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Microendoscopic Tailored Spine Decompression as a Less-Invasive, Stability-Preserving Surgical Option to Instrumented Correction in Complex Spine Deformities: A Preliminary Multicenter Experience

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OBJECTIVES: **The aim of this study was to explore the effectiveness of a less-invasive posterior spine decompression in complex deformities. We studied the potential advantages of the microendoscopic approach, supplemented by the piezoelectric technique, to decompress both sides of the vertebral canal from a one-sided approach to preserve spine stability, ensuring adequate neural decompression.**

METHODS: **A series of 32 patients who underwent a tailored stability-preserving microendoscopic decompression for lumbar spine degenerative disease was retrospectively analyzed. The patients underwent selective bilateral decompression via a monolateral approach, without the skeletonization of the opposite side. For omo- and the contralateral decompression, we used a microscopic endoscopy-assisted approach, with the assistance of piezosurgery, to work safely near the exposed dura mater. Piezoelectric osteotomy is extremely effective in bone removal while sparing soft tissues.**

RESULTS: **In all patients, adequate decompression was achieved with a high rate of spine stability preservation. The approach was essential in minimizing the opening, therefore reducing the risk of spine instability. Piezoelectric osteotomy was useful to safely perform the undercutting of the base of the spinous process for better contralateral vision and decompression without damaging the exposed dura. In all patients, a various degree of neurologic improvement was observed, with no immediate spine decompensation.**

CONCLUSIONS: **In selected cases, the tailored microendoscopic monolateral approach for bilateral spine decompression with the assistance of piezosurgery is adequate and safe and shows excellent results in terms of spine decompression and stability preservation.**

INTRODUCTION

The aim of this study is to explore the effectiveness, safety, and feasibility of a selective microendoscopic less-invasive posterior spine decompression in complex spine deformities tailored according to the clinical frame and radiologic findings in each individual patient, in order to avoid, whenever is realistically possible, full correction of the deformity and/or long spine fixation. Laminotomy, laminectomy, and hemilaminectomy are the most common surgical decompression procedures used in treating myeloradiculopathies in degenerative and neoplastic diseases of the lumbar spine. We studied the potential advantages of the microendoscopic minimally invasive approach, supplemented by the piezosurgery technique, for decompressing both sides of the vertebral canal from a one-sided approach to preserve spine

Key words
- Decompression
- Degenerative
- Laminectomy
- Lumbosacral
- Piezosurgery
- Sagittal balance
- Scoliosis
- Spinal stability
- Spondylolisthesis
- Stenosis

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stability in patients bordering on instability, ensuring at the same time adequate nerve root and spinal cord decompression.

The already-recognized microscopic and endoscopy-assisted less-invasive decompression technique was supplemented by the use of piezosurgery to further enhance the adequacy and safety of decompression when working close to the dural layer, nerve roots, and vessels. Piezoelectric osteotomy is based on the mechanical effect of ultrasound, which is increased by the physical phenomenon of cavitation.[1] Piezoelectric bone osteotomy is a recent innovative surgical technique that allows a selective cut of mineralized tissue while sparing soft tissues. The piezoelectric cut is realized by mechanical vibrations in a range between 60 and 210 μm, with a frequency of 29,000 times per second, thus obtaining an efficacy that does not significantly increase the overall duration of surgery, although slightly superior compared with the use of bone saws or burrs. Laminotomy, laminectomy, and hemilaminectomy are common surgical procedures used in the treatment of spinal compressive myeloradiculopathies in degenerative and neoplastic diseases. Quite often, osteotomies and drilling of bone are performed near neural tissues and

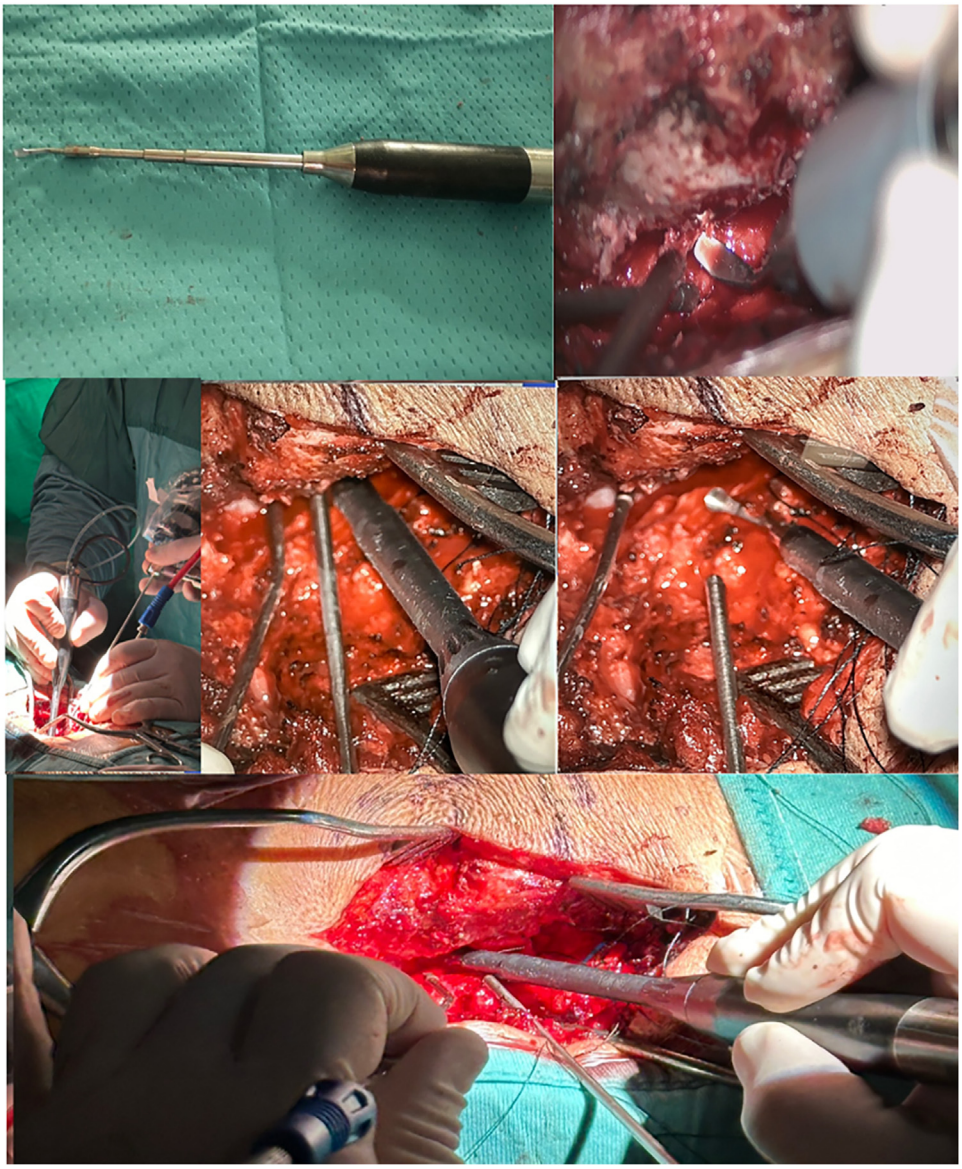

Figure 1. The piezoelectric osteotome (*upper row*) and intraoperative microendoscopic-assisted settings (*middle* and *lower rows*) are shown.

blood vessels. Some risks and potentially serious complications are associated with these instruments, such as dural injuries in patients with a narrow spinal canal and thermal and mechanical damage to neurovascular structures.[2-5] These potential risks are further increased in the case of narrow working angles, such as in micro- and endoscopic approaches, both at the brain and spinal level. In this study, we describe our preliminary focused experience with the use of selective, less-invasive posterior spinal decompression with piezoelectric osteotome surgery in patients affected by complex spine deformities, highlighting the advantages of this technique in decompressing both sides of the vertebral canal without compromising spinal stability (Figures 1-7).

METHODS

We retrospectively analyzed a series of 32 patients diagnosed between January 1, 2019, and December 31, 2022, with severe nerve root compression and/or spinal canal stenosis by lumbar spine deformities and degenerative disease. We specifically selected patients with back pain that did not worsen unbearably in an orthostatic posture, with a predominantly monolateral sciatic pain, and, in some case, with associated neurogenic claudication. All patients had a long-lasting clinical history of pain that was drug resistant and reported the failure of the conservative treatments. Importantly, the preoperative radiologic assessment had to document marked nerve root compression and/or significant spinal canal stenosis but without a clearly documented spine instability, even in case of severe deformity. Most patients were elderly (median age was nearly 64 years), and some presented with comorbidities; therefore, the prevention of long-lasting surgical operations with supposedly blood loss and anesthesiologic overstress was crucial.

Our present experience began precisely for this reason. Our first patients were elderly patients with intolerable back and leg pain that was unresponsive to conservative treatment, with noticeable comorbidities affected by a focal lateral recess and/or spinal canal stenosis with severe nerve root compression. Even within the framework of a complex but biomechanically stable spine deformity, we aimed to offer them an effective, tolerable, and durable safe treatment. The patients underwent selective bilateral decompression, using a monolateral approach, without the skeletonization of the opposite side. For the omo- and, above all, contralateral decompression, we used a minimally invasive, tailored, microscopic endoscopy-assisted approach with the adjunct of piezosurgery for a safe and accurate working area near the exposed dura mater.

The procedure began as a standard approach with a midline linear incision, without resorting, as they were not available in this preliminary experience, to the use of tubulars that could implement the technique, making it less invasive. Once the muscle fascia was reached, through the microscopic phase, only unilateral skeletonization was carried out until unilateral bone decompression was achieved. The approach was essential in minimizing bone removal and therefore reducing the risk of spine instability. At this point, always under microscopic guidance, the piezoelectric osteotomy was useful to safely perform the undercutting of the base of the spinous process for better contralateral vision and to realize contralateral decompression without damaging the exposed dura. Endoscopic magnification was exploited in this phase of the operation, especially to ensure better contralateral vision and more effective contralateral decompression where the

Figure 2. Illustrative case 1. Dynamic radiograph shows a stable severe spine deformity with an associated spinal canal stenosis prevalent at the right lateral recess on the concavity side of the apex of the scoliotic curve.

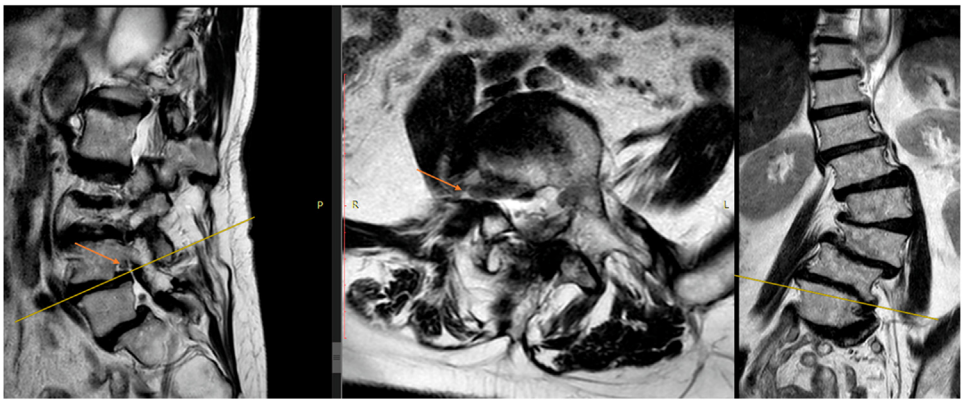

Figure 3. Illustrative case 1. Segmental stenosis is prevalent at the right lateral recess and foramen at the level of L3—L4 and L4—L5 (see *arrows* on magnetic resonance imaging).

surgical vision was particularly narrow in terms of working angle. The endoscopic technique was particularly useful in foraminotomy or in the removal of bone spurs at the level of the contralateral foraminal recesses, and this guaranteed adequate decompression of the corresponding nerve root.

According to the clinical and radiologic situation of each patient, we tailored a selective approach that varied from a single-side interlaminar approach to a maximum 2-level monolateral hemilaminectomy with the undercutting of the base of the spinous process to facilitate the microendoscopic opposite-side working angle and vision. The surgical procedure was supplemented by the complementary use of a piezoelectric osteotome. This technique is particularly useful for minimally invasive spinal canal decompression in both sides, even in cases in which one hemilamina is preserved, because the use of piezosurgery is quite safe for the thinning of the inner aspect of the contralateral lamina and the opposite-site foraminotomy without damaging the exposed dura and vessels (**Figures 5 and 7**). It is a versatile technique that has allowed the comfortable use of both the microscope and the endoscope, and it possesses the same maneuverability of a traditional drill but with much more safety in the narrow corridor of the contralateral side. The piezoelectric osteotome, based on the "piezoelectric effect" of microvibrations, operates with modulated ultrasound and thereby generates micromovements, allowing protection of the adjacent soft tissue and precise and regular bone margins. Osteotomies can be performed by placing the instrument on the bone and passing over the same point several times, applying light pressure; the complementary use of this particular type of osteotome ensures precision and safety in the delicate stages of the surgical procedure, for example, when working close to the nerve root to solve foraminal stenosis or neural compression. The piezoelectric surgery device offers water

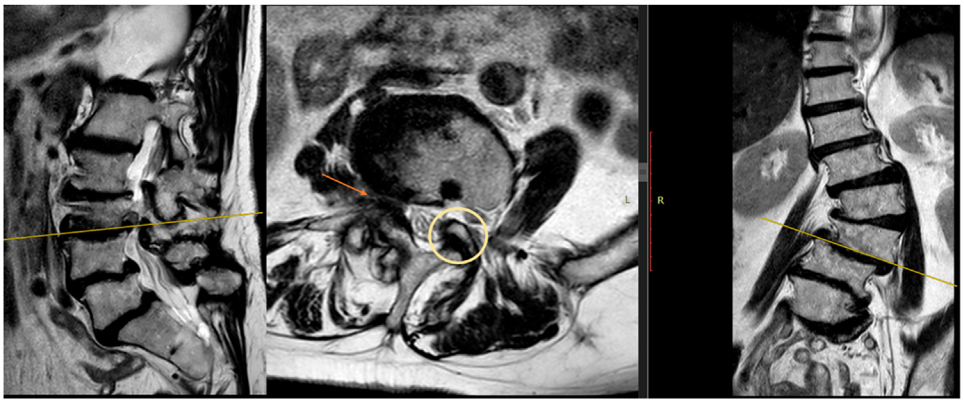

Figure 4. Illustrative case 1. At the L3—L4 level, a bony spur (see *circle*) with hypertrophied ligament is also evident, contralateral to the approach (see *red arrow*), that was safely removed with the assistance of the endoscope and the piezo bone scalpel (see **Figure 5**).

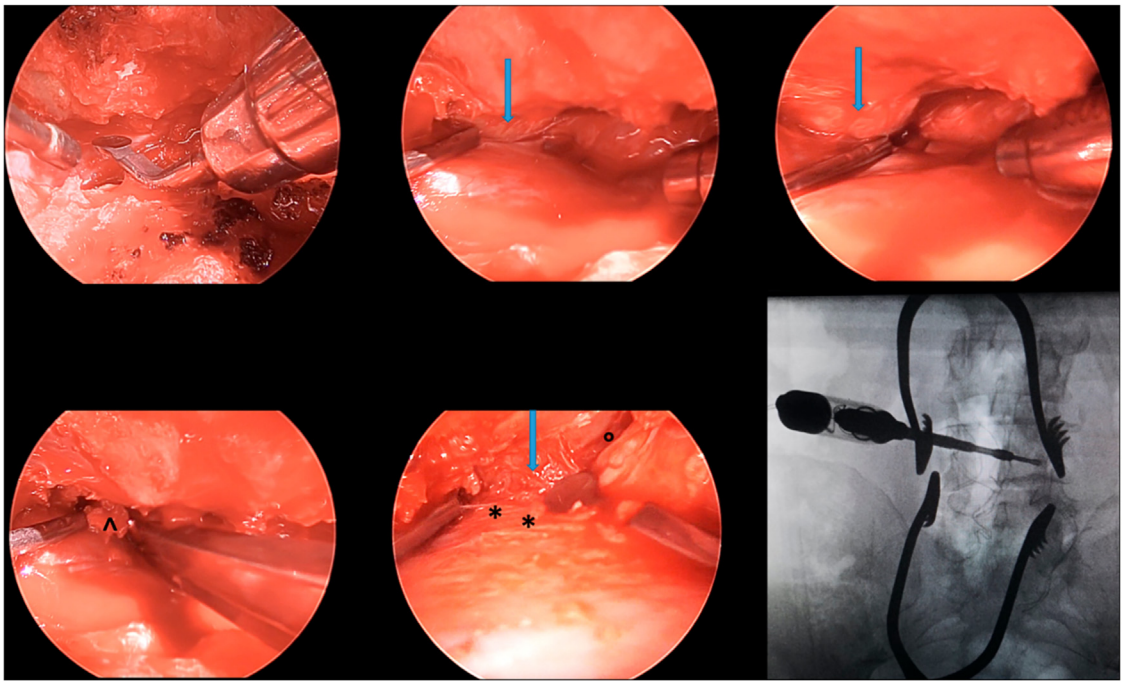

Figure 5. Illustrative case 1. Intraoperative images of the contralateral endoscopy-assisted decompression. In particular, the *arrows* show the bony spur and the hypertrophied ligament compressing the nerve root at the entrance of the foramen (see preoperative magnetic resonance imaging in Figure 4); bone and ligament removal occurred via a combination of piezosurgery and a Kerrison rongeur (-). The *asterisks* show the decompressed root at the foraminal entrance. The *circle* shows the contralateral pedicle, and the intraoperative radiograph documents the tip of the piezo device just under the left pedicle at the entrance of the foramen reached from the right side, the site of the monolateral approach, confirming the possibility of a contralateral decompression even from the opposite side, hence reducing the risk of spinal destabilization.

cooling artificially, avoiding the need of an additional assistant to provide water cooling; in addition, a various set of tips are available, which offers further versatility to the instrument.

For each patient, we collected and compared pre- and postoperatively clinical parameters such as clinical onset, Numerical Rating Scale pain scale scores, dynamic radiographs, computed tomography scans, and magnetic resonance imaging findings. Clinical and radiologic follow-up was performed at 1, 3, 6, and 12 months and every year postoperatively. Patients who were followed up were studied with both magnetic resonance imaging and/or computed tomography scans and dynamic radiographs to evaluate spinal stability. Patients who had already received posterior screw fixation were included, whereas candidates with a new posterior stabilization were excluded from this study. The patient selection method, with the aim to rule out evident lumbar spinal instability, included a multidisciplinary discussion between the orthopedic and neurosurgical members of the team; clinical and radiologic criteria were adopted, such as the presence of back pain that did not worsen unbearably in an orthostatic posture (with a predominantly monolateral sciatic pain, and, in some cases, with associated neurogenic claudication) and the presence of spinal balance, defined as the global concept of not only sagittal alignment and the absence of translation and/or rotation of a superior vertebra relative to its neighboring inferior vertebra on the preoperative radiograph but even sensorineural integration together with spinal anatomy and biomechanics evaluation in order to distinguish the mechanisms structurally disordering alignment and those by which the patient attempts to restore balance, the so-called compensatory mechanisms.

The study was conducted in accordance with the Declaration of Helsinki, and ethical approval was waived by our local ethics committee in view of the retrospective nature of the study and all the procedures being performed were part of routine care.

RESULTS

Our retrospective series was composed of 17 patients with marked lumbar spine stenosis, 8 patients with spondylolisthesis, and 7 patients with scoliosis (Table 1). Aside from the type of degenerative disease, all patients had a severe, one-side prevalent, nerve root compression and/or spine canal/lateral recess stenosis. Patients were an average age of 63.9 years (range 24–85 years) and our series had a male predominance (60% of all the patients). There were 19 men and 13 women. An average of acute duration, or exacerbation of symptoms, of 68 days from clinical onset occurred before treatment. The average period of hospitalization was 3.73 days. We retrospectively reviewed all the surgical records, and we found there were no procedure-related

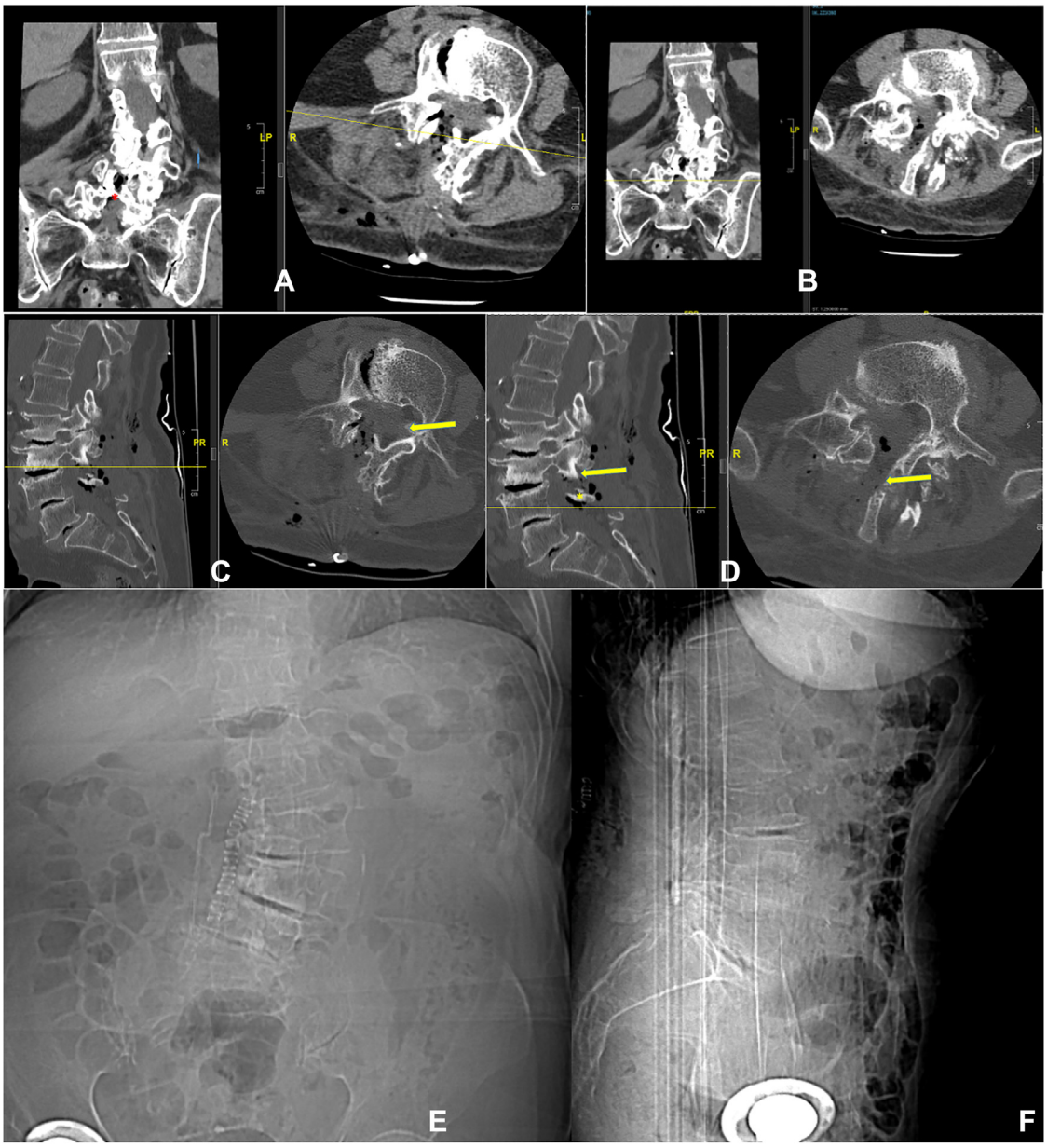

Figure 6. Illustrative case 1. (**A**–**B**) Immediate postoperative computed tomography scan showing adequate decompression with preservation of some bony bridge (*asterisk* in **A**) to avoid spinal instability. (**C**–**D**) The *arrows* show the removal of the contralateral bony spur and the undercutting of the base of the spinous process to provide a better endoscopic vision of the contralateral side without, theoretically, interfering with the spine stability. (**E**–**F**) Postoperative radiograph shows a compensated spine balance with adequate spinal canal decompression.

intraoperative complications, such as major bleeding or neural damage. In 2 cases, there was evidence of an accidental dural tear during the immediate postoperative period. No cerebrospinal fluid fistula was observed in one case; however, both cases were treated conservatively, one with external lumbar drainage. We overall observed that the piezoelectric osteotome was useful to safely perform the undercutting of the base of the spinous process and the thinning of the inner bone layer of the opposite lamina for better contralateral vision (Figures 5–7). The tip of the piezoelectric bone scalpel was particularly useful to perform the opposite-side foraminotomy safely and accurately and/or the spinal canal "recalibrage" without damaging the exposed dura

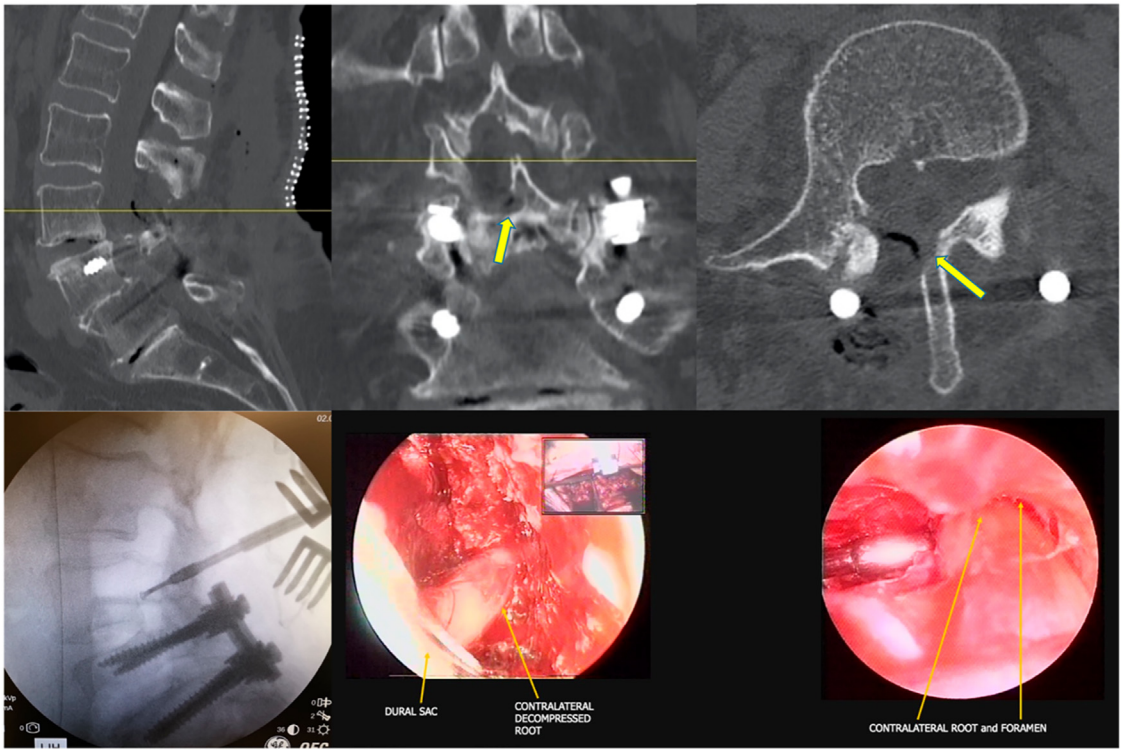

Figure 7. Illustrative case 2. Microscopic endoscopy-assisted bilateral decompression through a monolateral approach in a case of adjacent segment syndrome. The *arrows* (*upper row*) show the undercutting of the base of the spinous process to provide a better endoscopic vision of the contralateral side. The intraoperative radiograph (*bottom left*) shows the tip of the piezo osteotome reaching the contralateral foramen. The adequate, tailored, and selective contralateral foramen decompression and the recalibrated spinal canal is verified under the magnified vision through the endoscope (*bottom right*).

(see Figures 5–7). In all patients, during follow-up, various degrees of neurologic improvement, in terms of pain and neurologic function, were observed, with no evidence of immediate spine instability. Postoperative physiotherapy enabled all patients to walk independently within 2 days after surgery. At 2 years' follow-up postoperatively, only 1 patient (at 9 months) developed severe orthostatic back pain, with only minor sciatic leg pain. The radiologic assessment documented a biomechanical decompensation in a patient with L4–L5 spondylolisthesis, that was then operated on and fixed with screws. One patient underwent retreatment for surgical-site infection. Patients operated on for stenosis had an average postoperative stay of 4.2 days, 3.6 days for patients with spondylolisthesis, and 3.4 days for the patients treated for scoliosis.

Illustrative Case 1

A 68-year-old female patient presented with chronic back pain, not particularly exacerbated by posture, and a right prevalent sciatica with associated neurogenic claudication. Preoperative radiologic assessment documented a severe but stable spine deformity (Figure 2), with noticeable segmental stenosis, prevalent at the right lateral recess and foramen, at the level of L3–L4 and L4–L5 (Figures 3 and 4). At the L3–L4 level, a bony spur with a hypertrophied ligament was also evident, contralateral to the approach (circle in Figure 4), that was safely removed with the assistance of the endoscope and the piezoelectric bone scalpel, confirming the possibility of an accurate decompression even from the opposite side, hence reducing the risk of spinal destabilization (Figure 5). The patient had undergone numerous pain therapy procedures without benefit, some with needles, such as peridural injections, acupuncture, and repeated laser therapy sessions; since she also reported a sense of tightness at the lumbar level, with the suspicion of fibrosis, we proceeded with a wider skin incision. The need for a wider incision also arose from the fact that the patient had recent evidence of uncontrolled osteoporosis and bone fragility, which could potentially predispose her to a modification and conversion to a different surgical strategy. Postoperative imaging confirmed an adequate decompression and the preservation of the spine stability (Figure 6).

Illustrative Case 2

A 73-year-old female patient presented with adjacent segment syndrome 6 years after a posterior fixation. In this case, an endoscopy-assisted bilateral decompression with a monolateral

Table 1. Patient Overview

Characteristics	*n*
Number	32
Mean age at surgery, years	63.9 (24–85)
Sex	
Male	19
Female	13
Symptoms and signs	
Average exacerbation period before surgery, days	68
Low back pain	32
Monolateral sciatic pain	20
Neurogenic claudication	13
Average hospitalization stay, days	3.73
Stenosis	4.2
Spondylolisthesis	3.6
Scoliosis	3.4
Spinal disease/deformity diagnosis	
Stenosis	17
Monolevel	6
Multilevel	11
Spondylolisthesis	8
Grade I	5
Grade II	2
Grade III	1
Grade IV	0
Scoliosis	7
Scoliotic curve (Cobb angle range)	10–45.5
Intraoperative complications	0
Major bleeding	0
Neural damage	0
Accidental dural tear	2
Postoperative complications	2
CSF fistula	1
Infection and retreatment	1
Clinical outcome	
NRS preoperative score	8
NRS postoperative score (average at 12 months' f/u)	1.88
Average days for independent mobilization	2
Patients with symptoms relapse	1
Radiologic outcome	
Biomechanical decompensation (spondylolisthesis)	1
Need for reoperation (fixation)	1

CSF, cerebrospinal fluid; NRS, Numeric Rating Scale for pain; f/u, follow-up.

approach was chosen. The arrows in Figure 7 show the undercutting of the base of the spinous process to have adequate endoscopic vision of the entire contralateral side without the necessity of a bilateral approach, hence avoiding the extension of the fixation that it would have entailed the inclusion of a further motion segment.

DISCUSSION

The use of the piezoelectric device for spinal surgery provides several technical advantages. The micrometric vibrations of the insert and the absence of macrovibrations permit a safe and precise cut and allow the preservation of a blood-free surgical site by exploiting the physical phenomenon of cavitation. The precision and safety of the piezoelectric cut was particularly useful for hemilaminectomies and craniotomies, where it was possible to protect the underlying dura and the neurovascular structures, thus avoiding iatrogenic trauma. When used in hemilaminectomy, this technique allowed us to obtain a good decompression of the vertebral canal and neural structures while preserving the stability of the spine by preserving the posterior tension band, ligaments, and joints. The minimal invasiveness of the piezo cut also was confirmed by the follow-up imaging, where the incidence of osteosclerosis and bone resorption at the osteotomized surfaces was negligible.[6,7] Moreover, the osteotomy is very accurate because less strength is required of the surgeon to cut compared with that required using a drill, a craniotome, or rongeurs, thus allowing better control of the instrument.[8-12] The good outcomes reported in the present study allow us to consider the piezoelectric bone scalpel as a useful tool to be integrated into the neurosurgical armamentarium of the already minimally invasive microscopic and endoscopic techniques.[11,12] The main reported disadvantage of the currently available ultrasonic bone scalpels used in spinal surgery is the thermal dissipation, which may cause heat-related thermal injuries to soft tissues, but, above all, the continuous amount of water needed, mixed with the bubble of ultrasound, can cause water to splash, which may create blurred vision under microendoscopic conditions. The use of the piezo can also slightly lengthen the duration of the osteotomy. The authors do not recommend performing the hemilaminectomy entirely with the piezoelectric bone scalpel, to avoid prolonged surgical time, so it is advisable to use the tool only in selected surgical steps and during the more delicate surgical phases. As a general rule, it is important to know pros and cons of each technology and approaches to use them according to specific patients and conditions without any conditioning by mental barrier and/or personal philosophy.

Another advantage of this instrument is the angled and lightweight configuration of the handpiece, which allows the surgeon to handle the device comfortably and precisely under microscopic or endoscopic magnification, without obstacles to the surgeon's view, such as straight and bulky handpieces. In addition, piezoelectric surgery may improve bone healing, as it has been shown to cause less bone loss during the healing period in a canine model compared with conventional burr devices.[8,9] Our surgical experience is mainly focused on the use of piezosurgery in the decompression of the vertebral canal bilaterally with a monolateral approach; the monolateral skeletonization allows to

preserve the central posterior tension band. The use of piezo allows one to be selective in bone decompression, making it precise and preserving as much bone as possible, always in a minimally invasive fashion. Various minimally invasive techniques with the aim to reduce unnecessary exposure and tissue trauma have been reported as alternatives to conventional lumbar decompression. Soriano-Sánchez et al.[13] proposed a tubular retractor system to treat lumbar spinal stenosis and reported a shorter time to prepare the lumbar interspinous corridor in order to achieve the interlaminar window. Perez-Roman et al.[14] performed a meta-analysis and systematic review of studies comparing the outcomes between endoscopic (uni- and biportal) and microscopic techniques for the treatment of lumbar stenosis: endoscopy seems to be slightly superior in terms of back pain control rate and reduced length of hospital stay. The field of minimally invasive lumbar surgery can be implemented with the use of piezo osteotome; the use of tubulars, which could reduce the size of the skin access, was not available at the time of our study, but we hope to be able to integrate the technique of minimally invasive piezo osteotomy to additional tools like the aforementioned. To our knowledge, there is no recognized superiority of one minimally invasive technique over the other; our minimally invasive piezo technique could fit into the articulated world of minimally invasive surgery at the moment as a complementary tool, although it cannot completely replace traditional osteotomes at all stages of the surgical procedure. This retrospective, multicentric experience demonstrates that the piezoelectric osteotome, along with working under micro- and endoscopic vision, is a feasible, safe, and an accurate technique to perform a less-invasive, stability-preserving posterior spine decompression with a monolateral approach, even in cases of severe and complex spine deformities.

CONCLUSIONS

This study demonstrates that a selective, tailored microendoscopic monolateral approach for bilateral spine decompression, with the help of the piezoelectric osteotome for precise bone cutting, is adequate, feasible, and safe in performing an effective posterior spine decompression, even in selected cases of complex spine degenerative disease, in order to preserve spine stability.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Alessio Iacoangeli: Conceptualization, Data curation, Writing — original draft, Writing — review & editing. **Mostafà Alsagheir:** Methodology, Supervision, Validation. **Denis Aiudi:** Conceptualization, Data curation, Supervision, Validation. **Maurizio Gladi:** Conceptualization, Supervision, Validation, Visualization. **Alessandro Di Rienzo:** Validation, Visualization. **Domenic P. Esposito:** Validation, Visualization. **Mohammed Diab:** Validation, Visualization. **Hamza Naas:** Validation, Visualization. **Alì Eldellaa:** Validation, Visualization. **Antonio Gigante:** Conceptualization, Validation, Visualization. **Maurizio Iacoangeli:** Conceptualization, Data curation, Validation, Visualization, Writing — original draft, Writing — review & editing. **Nabeel S. Alshafai:** Validation, Visualization. **Gustavo Luzardo:** Validation, Visualization.

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