Stand-Alone Percutaneous Pedicle Screw Lumbar Fixation to Indirectly Decompress the Neural Elements in Spinal Stenosis: A Radiographic Assessment Case Series

Roberto Gazzeri[1] Konstantinos Panagiotopoulos[2] Marcelo Galarza[3] Matteo Luigi Giuseppe Leoni[4] Umberto Agrillo[2]

[1] Department of Neurosurgeon - Pain Therapy, San Giovanni-Addolorata Hospital, Roma, Lazio, Italy
[2] Department of Neurosurgery, San Giovanni-Addolorata Hospital, Roma, Lazio, Italy
[3] Department of Neurosurgery, Virgen de la Arrixaca University Hospital, El Palmar, Murcia, Spain

Address for correspondence Roberto Gazzeri, MD, Unit of Interventional and Surgical Pain Management, San Giovanni-Addolorata Hospital, Via Amba Aradam 9, Roma, Lazio 00184, Italy (e-mail: robertogazzeri@gmail.com).

[4] Unit of Interventional and Surgical Pain Management, Guglielmo da Saliceto Hospital, Piacenza, Emilia-Romagna, Italy

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Abstract

Background The ideal surgical treatment of lumbar canal stenosis remains controversial. Although decompressive open surgery has been widely used with good clinical outcome, minimally invasive indirect decompression techniques have been developed to avoid the complications associated with open approaches. The purpose of this study was to evaluate the radiologic outcome and safety of the indirect decompression achieved with stand-alone percutaneous pedicle screw fixation in the surgical treatment of lumbar degenerative pathologies.

Methods Twenty-eight patients presenting with spinal degenerative diseases including concomitant central and/or lateral stenosis were treated with stand-alone percutaneous pedicle screw fixation. Radiographic measurements were made on axial and sagittal magnetic resonance (MR) images, performed before surgery and after a mean follow-up period of 25.2 months. Measurements included spinal canal and foraminal areas, and anteroposterior canal diameter.

Results Percutaneous screw fixation was performed in 35 spinal levels. Measurements on the follow-up MR images showed statistically significant increase in the cross-sectional area of the spinal canal and the neural foramen, from a mean of 88.22 and 61.05 mm^2 preoperatively to 141.52 and 92.18 mm^2 at final follow-up, respectively. The sagittal central canal diameter increased from a mean of 4.9 to 9.1 mm at final follow-up. Visual analog scale (VAS) pain score and Oswestry Disability Index (ODI) both improved significantly after surgery ($p < 0.0001$).

Conclusion Stand-alone percutaneous pedicle screw fixation is a safe and effective technique for indirect decompression of the spinal canal and neural foramina in lumbar degenerative diseases. This minimally invasive technique may provide the necessary decompression in cases of common degenerative lumbar disorders with ligamentous stenosis.

Keywords
- neurogenic claudication
- degenerative lumbar spine
- decompression
- MRI
- percutaneous fixation
- spinal fixation
- minimally invasive spinal approach
- foraminal area
- spinal canal

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Georg Thieme Verlag KG,
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Introduction

Lumbar stenosis is characterized by diminished space available for neural and vascular elements in the spine, occurring in the central, lateral recess, or foraminal areas due to soft and/or bone tissue encroachment.[1,2] Reduction of the spinal canal space and neural foramina may also be found in cases of disk degeneration and/or spinal malalignment, as in spondylolisthesis or lumbar scoliosis. When conservative management fails to alleviate neurologic symptoms, direct resection of the posterior elements of the spinal column is indicated. For this purpose, laminectomy and/or facetectomy usually offer sufficient decompression of the neural structures.[3,4] Complications associated with these direct decompressive procedures are nerve root injury, incidental durotomies, infections, epidural hematoma, and postoperative fibrosis.[5–7] Furthermore, extensive laminectomy/facetectomy with resection of the posterior bony/ligamentous elements may result in increased instability, thus necessitating instrumented fusion procedures. Minimally invasive indirect decompression techniques have been developed to avoid the complications associated with open approaches.[8–13] Our technique utilizes stand-alone percutaneous pedicle screw fixation in distraction, providing indirect decompression of the spinal canal and neural foramina. This minimally invasive surgical technique may restore posterior disk height and correction of the malalignment through the ligamentotaxis of the posterior longitudinal ligament, stretching the redundant ligamentum flavum, thus enlarging the interlaminar space and neural foramina areas. The purpose of this study is to quantify the indirect decompression achieved in stand-alone percutaneous pedicle screw fixation and to evaluate the safety of this technique in the treatment of spinal ligamentous stenosis.

Patients and Methods

This study was a retrospective, single cohort, single-center, radiographic evaluation of patients with symptomatic lumbar degenerative diseases with central and/or lateral stenosis and low-grade segmental lumbar instability who underwent surgery with stand-alone percutaneous pedicle screw fixation technique. We included all the patients operated on between January 2014 and June 2018, who completed at least 12 months of postoperative radiographic follow-up with X-rays and magnetic resonance imaging (MRI). This yielded 28 consecutive patients with common degenerative lumbar disorders and ligamentous stenosis. During the same period of time, open lumbar spine decompression was performed in 318 cases.

All procedures performed were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration. Informed consent was obtained from all individual participants included in the study. All procedures were performed by experienced neurosurgeons. Hospital records were reviewed, and patients' demographic data and information on surgical indication, treatment level, operative details, and complications were collected using standardized data collection forms. Preoperative pathologies included low-grade lumbar spondylolisthesis and spinal canal and/or foraminal stenosis with associated microinstability. Candidates for the study were patients with low back pain (LBP) and neurogenic claudication, experiencing relief of symptoms in a forward flexed posture. The patients were referred to us after failure of extensive conservative treatment (physical therapy, anti-inflammatory medications, analgesics, and brace) for longer than 6 months. The minimum follow-up for inclusion in this study was 12 months. The exclusion criteria included previous history of spinal surgery, life expectancy of less than 2 years, severely increased risk of surgery due to cardiovascular or pulmonary diseases or other significant comorbidities, mid- or high-grade spondylolisthesis, major spinal lumbar deformities, and severe bony stenosis. All the patients in the present study had preoperative MRI scan available for evaluation. Overall, 52 patients were identified, approached via telephone, and counseled regarding the proposed follow-up investigation. A total of 28 patients agreed to perform lumbar spinal MRI and X-ray for follow-up. We found no correlation between refusal of participation and clinical outcome.

Surgical Technique

The aim of surgical treatment was the indirect decompression of the neural elements within the spinal canal. In all cases, the screws (Illico, Alphatec Spine, Carlsbad, California, United States and Viper MIS Spine System, DePuy Spine, Johnson & Johnson, Raynham, Massachusetts, United States) were inserted bilaterally with a standard percutaneous technique, under fluoroscopic control, to guide screw placement.[14,15] The rods were contoured and temporarily secured to the caudal and cranial screws. Once the caudal nuts were tightened over the rods, the pedicle screws were distracted to perform a ligamentotaxis increasing the interbody disk height, stretching the ligamentum flavum, and enlarging the neural foramina, and then the cranial nuts were tightened. A final intraoperative fluoroscopic control was obtained to confirm correct screw and rod positioning and increase in intervertebral disk space height and enlargement of the neural foramina (►**Fig. 1**). No patient underwent interbody and/or posterolateral fusion with bone graft and cages as an additional procedure.

Radiographic Analysis

Disk height, canal area, and right and left foraminal area dimensions were calculated on imaging obtained before and after pedicle screw fixation. Assessments were also done for segmental lordotic angle (SLA) and lumbar lordotic angle (LLA). All measurements were performed on a standardized radiology workstation by an independent spine surgeon and musculoskeletal radiologist.

Plain anteroposterior and lateral radiographs as well as T2-weighted sagittal and axial MR images were obtained before surgery and at final follow-up. Posterior disk height and foraminal height were measured on lateral X-rays. On MRI, the sagittal image through the anatomical center of the spine was used to determine the anteroposterior canal

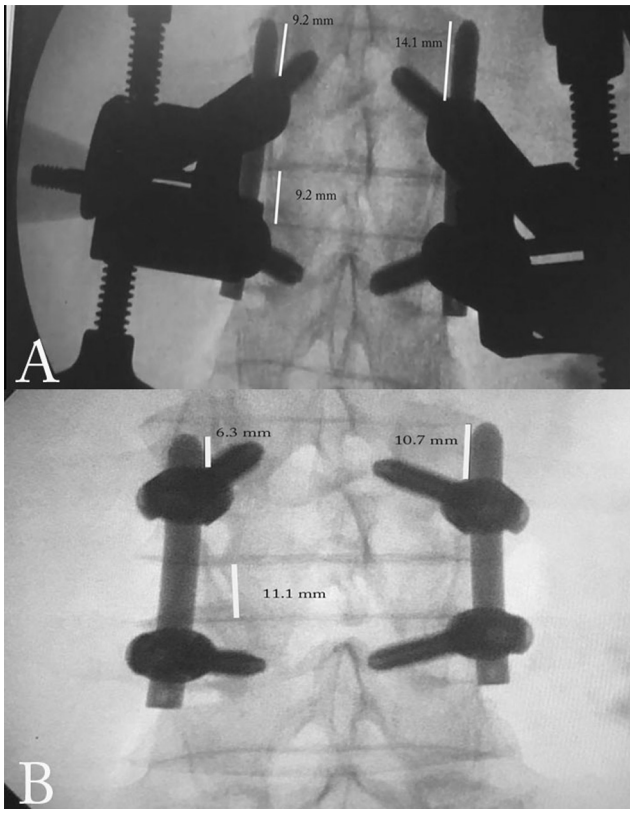

Fig. 1 Intraoperative anteroposterior (AP) fluoroscopic images showing L3–L4 intervertebral level (**A**) before and (**B**) after rod distraction between the screws with increase in disk height.

diameter. The axial image through the center of the disk was used to measure the cross-sectional area (CSA) of the spinal canal. All distance measurements were made at the narrowest point of the given anatomical area. The disk was chosen as the ventral border of the measured area, while the ligamenta flava were chosen as dorsal/lateral borders. On sagittal MR images, we calculated the area of the foramen, excluding normal bone, osteophytes, and any disk material in the foramen.

All the segments were grouped according to Schizas' lumbar stenosis classification (grades A1–A4, minor or no stenosis; B, moderate stenosis; C, severe stenosis; and D, extreme stenosis).[16]

Clinical Outcome Measures

All the patients were interviewed on clinical symptoms by an independent spine surgeon. Questionnaires were supplemented by reviewing the patients' medical records. Preoperative and postoperative pain was measured using a visual analog scale (VAS 0 mm = no pain; 10 mm = maximum pain), and functional performance was assessed with the Oswestry Disability Index (ODI). The neuropathic component of LBP was assessed using the Douleur Neuropathique 4 (DN4) questionnaire. Patient's global impression of change (PGIC) was scored by patients rating their improvement on a scale from 1 ("very much improved") to 7 ("very much worse") at 12 months of follow-up.

Statistical Analysis

A descriptive statistic was performed. Continuous variables were reported as median and interquartile range (IQR), and categorical data as relative number and percentage. The Shapiro–Wilk test was used for assessing normality.

Differences between pre- and postoperative continuous variables were assessed by Wilcoxon rank sum test.

The association between CSA spinal canal, CSA neural foramen, and sagittal central canal diameter with possible confounding variables (age, gender, single/multiple fixation level, and follow-up time) was evaluated using multiple linear regression models. The coefficients are reported along with the 95% confidence interval.

The variance inflation factor (VIF) was used to analyze the collinearity between the covariates. Collinearity was excluded since VIFs were lower than 1.50 for all the variables. Statistical significance was set at a two-tailed p value <0.05. R v4.2.2 (R Foundation for Statistical Computing, Vienna, Austria; www.rproject.org) was used for the analyses.

Results

Twenty-eight consecutive patients with common degenerative lumbar disorders and ligamentous stenosis with low-grade segmental lumbar instability were included during the study period. The median age of the patients was 66 years (range: 56–73 years) and 18 patients (82.7%) were females. The median follow-up was 20.5 months (range: 17.3–29.8 months). Single-level fixation was performed in 21 patients (75%), while two-level fixation was performed in the remaining 7 patients (25%). The most frequent level of single fixation was L4–L5 (13 patients, 46.4%), followed by L5–S1 (5 patients, 17.9%). The demographics and baseline characteristics of the included patients are presented in ►**Table 1**. The average operation time was 86.8 minutes, while the median

Table 1 Demographics and baseline characteristics of patients

Characteristics of the treated patients	
Variable	**Total patients included ($n = 28$) n (%)**
Age (y)	66 (56–73)
Gender	
Male	10 (17.3)
Female	18 (82.7)
Single-level fixation	21 (75)
L2–L3	2
L3–L4	2
L4–L5	13
L5–S1	4
Double-level fixation	7 (25)
L3–L4 and L4–L5	6
L4–L5 and L5–S1	1

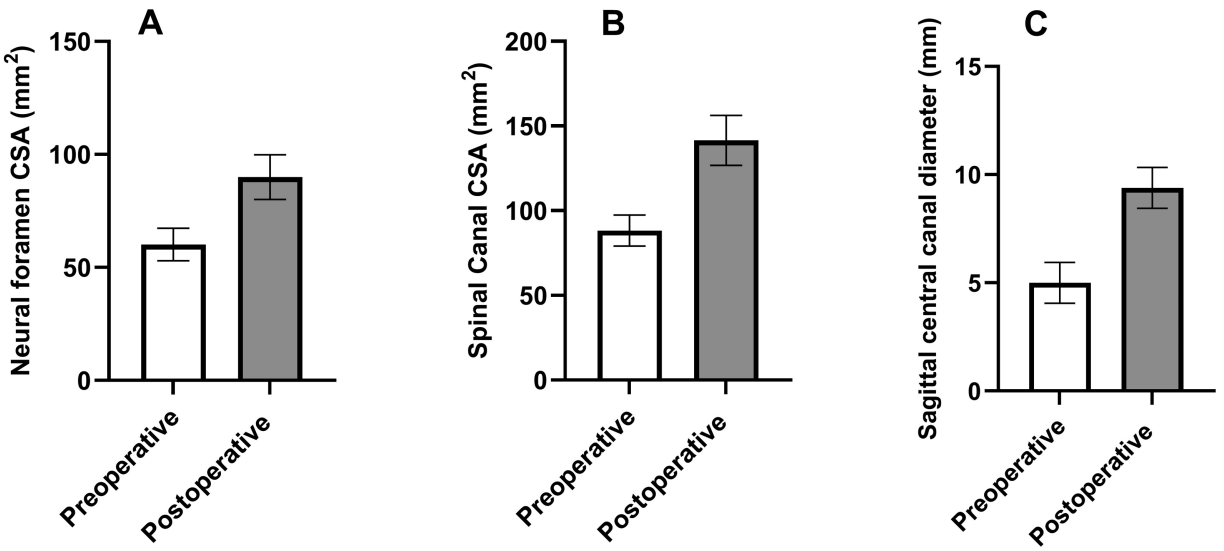

Fig. 2 (**A**) Measures from sagittal and axial spinal magnetic resonance (MR) images. Measurements of axis scale are in mm^2. Postoperative measures of the cross-sectional areas of the spinal canal and foramen were significantly increased compared with the preoperative measures ($p < 0.00001$). (**B**) Pre- and postoperative measures of the cross-sectional spinal canal area of 28 patients. (**C**) Measures from sagittal MR images. A statistically significant increase of the sagittal central canal diameter was appreciated compared with the preoperative images ($p < 0.0001$). CSA, cross-sectional area.

blood loss was 34 mL (range: 25–40 mL) per patient and the average hospital stay was 3.8 days (range: 3.4–4.4 days).

The median VAS score before surgery was 7.8 (range: 7–8), while at final follow-up it was significantly reduced (2.6 [range: 2–3], $p < 0.0001$). The same findings were observed for the ODI score (ODI score before surgery: 58% [range: 56–64%]; ODI score after surgery: 21% [18–26%]; $p < 0.0001$). The mean DN4 score was 5.7 at baseline, which decreased to 2.9 at the final follow-up. At 12 months of follow-up, 92.8% of patients reported a PGIC score ≤ 3 (the sum of minimal, much, and very much improved), with 57.1% of cases having a score of ≤ 2 (the sum of much and very much improved), while in 7.1% of cases it was 4.

Evaluation of the spine MR images at follow-up showed a significant increase in the CSA of the spinal canal (86.5 mm^2 [range: 83–96 mm^2] before surgery vs. 144 mm^2 [range: 137–152 mm^2] after surgery, $p < 0.0001$) along with a significant increase in the sagittal central canal diameter (5 mm [range: 4.2–5.6 mm] before surgery vs 9.7 mm [range: 8.9–10 mm] after surgery, $p < 0.0001$; ►**Fig. 2A–C**). ►**Table 2** shows the pre- and postoperative changes in the outcome variables. CSA of the neural foramen was significantly enlarged from a median of 60.1 mm^2 (range: 54.6–63.8 mm^2) preoperatively to 89.6 mm^2 (range: 81.9–97.7 mm^2) at follow-up ($p < 0.0001$; ►**Fig. 3–4**). In ►**Table 3**, the association between CSA spinal canal, CSA neural foramen, and sagittal central canal diameter in multiple linear regression analyses with possible confounding variables is evaluated.

The results showed that only age ($\beta = -0.78$, $p = 0.02$) and follow-up time ($\beta = -0.71$, $p = 0.04$) had a significant negative association with CSA spinal canal. According to Schizas' classification, the levels analyzed were rated B, C, or D (5, 17, and 8 levels, respectively) in 33 of 35 levels preoperatively. At the final follow-up, 25 of 35 levels were rated A1–A4, 7 levels were rated B, while 3 levels were rated C. The SLA increased from a mean of 18.7 (± 5.9) degrees preoperatively to 21.3 (± 4.6) degrees at the final follow-up. The LLA increased from 45.6 (± 12.4) degrees preoperatively to 49.4 (± 11.9) degrees at the final follow-up.

No patient required blood transfusion or drainage. There was no incident of screw malposition. No intraoperative major complications occurred. There were only two cases of postoperative complications. In one case, the patient developed superficial wound infection that resolved with

Table 2 Pre- and postoperative changes in the outcome variables

Variables	Preoperative Median (IQR)	Postoperative Median (IQR)	*p* value
CSA spinal canal (mm^2)	86.5 (83–96)	144 (137–152)	<0.0001
CSA neural foramen (mm^2)	60.1 (54.6–63.8)	89.6 (81.9–97.7)	<0.0001
Sagittal central canal diameter (mm)	5 (4.2–5.6)	9.7 (8.9–10)	<0.0001
VAS	8 (7–8)	2 (2–3)	<0.0001
ODI	58 (56–64)	21 (18–26)	<0.0001

Abbreviations: CSA, cross-sectional area; IQR, interquartile range; ODI, Oswestry Disability Index; VAS, visual analog scale.

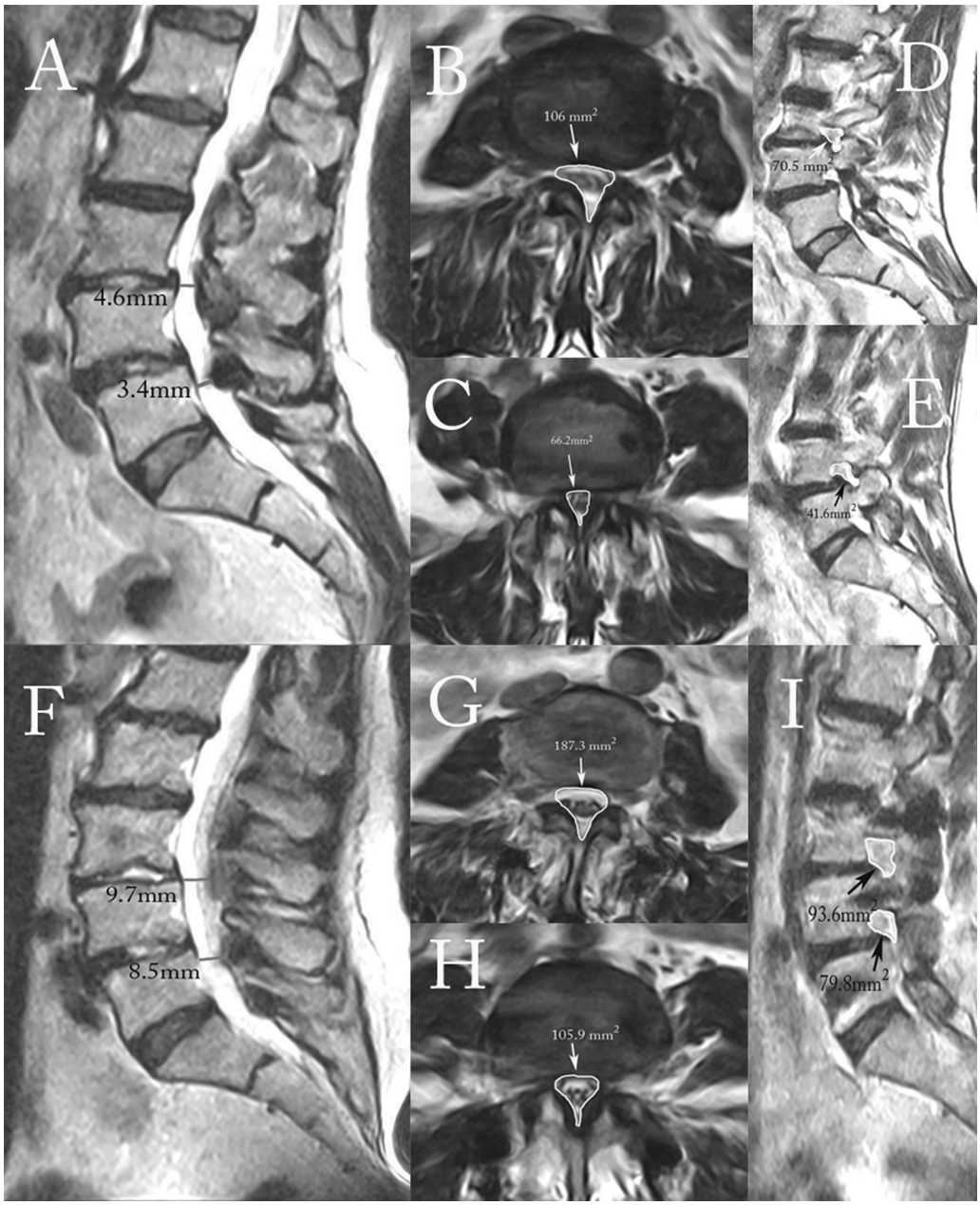

Fig. 3 This 67-year-old woman with lumbar stenosis and minor instability at L3–L4 and L4–L5 underwent a stand-alone L3–L4–L5 pedicle screw fixation with indirect decompression. Pre- and postoperative comparison on magnetic resonance (MR) images. (**A–E**) Preoperative and (**F–I**) postoperative images. Measurements of pre- and postoperative sagittal central canal diameter (**A**,**F**), cross-sectional area of the L3–L4 and L4–L5 foramen (**D**,**E**,**I**), and cross-sectional area of the spinal canal (**B**,**C**,**G**,**H**) were evaluated pre- and postoperatively at 12 months of follow-up.

antibiotic medications. Moreover, a patient who underwent an L3–L4 fixation had a significant improvement in his back and leg pain postoperatively. After roughly 14 months, the patient started to develop recurrent leg pain. Lumbar MRI revealed only minimal increase of the canal and foraminal areas compared with preoperative images and thus an additional laminectomy was proposed. Nevertheless, the patient refused to perform open decompression surgery and was managed conservatively. At the final follow-up, there was no screw loosening in this series of patients. No patient developed postoperative adjacent level disease.

Discussion

Hypertrophy of the ligamentum flavum and facets may lead to symptomatic neural compression within the spinal canal, which can be aggravated by concomitant degenerative lumbar instability. The ideal surgical treatment of lumbar stenosis associated with degenerative instability remains controversial.[8,17–20] In this study, we quantified with radiographic parameters the efficacy and safety of stand-alone percutaneous pedicle screw fixation to provide indirect decompression of neural structures in the treatment of lumbar stenosis and instability.

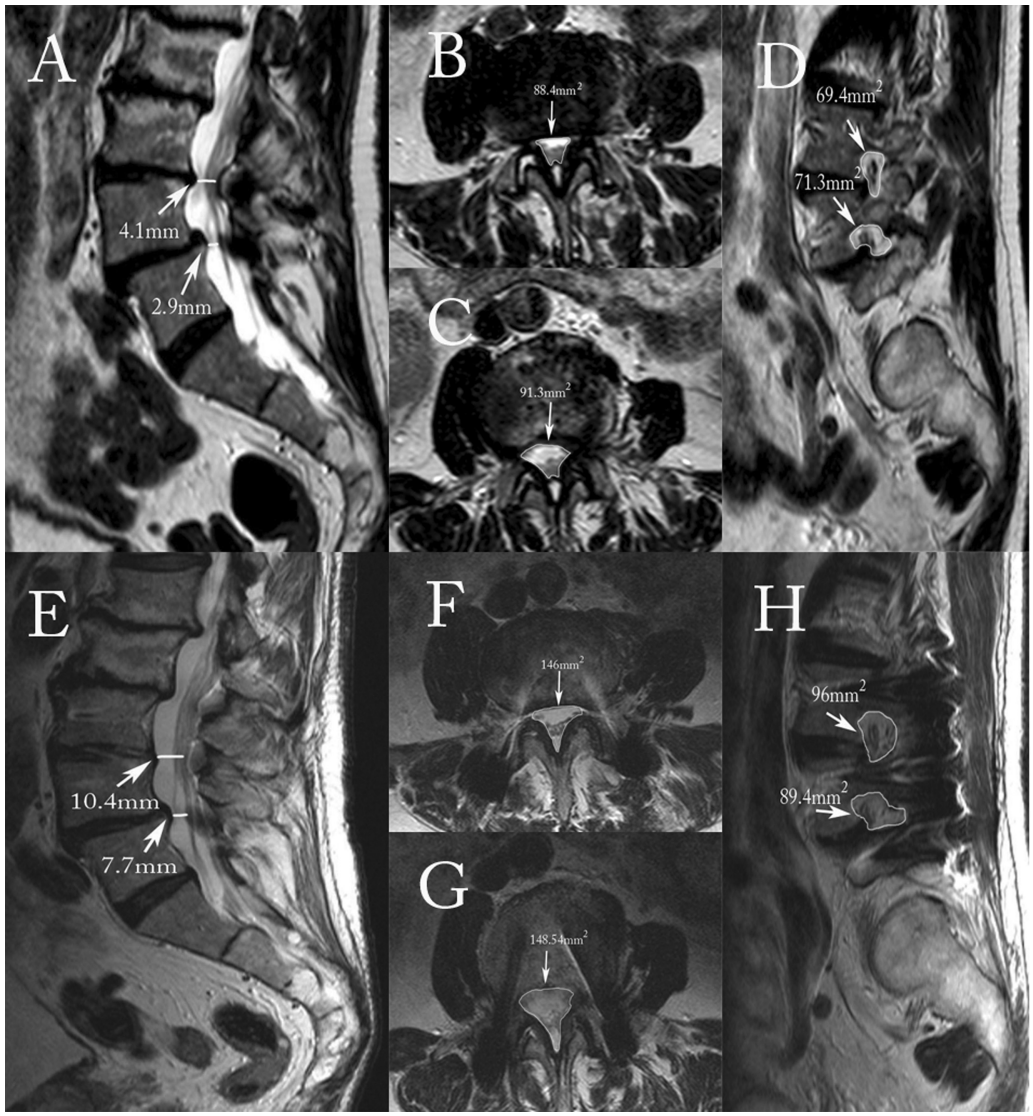

Fig. 4 This 77-year-old man with L4–L5 minor spondylolisthesis and L3–L5 stenosis underwent a two-level L3–L5 fixation procedure. (**A–D**) Preoperative and (**E–H**) postoperative magnetic resonance (MR) images demonstrating increase of the diameter of the central canal diameter (**A,E**) and cross-sectional area of the spinal canal (**B,C,F,G**), and foraminal areas at L3–L4 and L4–L5 (**D,H**) following indirect decompression after stand-alone percutaneous screw fixation.

Reduction of spinal deformities has been reported to enlarge the central canal and the neural foramina area.[8] Various studies have shown the efficacy of indirect neural decompression in degenerative unstable lumbar spine disorders analyzing clinical and radiologic outcomes.[21–25] Although anterior and lateral approaches combined with supplemental posterior fixation may, in some cases, provide good radiographic and clinical outcomes, they may necessitate longer surgical procedures with higher complication rates.[26,27] In our series, we used a percutaneous pedicle screw fixation in distraction technique for selected cases of lumbar degenerative disease. Radiographic measurements demonstrated the effectiveness of the procedure in decompressing lumbar ligamentous stenosis associated with instability.

We had already demonstrated the clinical effectiveness and long-term solidity of stand-alone percutaneous pedicle screw fixation without in situ fusion in patients with low-grade lumbar segmental instability in a previous study.[28] The percutaneous pedicle screw fixation technique has several advantages over conventional open procedures, including shorter surgical time, less tissue trauma with smaller skin incisions and limited muscle splitting, and less blood loss.[14,28] These characteristics may result in decreased hospital stay and prompt functional rehabilitation.

Patients with mild to moderate intermittent neurogenic claudication secondary to spinal stenosis determined primarily by ligamentous hypertrophy were optimal candidates for this technique. The key clinical selection criteria for surgical indication were patients' neurologic symptom relief by flexion of the lumbar spine. Flexion of the stenotic lumbar spine stretches the redundant ligamentum flavum and enlarges the neural foramina, thus relieving lower extremity symptoms.[29] The distraction applied with pedicle screws and longitudinal bar fixation system at the stenotic vertebral segment may provide a controlled minimal indirect

Table 3 Multiple linear regression models for the evaluation of the association between CSA spinal canal, CSA neural foramen, and sagittal central canal diameter with possible confounding variables

	Dependent variable: CSA spinal canal		
Independent variables	**Coefficient**	**95% confidence interval**	***p* value**
Gender			
Female	Reference category	–	–
Male	−7.2	−18.3 to 3.96	0.19
Multiple-level fixation	−1.12	−13.5 to 11.3	0.85
Age	−0.78	−1.44 to 0.13	0.02
Follow-up time	−0.71	−0.97 to 0.38	0.04
Dependent variable: CSA neural foramen			
Gender			
Female	Reference category	–	–
Male	−1.8	−10.1 to 6.51	0.66
Multiple-level fixation	1.73	−7.54 to 10.99	0.70
Age	−0.29	−0.78 to 0.19	0.23
Follow-up time	−0.39	−0.89 to 0.11	0.12
Dependent variable: sagittal central canal diameter			
Gender			
Female	Reference category	–	–
Male	−0.22	−1.07 to 0.64	0.61
Multiple-level fixation	−0.03	−0.98 to 0.92	0.95
Age	0.005	−0.04 to 0.056	0.82
Follow-up time	−0.004	−0.056 to 0.05	0.88

Abbreviations: CSA, cross-sectional area.
Note: The coefficients are reported along with the 95% confidence interval.

reduction of the malalignment along with an increase in the neural foramen area, thus obtaining an indirect neural decompression without the need for open surgery. In this series, the exclusion criteria were the presence of a fused facet joint and/or a large extruded disk fragment. For such cases, decompression via open laminectomy was performed and were not included in the study. A concern with the use of pedicle screw fixation in distraction, as previously with the use of interspinous devices in the treatment of lumbar stenosis, is their potential to introduce segmental kyphosis through an increase in segmental spinal flexion as the mechanism of indirect decompression. This has led to significant concern on how placement of lumbar pedicle screws in distraction can potentially affect overall sagittal balance. In our series of patients, we used multiaxial screws that became uniaxial after a first slight tightening of the lock plugs, permitting, a greater application of appropriate forces in distraction to the construct prior final tightening. The fixed head of the uniaxial screw permits forces and torques to be directly applied to the vertebrae for sagittal correction maneuvers. Multiaxial screws are less effective than uniaxial screws in transmitting distraction to the anterior spine, because of the pivoting mobility in the sagittal plane, which results in differential distraction of the posterior and anterior parts of the vertebrae.

The same concern of possibility of segmental kyphosis was investigated for the interspinous devices. Alfieri et al performed a systematic review of clinical studies that involved interspinous devices and described the risk of introducing kyphosis at the operated lumbar segment. They identified 11 studies in which kyphosis was measured preoperatively and postoperatively and reported no differences in the segmental angle.[29] Moreover, Schulte et al found an average improvement of overall sagittal balance in their series of 20 patients treated with indirect kyphotic decompression using an interspinous device. They suggested that the achievement of postoperative relief of the stenotic canal allowed the spine to maintain a more efficient sagittal balance through the entire lumbar spine, with only a local segmental kyphotic effect.[30]

In all but one patient in the present series, indirect decompression after surgical procedure was demonstrated quantitatively. The spinal canal and foraminal areas were measured before and after surgery. There was 60.4% increase of the CSA of the spinal canal after surgery, which was accompanied by an enlargement of 50.9% of CSA of the foramen. Other parameters, such as sagittal central canal diameter measured on MRI and posterior disk space and

foraminal height on radiographs, also significantly improved in our study.

For each patient, the decision regarding the use of this surgical approach was managed on an individual basis. All patients included in this study, after having been fully informed of the various surgical alternatives, decided to avoid a major surgical open and/or lateral corrective procedure, opting for a less invasive procedure. The aim of patients was to obtain immediate pain relief. Each patient received a detailed explanation of the goals of the percutaneous procedure and were informed of the risk of the need for direct decompression in case of unsatisfactory outcome. Contraindications to this surgical technique included cases with lateral recess and foraminal bony stenosis with osteophytes. Distraction maneuvers are blocked by significant facet arthropathy and bony lateral recess stenosis is a significant predictor of failure of indirect decompression.[31]

In our surgical experience, further indications to avoid this percutaneous approach and to go for open posterior decompression include migrated herniated disk fragment, radicular symptoms not improving with flexed posture, and facet ankylosis. Conversely, stand-alone pedicle screw fixation appears to provide sufficient indirect decompression for collapsed disk with loss of foraminal height and/or ligamentum flavum/posterior anulus encroachment of the spinal canal. Furthermore, this technique provides sufficient indirect decompression in cases of low-grade segmental lumbar instability with narrowing of the central canal and neural foramens due to malalignment. Indirect decompression partially restores "physiological" corridors instead of creating new ones, the latter being achieved only by direct decompression.

Our secondary study endpoint was to determine whether indirect decompression of neural structures reflected in a good functional outcome without the need for open laminectomy. In our series, the VAS and ODI scores for pain was improved at final follow-up.

Direct posterior open decompression surgery carries risks related to operative time and dissection of paraspinal musculature, which may contribute to several complications such as intraoperative blood loss, infections, and persistent LBP after surgery.[4,20,32,33] Open spinal decompression with subperiosteal muscle dissection and retraction may lead to more damage of the posterior supporting structures with postoperative muscle atrophy and back pain.[34] Percutaneous spinal fixation better preserves the posterior supporting structures of the lumbar spine and blood and nerve supply of the muscles, avoiding fatty infiltration in the erector spinae and multifidus muscles.[35,36]

The overall complication rate for lumbar decompressive open surgery is 12.6% with an incidence of symptomatic postoperative hematoma requiring emergency evacuation of 0.5% after laminectomy and 0.67% after posterior lumbar interbody fusion.[7,33]

The overall complication rate in our series of patients was 7.1%, demonstrating that the percutaneous technique used was relatively safe. No major peri- and/or postoperative complications were noted. There were no cases of screw malposition as well. One patient, who underwent an L3–L4 fixation with initial significant improvement of preoperative symptoms, developed recurrent leg pain 14 months after surgery. Spinal MR images showed that the canal and foraminal areas were not increased significantly compared with the preoperative images. An additional laminectomy was proposed, but the patient refused to undergo a redo surgery. Of note, the postoperative pain recurrence rate in our study was 3.5%. It compares favorably to data previously reported from a series of posterior instrumented fusion procedures, which ranged between 18 and 35%.[20,33,37] In our study, only patient age and follow-up time had a minor association with the loss of CSA of the spinal canal. Sequential measurements in the postoperative period with a longer follow-up would have given more information regarding the loss of canal and foraminal area dimensions, and disk space distraction over time.

Compared with the spine patient outcomes research trial (SPORT) trial, the largest outcome study of spinal stenosis patients, the outcome measures of our study exceed expectations.[38] The results in our study and those in Weinstein et al are not comparable. In our study, the decision regarding the use of this surgical approach was managed on an individual basis, while the patients in the SPORT trial were enrolled in either a randomized cohort or an observational cohort at 13 different spine clinics and managed with decompressive surgery or conservatively. In our series, the approach was performed in a very carefully selected group of patients. The key clinical selection criteria for surgical indication were neurologic symptom relief in a forward flexed posture. The surgical outcomes in our study were generally comparable to other previous surgical spinal fixation series for lumbar degenerative diseases in selected patients.[39–41]

The limitation of our study is the small sample size. However, this is a short series of highly selected cases. The retrospective design of the study adds bias in terms of patient selection. Another limitation of the study is the absence of a control group to compare the effectiveness of the stand-alone percutaneous pedicle screw fixation technique with other surgical techniques. Future clinical and radiologic comparative prospective studies with larger series and longer follow-up are necessary for a more comprehensive evaluation.

Conclusion

In summary, our data demonstrate a significant increase in the cross-sectional central canal and foraminal areas with adequate patient safety and good radiographic and clinical outcome at a mean follow-up of 25.2 months. To our knowledge, this is the first study to quantify the indirect decompression achieved using a stand-alone percutaneous pedicle screw fixation in lumbar degenerative disorders. This technique provides the necessary decompression for treating lumbar stenosis without the need for direct resection of the posterior spinal elements. The decision regarding the use of this surgical approach must be made on an individual basis, following tailored indications.

Author Contributions
Study conception and design were done by R.G. and U.A. Data collection was done by R.G. and K.P. Analysis and interpretation of results were done by M.G. and M.L.G.L. All the authors reviewed the results and approved the final version of the manuscript.

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Conflict of Interest
None declared.

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