symptoms can be advocated to reduce surgical morbidity. The purpose of this study was to evaluate the midterm outcomes of 1- or 2-level minimally invasive ALIFs in ADS patients with 1- or 2-level dislocations.

METHODS A total of 47 patients (average age 64 years; range 43–80 years) with 1- or 2-level ALIF performed for ADS (64 levels) in a single institution were included in the study. An independent spine surgeon retrospectively reviewed all the patients' medical records and radiographs to assess operative data and surgery-related complications. Clinical outcome was reported using the Oswestry Disability Index (ODI) and the visual analog scale (VAS) for lumbar and leg pain. Intraoperative data and complications were collected. Fusion and risk for adjacent-level degeneration were assessed.

RESULTS The mean follow-up duration was 3 years (range 1–10 years). ODI, and back and leg pain VAS scores were significantly improved at last follow-up. A majority of patients (74%) had a statistically significant improvement in their ODI score of more than 20 points at latest follow-up and 1 had a worsening of his disability. The mean operating time was 166 minutes (range 70–355 minutes). The mean estimated blood loss was 410 ml (range 50–1700 ml). Six (5 major and 1 minor) surgical complications (12.7% of patients) and 13 (2 major and 11 minor) medical complications (27.7% of patients) occurred without death or wound infection. Fusion was achieved in 46 of 47 patients. Surgery resulted in a slight but significant decrease of the Cobb angle, and improved the pelvic parameters and lumbar lordosis, but had no effect on the global sagittal balance. At latest follow-up, 9 patients (19.1%) developed adjacent-segment disease at a mean of 2 years' delay from the index surgery; 4 were symptomatic but treated medically, and none required iterative surgery.

CONCLUSIONS Single- or 2-level minimally invasive fusion through a minimally invasive anterior approach in some selected cases of ADS produced a good functional outcome with a high fusion rate. They were associated with a significantly lower rate of complications in this study than the historical control.

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KEY WORDS degenerative scoliosis; dislocation; minimally invasive anterior lumbar interbody fusion; aging spine; surgery outcomes; morbidity

ADULT spinal deformity has become a major health issue, with the demographic shift involving an aging population. In people older than 50 years, the prevalence of scoliosis, defined as a spinal deformity with a Cobb angle greater than 10°, is about 6%.¹ It usually ends in some form of uni- or multisegmental sagittal and/or frontal instability (spondylolisthesis, but also translational dislocations in the frontal plane or rotational dislocations).¹ Translatory shift, lateral and rotatory subluxation, lateral spondylolisthesis, lateral subluxation,

lateral translation, lateral slip, lateralolisthy, and rotatoryolisthesis are synonymous terms, all referring to the same lesion³⁰ that we will call dislocation in this study. Some previous studies have focused on the correlation between lateral spondylolisthesis and curve progression and pain.^{19,26,27,30}

The treatment of adult degenerative scoliosis (ADS) remains a challenging problem. Surgical management may be indicated in case of failure of nonsurgical management. It includes, more often, a posterior fusion with pedicle

ABBREVIATIONS ADS = adult degenerative scoliosis; ALD = adjacent-level degeneration; ALIF = anterior lumbar interbody fusion; AP = anteroposterior; EBL = estimated blood loss; LL = lumbar lordosis; ODI = Oswestry Disability Index; PI = pelvic incidence; SFD = sacrofemoral distance; SSA = spinosacral angle; SVA = sagittal vertical axis; VAS = visual analog scale.

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screw instrumentation in addition to decompression of neural elements.¹ It is associated with a rather high rate of complications, up to 80%, especially in the elderly population.^{9,27} Age, medical comorbidities, being overweight, increased blood loss, and the number of levels fused seem to have an impact on the complication rate.^{7,10,13,22} We hypothesized that fusion of the single dislocated level(s) through a minimally invasive anterior approach would relieve pain with lower morbidity, and the purpose of this review was to evaluate its midterm outcomes.

Methods

Study Design

A retrospective study was conducted to evaluate the efficacy of video-assisted anterior lumbar interbody fusion (ALIF) in the surgical treatment of lumbar or thoracolumbar ADS including 1- or 2-level dislocations.

Participants

Inclusion criteria were as follows: age older than 40 years; degenerative lumbar or thoracolumbar scoliosis with a Cobb angle greater than 10° on anteroposterior (AP) radiographs, including 1- or 2-level dislocation, defined as a lateral vertebral translation higher than 3 mm at the apex of the deformity; back and/or leg pain refractory to appropriate conservative treatment conducted for more than 12 months; and having undergone surgery between 2000 and 2010.

Exclusion criteria were idiopathic adolescent scoliosis of the lumbar spine that had progressed in adult life; ADS without dislocation; ADS with more than 2 dislocations; and contraindication to an anterior approach to the lumbar spine, excluded disc herniation, or presence of a previously implanted posterior device at the level to be treated. Sagittal imbalance was not an exclusion criterion.

Surgical Technique

The anterolateral retroperitoneal approach was performed with fluoroscopic and videoscopic control after positioning the patient in a lateral position. After a minilumbotomy (5–8 cm) centered over the apex from the convex side, the lumbar spine was approached using mini-invasive techniques (muscle splitting of the abdominal wall and psoas muscle retraction techniques; muscles were not cut, nor was a transpsoas approach used). An endoscope was used to provide light for the surgeon and visualization for the surgical assistants. After extensive discectomy, especially in the concave part of the intervertebral space to open it, the cartilage endplate was removed and the proper size of the implant was determined using the trial implants. Particular attention was paid to preserving both endplates during preparation of the disc and implant insertion. Interbody cages filled with either bone graft harvested from the iliac crest alone (n = 7) or combined with rhBMP-2 (recombinant human bone morphogenetic protein–2) (n = 40) (4 mg InductOs [diboterminal alfa]; Medtronic Inc.) were inserted under fluoroscopic control in the intervertebral space to maintain the correction and promote fusion. In cases of poor bone quality, anterior vertebral plating was also used (Table 1).

Outcomes

A database including preoperative demographic data, medical history, characterization of pain, claudicating symptom, intra- and postoperative data, and radiographs of patients who had ALIF via a minimally invasive anterior approach for degenerative scoliosis was reviewed by an independent spine surgeon. The comorbidities were analyzed according to the American Society of Anesthesiologists score.²⁵ Charts were used for collection of perioperative data (blood loss, surgical time, and any medical- and surgery-related complications) and postoperative data, including clinical and radiological issues, and revision surgeries.

Preoperatively and at last follow-up, patients completed questionnaires, including the standardized Oswestry Disability Index (ODI),³² the 36-Item Short Form Health Survey,³⁴ and the visual analog scale (VAS) for lumbar and leg pain (0–10 cm). Patients also rated satisfaction regarding 4 items—the procedure, low-back pain, leg pain, and walking capacity—as follows: 1, highly satisfied; 2, satisfied; 3, unsatisfied; and 4, very unsatisfied.

Preoperatively, each patient underwent MRI and lumbar and full-spine AP and lateral radiography in a standardized standing position with fingers of the upper arm overlying the ipsilateral clavicles. At each follow-up visit, patients underwent lumbar and full-spine AP and lateral radiographs. A CT scan was acquired at 1-year follow-up to assess fusion graded as follows: acquired fusion: trabecular bone continuity between the 2 vertebrae within and/or out of the cage, at least on 1 image in the sagittal and/or coronary plane; fusion failure: no trabecular bone continuity between the 2 vertebrae within and/or out of the cage, in both planes; and doubtful fusion.

The radiographs were evaluated for several parameters by a blinded, independent, single reviewer using the Kodak Carestream Picture Archiving and Communications System (Eastman Kodak/Carestream Health). From the frontal plane, the following were recorded: Cobb angle of the scoliotic curvature, and maximal lateral spondylolisthesis (offset) between any 2 adjacent lumbar vertebrae, which was evaluated as a slip percentage (ratio between the width of the uncovered endplate and the total endplate's width) (Fig. 1).

TABLE 1. Instruments used to achieve spinal fusion

Medical Device	No. of Patients (%)	Fusion Level (no. of patients)		No. of Fused Levels
		1	2	
HMA cage (stand-alone)*	4 (8.5)	4	0	4
+ Vantage plate†	5 (10.6)	2	3	8
ROI-A cage (stand-alone)‡	23 (48.9)	15	8	31
+ Vantage plate†	6 (12.8)	2	4	10
Avenue L cage (stand-alone)‡	9 (19.2)	7	2	11
Total	47	30	17	64

HMA = hollow modular anchorage; ROI-A = radiolucent open implant–anterior.

* Aesculap Implant Systems.

† Medtronic Sofamor Danek USA.

‡ LDR Medical.

From the sagittal plane, the following were recorded: lumbar lordosis (LL) (from L-1 to S-1), pelvic incidence (PI), sacral slope, pelvic tilt, spinosacral angle (SSA) (the angle between a line connecting C-7 to the midpoint of the sacral plate and the sacral plate), sagittal vertical axis (SVA) and SVA to sacrofoemoral distance (SFD) ratio (SFD is the horizontal distance between the vertical bicoxofemoral axis and the vertical line passing through the posterior corner of S-1) (Fig. 2).^{4,21}

Instrumentation loosening or breakage and degenerative alterations of adjacent levels, defined as a loss of disc space height greater than one-third of the previous disc height, or emergence of a spondylolisthesis adjacent to the fused level, were noted.

The primary outcome was the functional outcome, evaluated from standardized ODI questionnaires³² and the VAS. The secondary outcome was the risk of adjacent-level degeneration (ALD).

Statistical Analysis

Statistical analysis included descriptive statistics and Student t-test. SPSS version 18.0 (IBM Corp.) was used for analysis. Results are expressed as the mean (range). Statistical significance was set at $p < 0.05$.

Results

Preoperative Patient Data

A total of 47 consecutive patients (64 levels fused) were included in the study and reviewed at a mean follow-up time of 3 years (range 1–10 years). None was lost to follow-up. The demographic and functional characteristics of the patients are summarized in Tables 2 and 3. Seventeen patients (36.2%) had undergone a previous spine surgery. All 47 patients presented a degenerative lumbar ($n = 29$) or thoracolumbar ($n = 18$) scoliosis with 64 dislocations located at L2–3 ($n = 11$), L3–4 ($n = 36$), or L4–5 ($n = 17$). Seventeen patients (36.2%) showed 2 dislocated levels. The mean slippage of the lateral spondylolisthesis was 14.3% (range 5%–26%). Dislocated levels included 14 anterolistheses and 7 retrolistheses. Preoperative pelvic and sagittal balance parameters are summarized in Table 4.

FIG. 1. The Cobb angle was measured by taking the angle of the lines that intersect from the perpendicular line drawn from the endplates of the most angulated vertebrae involved in the pathological curves. The maximal lateral spondylolisthesis (offset) was evaluated as a slippage percentage (i.e., the ratio between the width of the uncovered endplate (a) and the total endplate's width (b)).

FIG. 2. Illustrations indicating sagittal parameters. **Left:** Pelvic parameters: PI, sacral slope (SS), and pelvic tilt (PT). **Right:** Other sagittal parameters: lumbar lordosis (from L-1 to S-1), SSA (the angle between a line connecting C-7 to the midpoint of the sacral plate and the sacral plate), SVA, and SVA to sacrofoemoral distance (SFD) ratio (SFD is the horizontal distance between the vertical bicoxofemoral axis and the vertical line passing through the posterior corner of S-1). Figure is available in color online only.

Procedural Data

A single-level ALIF was performed in 30 patients (63.8%: L2–3 in 2 cases, L3–4 in 20 cases, L4–5 in 8 cases) and a 2-level ALIF in 17 patients (36.2%: L2–4 in 8 patients [Fig. 3], L3–5 in 8 patients, and 2 ALIF at L2–3 and L4–5 in 1 patient). Mean operating time was 166 minutes (range 70–355 minutes). The mean estimated blood loss (EBL) was 410 ml (range 50–1700 ml), exceeding 500 ml in 9 cases (19.1%). Plating was judged necessary in 11 cases (23.4%). Complementary posterolateral fusion with pedicle screw fixation was performed in 2 patients because of insufficient anterior fixation due to poor bone quality.

Clinical Outcome

The mean ODI score, VAS low-back pain scores, and VAS leg pain scores significantly improved at the latest follow-up compared with preoperative scores (Tables 3 and 5). The majority (74%) of patients had a statistically significant improvement in their ODI score of more than 20 points at latest follow-up and 1 had a worsening of his disability. Patient satisfaction rates are summarized in Fig. 4.

Radiological Outcome

Fusion was achieved at 63 of 64 levels; 1 patient had a nonunion complicated by an implant loosening, which necessitated a complementary posterolateral fusion. Modifications of the radiological pelvic and spine parameters are summarized in Table 4 and can be seen in Fig. 5. Surgery resulted in a slight but significant decrease of the Cobb

TABLE 2. Summary of demographics and symptoms

Demographics	
Average age at op, yrs (range)	64 (43–80)
M/F ratio (%)	9 (19)/38 (81)
Average BMI, kg/m ² (range)	26.15 (19–34)
Medical history & comorbidities, no. (%)	
ASA score	
I	12 (25.5)
II	34 (72.4)
III	1 (2.1)
History of spine surgery	17 (36.2)
Smoking	6 (12.7)
Obesity*	10 (21)
Symptoms, no. (%)	
Low-back pain	47 (100)
Leg pain	44 (93.6)
Claudication	37 (78.7)

ASA = American Society of Anesthesiologists; BMI = body mass index.

* BMI > 29.9 kg/m².

angle and improved the pelvic parameters, but had no effect on the global sagittal balance. At latest follow-up, 9 patients (19.1%) developed adjacent-segment disease at a mean follow-up of 30 months (range 6–60 months); 4 of them were symptomatic but treated medically, and none required iterative surgery.

Complications

Specifics of each type of complication are listed in Table 6. The vascular and ureteral injuries were treated by end-to-end anastomosis by a specialist surgeon, with no sequelae. One corporeal fracture and 2 endplate fractures occurred during implantation of the interbody cage, necessitating a complementary instrumentation with an anterior plate in 2 cases (4.3%) and a vertebroplasty with cement in 1 case (2.1%).

The 2 patients who had the 3 major medical complications (6.4%) required an intensive care unit stay. There were no reports of stroke, phlebitis, or pulmonary embolism; no deaths; and no infection of the surgical wound. The EBL exceeded 500 ml in 9 patients (19.1%) and 4 patients (8.5%) received a transfusion. One patient had a persisting, complete, postoperative L-5 palsy without residual compression on CT scan.

Revision Surgeries

Four patients (8.5%) needed to undergo a revision surgery: 2 at the index level and 2 at another level. A cage mobilization resulting from a fall 9 months after surgery occurred in a patient with Parkinson's disease and a nonunion necessitated a complementary decompression and posterolateral fusion. One patient had an intraoperative L-3 vertebral body fracture during a L3–4 fusion, which required a revision anterior approach and L2–4 fusion. One disc herniation adjacent to the fused level at a 15-month follow-up was successfully surgically treated. Posterior fusion in a patient with L5–S1 isthmic spondy-

TABLE 3. Functional outcomes

Parameter	Functional Outcome Score (range)		p Value
	Preop	Latest Follow-Up	
ODI score	51 (32–80)	25 (0–60)	<0.001
SF-36 score			
Physical	25.7 (6.7–89)	50 (8.3–88)	<0.01
Mental	29.9 (12–67)	54 (20.5–90)	<0.01
VAS score			
Back pain	63 (10–90)	31 (0–90)	<0.001
Leg pain	60 (0–100)	23 (0–82)	<0.001
Walking capacity, m	421 (10–2000)	4934 (30–10,000)	<0.001

SF-36 = 36-Item Short Form Health Survey.

lolisthesis, preoperatively noted but not included in the fusion, was performed 15 months after an L2–4 fusion.

Discussion

ADS is the result of asymmetrical disc degeneration and facet-joint arthritis, which induce frontal deviation and rotation of the spine.^{26,30} Ultimately, a lateral spondylolisthesis appears at the most degenerative level(s) and is a sign of evolution of the scoliosis.²⁰ It is responsible for low-back pain and root entrapment,³¹ leading to neurogenic claudication and decreased autonomy. According to Oskouian and Shaffrey, the goals of the surgery for scoliosis should always be to achieve the following: 1) restoration of sagittal balance; 2) decompression of compromised neural elements; 3) minimization of complications, pain, and discomfort; and 4) improvement of quality of life.²⁴ However, should we treat adolescent and adult deformity the same way? Indeed, patients with ADS are older and have shorter life expectancy than the population with idiopathic scoliosis. Thus, their demands of daily life, professional performance, and leisure activities vary substantially. The perioperative rates of complication are high with ADS correction procedures and the number of levels to fuse is significantly associated with a higher rate of complications, especially infection.^{10,13} Consequently, in this elderly population with increased incidence of medical comorbidities, the analysis of the risk/benefit balance must be considered before any surgical treatment. These factors have provided impetus to the desire to address spinal deformity in the elderly patient, using minimally disruptive techniques.^{3,17} Numerous techniques have been described, from local decompression to complete correction of the deformity with fusion. To date, there is no evidence of the superiority of any of the existing procedures.

We demonstrated in this series that in the smaller frontal deformities, between 10° and 60°, limited fusion of the dislocated level(s) and restoration of disc height to release the root entrapment significantly improves the patient's function, pain, and quality of life. We report an average ODI decrease of 26 points, with 74% of patients having a significant improvement of more than 20 points in their ODI score at latest follow-up, confirming the quality of midterm functional results after limited lumbar fusion

TABLE 4. Radiological outcome: Cobb angle and sagittal balance parameters

Parameter	Radiological Measure (range)		p Value
	Preop	Latest Follow-Up	
Mean Cobb angle	23.1° (10°–60°)	17.9° (0°–73°)	<0.001
Mean PI	57° (38°–74°)	57° (38°–74°)	NS
Mean pelvic tilt	21.8° (6°–34°)	21.3° (5°–34°)	NS
Mean sacral slope	35.1° (18°–54°)	35.6° (6°–34°)	0.049
Mean LL L1–S1	43° (7°–75°)	49° (10°–64°)	0.003
Mean SVA/SFD ratio*			
≤0	–0.565 (–0.15 to –1.06); n = 6	–1.315 (–0.15 to –3.56); n = 7	
>0 to ≤1	0.365 (0.04–0.85); n = 18	0.471 (0.06–0.85); n = 21	
>1	1.244 (1.06–1.73) n = 5	1.348 (1.07–1.66) n = 7	
SSA	124.6° (106°–140°)	124.5° (99°–140°)	NS

LL = lumbar lordosis; NS = nonsignificant.

* A negative value means that SVA is anterior to the femoral heads, resulting in sagittal imbalance. A value > 1 means the SVA is posterior to the posterior point of S-1, resulting in a well-balanced spine. A value from 0 to 1 means the SVA projects between the femoral head and the S-1 vertical line, resulting in a compensated, unbalanced spine.

(Table 3). These data compare favorably with a recent literature review by Yadla et al. reporting on functional results and complications after scoliosis surgery, in which 11 studies (911 patients) reported an average ODI score decrease of 15.7 points (range 3.1–32.3 points).³⁵ Patients were more satisfied with the decrease of their low-back pain than their leg pain (Fig. 4). However, the decrease in VAS leg pain score (60 to 23) confirms that instability of the dislocated level is one of the main causes of radiculopathy and that posterior decompression is not necessary in most cases (1 case in our series). Besides, the outcome seems to slightly deteriorate over time (Table 5). This might be due to progression of the deformity because of disc degeneration or osteoporotic fractures.

Frontal deformity is significantly but not fully corrected with this technique. The LL is significantly improved (less than 10°) but the global sagittal balance represented by the SSA is unchanged (Table 4). This is because we performed limited fusions without any posterior osteotomy

that might have further improved correction. Moreover, at the beginning of our experience, we used nonlordotic cages, which increase disc height but are less efficient in increasing segmental lordosis.²⁹ However, the patients reported good midterm outcome (Tables 3 and 5), which proves that their clinical improvement is mainly due to the treatment of neurological symptoms, instability, and/or regional osteoarthritis. Moreover, we need to point out that the mismatch between LL and PI was mild for this group of patients, which probably explains why they reported a good outcome without correction of their sagittal balance. These data are supported by the fact that no significant correlation between the importance of the curve and the symptoms can be found in the literature, and that numerous studies have shown a significant correlation between the presence of a lateral spondylolisthesis and pain in the scoliotic population.^{19,26} Therefore, treatment of this patient population should be more focused on the management of symptoms due to spinal column incom-

FIG. 3. Radiographs of a 63-year-old male patient with lumbar degenerative scoliosis. Anteroposterior preoperative view (A) with the apex to the right at L-3. The patient had a previous L3–5 decompression. Anteroposterior (B) and lateral (C) postoperative radiographs after L2–4 ALIF using Avenue L cages.

TABLE 5. Functional outcomes according to follow-up

Parameter	Follow-Up Duration		
	<2 Yrs (n = 15)	2–5 Yrs (n = 26)	≥5 Yrs (n = 5)
ODI score (range)	10 (5–12)	23.6 (2–53)	17.3 (5–28)
SF-36 score (range)	87.25 (83–93)	50 (8.3–88)	84 (80–88)
VAS: back pain (range)	13 (0–40)	23 (0–56)	27 (0–70)
VAS: leg pain (range)	13 (0–40)	19 (0–46)	22 (0–70)
Walking capacity, m (range)	5778 (30–10,000)	4534 (50–10,000)	4534 (50–10,000)

petency and not necessarily directed at the deformity *per se*, but rather with deformity as an important subcontext.³³ However, as demonstrated by Mummaneni et al.,²³ severe deformities should not be treated with this method, as SVA will not be restored with it. Furthermore, this surgical option has limited ability to restore LL in cases where LL-PI mismatch is greater than 30°.

The complication and morbidity rates in this older and fragile population can be significantly reduced by the described procedure of limited lumbar fusion using minimally invasive techniques. With an overall complication rate of 14.2%, including 5 major surgical and 2 major medical complications, with no postoperative death or wound infection (reported in other minimally invasive surgical series³³), and 1 case of nonunion (2.1%), our series compares favorably with results of other surgical series.^{3,5,28,33,35} In the review by Yadla et al., 41 articles reported on 897 complications (2175 patients), giving a pooled incidence of 41.2%.³⁵ Thirty-nine articles (2469 patients) reported on 319 cases of pseudarthrosis, giving a pooled incidence of 12.9%. In a series of 79 patients, Blamoutier et al. found 32% had severe complications, and a second operation was necessary in 25% of the patients at 1 year and 50% of the patients at 6 years of follow-up.⁵ Minimally invasive lumbar fusion logically minimizes morbidity and complication rate compared with extensive posterior fusion. We obtained perioperative complication rates similar to those

of Anand et al., who reported a 22.9% rate of complications in a recent retrospective study in a series of 71 patients treated for scoliosis by minimally invasive surgery.³ Blood loss is a major concern in this elderly population. It is associated with delirium and increasing morbidity and mortality.³ Posterior instrumented spinal fusion has been reported to have a blood loss range of 1 to 3 L.^{2,6,14,16} Short-segment instrumentation via mini-invasive techniques considerably decreases blood loss, with an average of 410 ml in our series, exactly equal to that of Anand et al. (mean blood loss 412 ml).³ Osteoporosis is a major concern in this population and must be assessed preoperatively. In this series, anterior plating was judged necessary in 23.4% of cases (Table 1) and a fracture occurred 3 times (6.3%) (Table 6). In case of poor bone quality, the risk of fracture or cage subsidence prevents the use of stand-alone cages, and, therefore, anterior plating or complementary posterior instrumentation should probably be considered.

Adjacent-level degeneration is defined as a disc deterioration adjacent to a surgically fused level, symptomatic or not, with a minimum 6-month asymptomatic period after surgery.¹¹ Despite the absence of surgical correction of the whole spinal deformity, we report a relatively low level of ALD (19.1%) and 2 cases of adjacent-level surgery after the index fusion. This compares favorably to other series reporting 16%–42.6% of patients with ASD, with 15%–30.3% being symptomatic.^{8,18} Risk factors for the occurrence of ALD include low (< 20°) postoperative segmental lordotic angle, the existence of a previous degenerative disc disease or previous facet degeneration, older age,¹² and excess of disc distraction.¹⁵ Number of fused levels, LL, excessive weight, and sex are controversial risk factors, even though numerous studies have reported an increased severity of ALD with increasing number of levels fused.^{11,19} We hypothesize that the relatively low level of ALD in our series is due to the very low number of levels fused, the absence of a posterior approach damages the muscles, and the absence of pedicle screws, which may injure the facets of the adjacent level to the fusion.

Nevertheless, the present series should be interpreted in the context of its limitations, including the retrospective, noncontrolled nature of the data and the heterogeneity of the population and instrumentation used during the course of our experience over 10 years. Fine analysis of correlation between sagittal imbalance and clinical results, therefore, was not possible. Another limitation of this study is the significant disparity in the follow-up time (between 1 and 10 years), which makes the interpretation of data difficult, especially to determine whether the progression

FIG. 4. Bar graph of patient satisfaction regarding the procedure, the improvement of their low-back pain (LBP), leg pain, and walking capacity.

FIG. 5. Lateral long-cassette radiographs showing 1 patient's sagittal balance. **Left:** Preoperative radiograph. **Right:** Postoperative radiograph at 1-year follow-up.

of ALD rates is acceptable compared with longer fusion constructs. However, literature on this topic is relatively scarce, and this study adds to a growing body of evidence that single- or 2-level, minimally invasive ALIF is an efficient alternative to the standard invasive treatment with long fusion in ADS, including 1- or 2-level dislocation with a Cobb angle lower than 60° in an aging population.

Prospective additional follow-up is needed to evaluate the fate of the functional and radiological results, especially at adjacent levels. In particular, further analysis of the role of the coronal and sagittal imbalance on the adjacent disc and posterior facets' degeneration needs to be done. Our goal is to determine the limit values of the Cobb angle and other scoliosis parameters, which can allow us to perform short fusion with a good predictive outcome and also to analyze the sagittal imbalance parameters that will contraindicate short fusions and impose some surgical corrections and long fusions.

Conclusions

Midterm outcome of 1- or 2-level minimally invasive ALIF in the treatment of lateral spondylolisthesis in ADS

TABLE 6. Perioperative complications in 47 patients who underwent surgery for adult degenerative scoliosis with lateral spondylolisthesis at 1 or 2 levels

Complication	Complication, No. (%)	
	Major	Minor
Surgical complications (overall rate 12.7%)		
No. of patients	5 (10.6)	1 (2.1)
Type		
Iliac vein laceration	1 (2.1)	
Ureteral injury	1 (2.1)*	
L-3 corporeal fracture	1 (2.1)	
Endplate fractures	2 (4.2)	
L-5 palsy		1 (2.1)
Medical complications (overall rate 27.7%)		
No. of patients	2 (4.2)	11 (23.5)
Type		
Acute coronary syndrome†	1 (2.1)	
Cardiac arrest‡	1 (2.1)	
Acute cardiac arrhythmia§	1 (2.1)	
Common bile duct lithiasis		1 (2.1)
Acute urinary retention		6 (12.8)
Urinary tract infections		4 (8.5)
Paralytic ileus		1 (2.1)

* This complication occurred during a revision surgery.

† Low blood flow related to iliac vein laceration.

‡ Related to anaphylactic reaction to ondansetron injection.

§ Necessitated pacemaker implantation.

with smaller frontal deformities shows decreased back and leg pain, decreased invalidity, and increased quality of life. In these cases, most of the symptoms are related to lateral instability more than to deformity and imbalance. This technique allows some correction of the frontal deformity and an increase of LL without significant change in the global sagittal alignment. Therefore, patient selection is of the utmost importance to obtain a good outcome and decrease the rate of complications. Patients with multilevel instability and severe sagittal imbalance should probably not undergo surgery with this technique. Morbidity, including blood loss, is decreased compared with that attendant on long posterior fusions. Osteoporosis should be assessed preoperatively to avoid intraoperative fractures and/or to plan complementary posterior instrumentation, if necessary.

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