

Long-term Outcomes after Microsurgical Decompression of Lumbar Foraminal Stenosis and Adverse Effects of Preoperative Scoliosis: A Prospective Cohort Study

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Abstract

Lumbar foraminal stenosis is a common disorder, with surgical treatment varying from simple decompression to interbody fusion. It is often associated with degenerative lumbar scoliosis, but the effects of scoliosis on outcomes are unclear. The objectives of this study were to clarify long-term outcomes after microsurgical decompression of lumbar foraminal stenosis through Wiltse's approach and to determine the effects of scoliosis on these outcomes. A total of 86 consecutive patients with lumbar foraminal stenosis were prospectively followed after microsurgical decompression. They were categorized in multiple subcohorts with follow-up durations ranging from 6 months to 5 years. Outcomes were assessed using the Short Form 36 questionnaire (average physical scores and bodily pain scores). Local Cobb angle of the operative segment was measured preoperatively, and its effects on outcomes were analyzed. Average physical scores improved significantly from 33.8 (95% confidence interval [CI]: 29.1–38.5) preoperatively to 59.5 (95% CI: 54.6–64.3) at 6 months postoperatively and remained improved for 5 years. Bodily pain scores improved significantly from 23.7 (95% CI: 18.7–28.6) preoperatively to 56.3 (95% CI: 51.2–61.6) at 6 months postoperatively and remained improved for 5 years. Patients with preoperative scoliosis (local Cobb angle >10 degrees) had poorer outcomes: average physical scores were worse by 9.6 points ($p = 0.07$) and bodily pain scores were worse by 12.1 points ($p = 0.02$), compared with patients without scoliosis (local Cobb angle ≤ 10 degrees). Microsurgical foraminal decompression produced overall excellent outcomes in patients with lumbar foraminal stenosis. Preoperative scoliosis attenuated these beneficial effects.

Keywords: spinal stenosis, lumbar vertebrae, foraminal stenosis, surgical decompression, treatment outcome, microsurgery

Introduction

Lumbar foraminal stenosis, representing 8–11% of lumbar degenerative diseases,^{1,2)} is a common disorder treated by spine surgeons. Direct compression of the dorsal root ganglion produces low back pain and radicular pain, which are often severe.³⁾ Symptom improvement requires accurate diagnosis and appropriate treatment; however, there is no consensus regarding the best surgical strategy.^{1,2,4–17)}

There are two main categories of surgical treatment for lumbar foraminal stenosis¹⁰⁾: total facetectomy with or without fusion and facet-preserving microsurgical or endoscopic foraminotomy. Because total facetectomy may produce postoperative instability,¹⁸⁾ it is usually supplemented with interbody fusion. Facet-preserving microsurgical foraminotomy includes two approaches: traditional midline approach with lateral extension⁶⁾ and posterolateral approach through the erector spinae muscles, originally described by Wiltse et al.¹⁹⁾

Treatment is complicated by the presence of degenerative lumbar scoliosis. Scoliosis reduces the height of intervertebral foramen on the concave side of the curve, promoting foraminal stenosis.^{20,21)} Foraminal stenosis is a common cause of symptoms in lumbar degenerative scoliosis. However, decompression of

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foraminal stenosis in the presence of scoliosis may lead to poor outcomes because of underlying spinal instability, as exemplified in anecdotal cases.^{13,22,23)} Thus, most surgeons perform fusion with instrumentation (including complicated long fusion) in this situation.

Nevertheless, it is unclear whether fusion with instrumentation provides additional benefits in patients with scoliosis. In a randomized controlled trial of patients with lumbar foraminal stenosis comparing bilateral foraminotomy, posterolateral instrumented fusion, and transforaminal lumbar interbody fusion, Hallett et al.²⁴⁾ observed no additional benefits with instrumented fusion. Likewise, Kim et al.²⁵⁾ found no difference in outcomes between microsurgical foraminotomy and posterior lumbar interbody fusion in patients with lumbar foraminal stenosis. Conversely, preoperative scoliosis was associated with slightly worse outcomes after microsurgical foraminotomy in Yamada et al.'s retrospective study.⁸⁾

In this study, we had two hypotheses: 1) microsurgical foraminotomy using Wiltse's approach provides good long-term outcomes in patients with lumbar foraminal stenosis and (2) these outcomes are influenced by preoperative presence of lumbar scoliosis.

Accordingly, we performed a prospective multi-cohort study of consecutive patients undergoing microsurgical foraminotomy to evaluate long-term outcomes and examine whether preoperative scoliosis affected these outcomes.

Methods

Study design

Our institutional review board approved this prospective multi-cohort study. After obtaining written informed consent, we enrolled 86 consecutive patients undergoing posterolateral foraminotomy from November 2007 to December 2016. The inclusion criteria were low back pain and/or sciatic pain unrelieved by conservative therapy; MRI demonstrating nerve root compression at the intervertebral foramen, compatible with symptoms and neurological findings; no associated canal stenosis; and no previous back surgery.

Follow-up continued until April 2017. Patients were classified into subcohorts based on follow-up duration: 6 months, 86 patients; 1 year, 78 patients; 2 years, 72 patients; 3 years, 57 patients; 4 years, 49 patients; and 5 years, 38 patients.

Surgical technique

The first author performed all operations using an identical procedure: microsurgical decompression

of the intervertebral foramen using modified Wiltse's technique.²⁶⁾ After making a 5-cm skin incision approximately 4 cm from the midline, a corridor was established using the plane between the multifidus and longissimus muscles. Under operating microscope visualization, the posterolateral aspect of the facet joints and pars interarticularis were exposed. The tip of the superior articular process of the lower vertebra was removed with a high-speed drill and an ultrasonic bone curette (SONOPET; Stryker, Kalamazoo, MI, USA). With this oblique viewing angle, we reached the entrance (lateral recess) of the foramen. The lateral part of the pars interarticularis was resected, and the foramen was unroofed along the medial aspect of the pedicle. After completing bony decompression, we carefully dissected the yellow ligament from the nerve root to achieve good decompression. This posterolateral oblique view enabled nerve root decompression along its entire course within the foramen (entrance, midzone, and exit) (Fig. 1).

Data acquisition

Preoperative studies included standing lumbar-spine x-rays with flexion and extension views, lumbar-spine MRI, and lumbar-spine CT. Postoperative imaging included lumbar-spine x-rays and CT on postoperative day 1 and lumbar-spine MRI 1 month postoperatively. Standing lumbar x-rays with dynamic studies were obtained at each follow-up time. Local Cobb angle was defined as the angle formed by the superior endplate of the superior vertebra and the inferior endplate of the inferior vertebra of the operative segment, measured on the antero-posterior view of standing lumbar-spine x-rays.

Short Form 36 (SF-36) questionnaires were completed preoperatively as well as at 6 months and 1, 2, 3, 4, and 5 years postoperatively. Average SF-36 physical score (average of physical functioning, role physical, bodily pain, and general health subscales) was used as an indicator of quality of life. SF-36 bodily pain score was used as an indicator of pain status.

Statistical analysis

As our data included repeated measures from the same individuals, it was well suited for linear mixed-effects models. These models are a type of multiple regression analysis, with added random effects that allow analysis of repeated-measures data.^{27,28)} Each individual was treated as a random effect influencing the data, which allowed the data to be analyzed using methodology similar to usual linear multiple regression. Separate models were

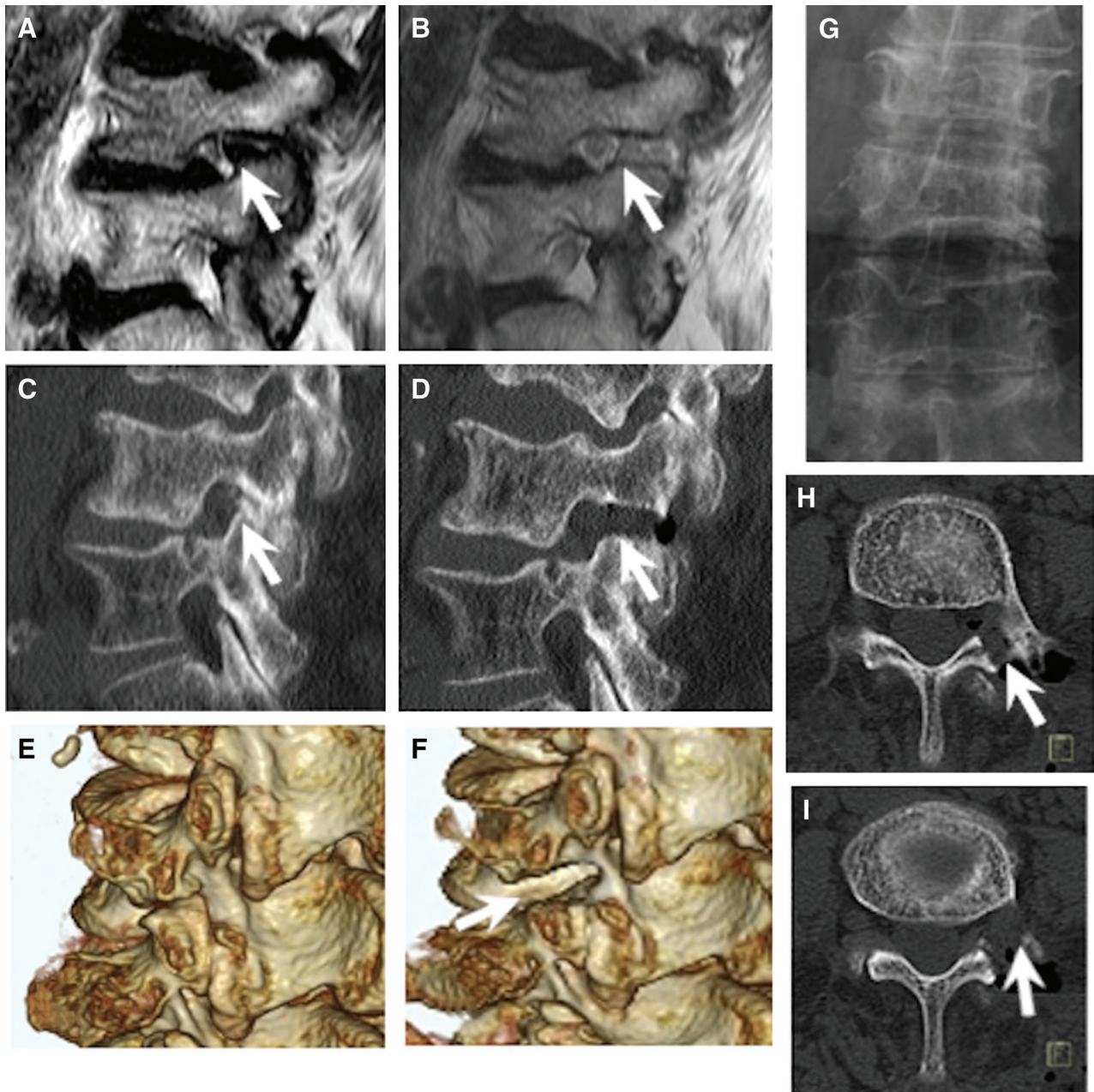


Fig. 1 Pre- and postoperative images of a 70-year-old woman who underwent posterolateral foraminotomy at left L4/5. (A) Preoperative lumbar-spine MRI sagittal section showing stenosis (arrow) at the left L4/5 foramen. (B) Postoperative MRI image of the same section. The left L4/5 foramen is well decompressed (arrow). (C) Preoperative lumbar-spine CT sagittal section showing stenosis of the left L4/5 foramen (arrow). (D) Postoperative image of the same section. Decompression of the left L4/5 foramen can be seen (arrow). (E and F) Pre- and postoperative 3D-CT images of the left L4/5 foramen viewed from the left posterolateral side. The arrow shows the site of decompression. (G) Preoperative lumbar-spine x-ray (antero-posterior view) showing mild degenerative scoliosis. (H and I) Postoperative lumbar-spine CT (contiguous axial slices). The medial limit of the decompression reaches the lateral recess (arrow in H), and the lateral limit reaches the extraforaminal area (arrow in I).

constructed for average physical and bodily pain scores, using timing of questionnaire (preoperatively, 6 months, and 1, 2, 3, 4, and 5 years postoperatively) and preoperative local Cobb angle as explanatory

variables. For questionnaire timing, the model calculated coefficients using preoperative score as the reference. P-values <0.05 were considered as statistically significant. Statistical power of each

Table 1 Characteristics of the patients

N	86
Male	46
Female	40
Mean age (SD)	69 (10.3)
Local Cobb angle	
Median	4.0
Interquartile range	1.3–7.5
Range	0–17.2
Groups	
N (local Cobb angle ≤10)	74
N (local Cobb angle >10)	10
Levels	
L2/3	6
L3/4	14
L4/5	37
L5/S1	30

SD: standard deviation.

regression model was estimated using *simr* package (*R* statistical software).

Preliminary data analysis suggested that average physical and bodily pain scores and outcome scores worsened with preoperative local Cobb angles >10 degrees. Patients were therefore divided into two groups: scoliosis (Cobb angle >10 degrees) and non-scoliosis (Cobb angle ≤10 degrees) groups. Outcomes of both groups were compared.

Scoliosis progression was analyzed in patients with preoperative local Cobb angles >7.5 degrees. Paired t-test was used to compare mean preoperative Cobb angle with mean Cobb angle at the last visit. Reoperation rates were evaluated using survival analysis. All reoperations involved simple decompression and were classified as decompression of the original foramen (true reoperations) or decompression of de novo lesions. Five-year reoperation rates for true reoperations were estimated using the Kaplan–Meier method, with rates for stenosis and non-stenosis groups compared using the log-rank test.

All analyses were performed using *R* version 3.6.2 (R Core Team, R Foundation for Statistical Computing, Vienna, Austria) and *RStudio* version 1.2.5033 (RStudio Team, RStudio, Inc., Boston, MA, USA), with *lmer4* package version 1.1-21, *emmeans* package version 1.4.5, *survival* package version 3.1.8, *survminer* package version 0.4.6, and *simr* package version 1.0.5.

Table 2 Number of patients and follow-up rate of the subcohorts

Subcohort	Category	N	Median Cobb angle	Follow-up rate (%)
6 months	Registered	86	4.0	94
	Followed up	81	4.0	
1 year	Registered	78	4.3	87
	Followed up	68	4.3	
2 years	Registered	72	4.5	75
	Followed up	54	4.3	
3 years	Registered	57	4.4	63
	Followed up	36	4.4	
4 years	Registered	49	4.1	61
	Followed up	30	4.4	
5 years	Registered	38	4.3	66
	Followed up	25	5.1	

Results

The study included 46 males and 40 females, with a mean age of 69 years (Table 1). All patients underwent one-level posterolateral foraminotomy except one, who underwent two-level posterolateral foraminotomy on the same side. In two patients, foraminotomy was combined with lateral recess decompression through the midline approach to decompress the same nerve root. Operative levels are shown in Table 1. Median preoperative local Cobb angle was 4.0 degrees (interquartile range: 1.3–7.5; range: 0–17.2).

Table 2 shows the number of patients and follow-up rates in each subcohort. Mean preoperative local Cobb angles of enrolled and followed patients in each subcohort were similar, suggesting that dropout and followed patients were similar in terms of preoperative scoliosis.

Overall outcomes

Overall, average physical scores improved significantly from preoperatively (33.8; 95% confidence interval [CI]: 29.1–38.5) to 6 months postoperatively (59.5; 95% CI: 54.6–64.3) and remained significantly improved up to 5 years (Fig. 2 and Table 3). Bodily pain scores also improved significantly from preoperatively (23.7; 95% CI: 18.7–28.6) to 6 months postoperatively (56.3; 95% CI: 51.2–61.6) and remained significantly improved up to 5 years (Fig. 2 and Table 4).

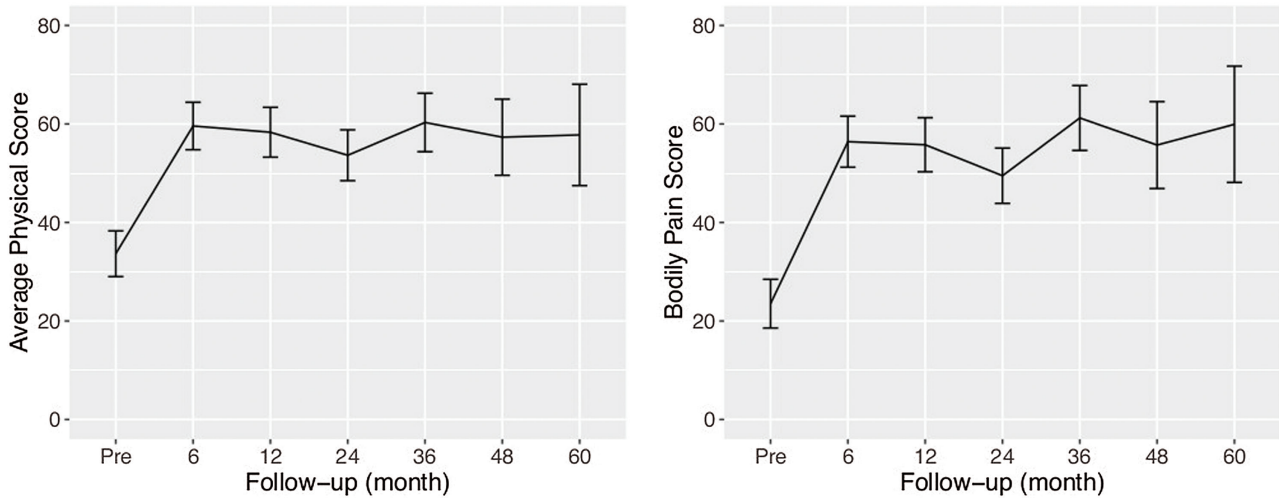


Fig. 2 Mean average physical scores (left) and bodily pain scores (right) before surgery (pre) and at each post-operative time point. Error bars indicate 95% CI of the mean, calculated by linear mixed-effects models. CI: confidence interval.

Table 3 Results of linear mixed-effects model on the average physical score

Factor	Coefficient	95% CI	p-value
Cobb angle > 10	-9.6	-19.8 to 0.7	0.07
6 months	25.7	21.0–30.5	<0.001
1 year	23.7	18.9–28.5	<0.001
2 years	20.5	15.6–25.5	<0.001
3 years	24.6	19.0–28.5	<0.001
4 years	23.0	16.9–29.2	<0.001
5 years	20.9	14.3–27.5	<0.001

CI: confidence interval.

Effects of scoliosis

Average physical and bodily pain scores over time tended to be worse in the scoliosis group than in the non-scoliosis group (Fig. 3). The linear mixed-effects model for average physical scores showed that Cobb angles >10 degrees lowered the score by 9.6 points compared with Cobb angles ≤10 degrees ($p = 0.07$). Power analysis indicated that this model had an 86% (95% CI: 77.6–92.1%) power to detect a 15-point physical score difference between groups. The linear mixed-effects model for bodily pain scores revealed that Cobb angles >10 degrees lowered scores by 12.1 points compared with Cobb angles ≤10 degrees ($p = 0.02$). This model had an 89% (95% CI: 81.2–94.4%) power to detect a 15-point difference between groups.

Table 4 Results of linear mixed-effects model on the bodily pain score

Factor	Coefficient	95% CI	p-value
Cobb angle >10	-12.1	-21.8 to -2.3	0.02
6 months	32.8	27.2–38.3	<0.001
1 year	31.3	25.7–36.9	<0.001
2 years	26.9	21.1–32.7	<0.001
3 years	35.6	29.1–42.2	<0.001
4 years	32.7	25.5–39.9	<0.001
5 years	31.0	23.3–38.7	<0.001

CI: confidence interval.

Complications

Only one surgery-related complication occurred. One patient developed transient paresthesias in the distribution of the decompressed nerve root, which resolved completely in 2 weeks. No patient received a blood transfusion. No surgery-related infections occurred.

Progression and reoperations

Follow-up x-rays showed no definite scoliosis progression. In patients with preoperative local Cobb angles >7.5 degrees ($n = 21$), the mean angle decreased from 10.52 (standard deviation [SD], 2.1) preoperatively to 9.8 (SD, 3.8) at the last visit ($p = 0.37$).

True reoperations occurred in three patients. One patient underwent reoperation 10 months postoperatively because of insufficient decompression. The

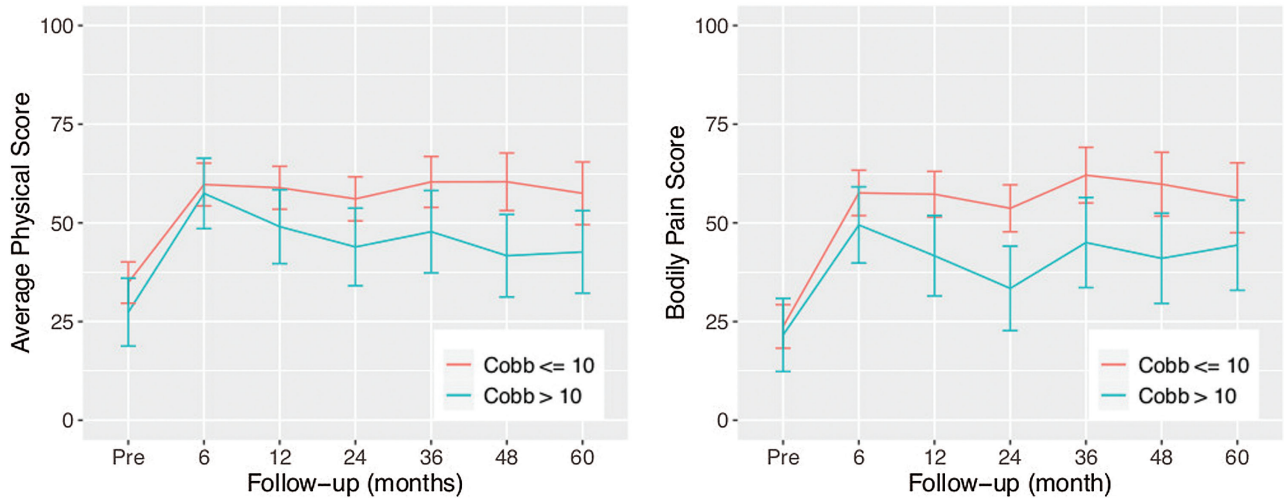


Fig. 3 Time course of average physical scores (left) and bodily pain scores (right) of patients with Cobb angles ≤ 10 degrees (red) and those with Cobb angles > 10 degrees (green). Error bars indicate 95% CI of the mean. CI: confidence interval.

other two patients underwent repeat decompression 4 years postoperatively for restenosis of the operated foramen. All reoperations were performed through the same Wiltse's approach, with microsurgical decompression. Overall 5-year reoperation rate was 6.7% (95% CI: 0–14), according to the Kaplan–Meier analysis. The log-rank test revealed no difference in reoperation rates between scoliosis and non-scoliosis groups ($p = 0.9$).

Discussion

Our results demonstrated that microsurgical facet-preserving foraminotomy using Wiltse's approach provides excellent outcomes in patients with lumbar foraminal stenosis. However, preoperative scoliosis (Cobb angle > 10 degrees) adversely affected outcomes, reducing average physical scores by 9.6 points ($p = 0.06$) and bodily pain scores by 12 points ($p = 0.02$).

The posterolateral intermuscular approach, first described by Wiltse et al.,²⁹ has many advantages for lumbar foraminal stenosis. By using the natural corridor between the multifidus and longissimus muscles, it is less invasive. It also facilitates decompression of the nerve root in all foraminal zones, including the entrance (lateral recess) zone, midzone (area between pedicles), and exit zone (area outside the lateral limit of the pedicles).^{1,30} The posterolateral view optimizes decompression of the exit zone because this is the first area exposed. By contrast, this zone is difficult to access through the traditional midline approach because it requires more muscle dissection, which is potentially hazardous.³¹ The

oblique surgical angle of the posterolateral approach allows midzone and entrance zone decompression without compromising spinal stability. Only the lateral portion of the pars interarticularis and the tip of the facet joint are removed, minimally affecting spinal stability according to cadaver and finite element analysis studies.^{2,32}

Our technique is also safe. We observed no surgery-related complications except transient paresthesias in one patient; this is a well-known postoperative symptom, which is possibly related to dorsal root ganglion manipulation.^{1,10,11} Using SONOPET, we removed bony elements compressing the nerve root without causing damage. Conversely, long fusion with instrumentation for lumbar degenerative scoliosis is more invasive, with complication rates of 20–80%,^{13,14,16,33} including both short-term (e.g., blood loss, infection, nerve injury) and long-term (e.g., instrument failure, pseudoarthrosis, adjacent-level disease, proximal junctional kyphosis) complications.^{13,33}

Several series of facet-sparing foraminotomy (microsurgical or endoscopic) for lumbar foraminal stenosis have been published. In 31 patients with a mean follow-up of 3.2 years, Baba et al. reported overall good results with subjective outcome measures.⁷ In 46 patients undergoing microsurgical foraminotomy through the posterolateral approach, Yamada et al. reported significantly improved Japanese Orthopedic Association scores, with poorer outcomes in patients with preoperative Cobb angles > 10 degrees.⁸ Our surgical technique was similar to that used by Yamada et al., as was our finding of slight adverse effects of scoliosis.⁸ Our results reconfirm

excellent outcomes of facet-preserving microsurgical foraminotomy in a larger study, with a longer follow-up period and patient-oriented outcome measures.

Some series of endoscopic foraminotomy have been reported. Ahn et al. showed good results in 33 patients at 2-year follow-up.¹¹⁾ Madhavan et al. noted good results in 16 patients with mild scoliosis at a mean follow-up of 7.5 months.³⁴⁾ Kim et al. reported good results at 1-year follow-up using a biportal endoscopic technique in 31 patients with lumbar foraminal stenosis.²⁾ Endoscopic techniques may require removing a larger proportion of the facet than our microsurgical technique. Kim et al.²⁾ removed approximately 50% of the superior articular process using an osteotome. In Sairyo et al.'s percutaneous endoscopic lumbar foraminotomy technique, which enabled lateral recess zone decompression, the entire superior articular process was removed.¹²⁾ In contrast, we removed only the tip of the superior articular facet. SONOPET allows fine control of the amount of bone removed. It is also safer than drills or osteotomes for removing bone close to nerve roots because it lacks rotating motion.

Preoperative scoliosis had relatively small, but clear, adverse effects on outcomes, reducing average physical scores by 9.6 points and bodily pain scores by 12.1 points. These effects may have been due to scoliosis progression—a possibility equivocally supported by our data. Adverse effects on average physical scores increased during follow-up, whereas adverse effects on bodily pain scores showed no such tendency. Moreover, follow-up x-rays showed no clear evidence of scoliosis progression in patients with preoperative scoliosis, and the literature suggests that mild scoliosis does not increase the risk of further progression. Therefore, the hypothesis that gradual scoliosis progression produced adverse effects is feasible but not definitively supported by our data.

An alternative hypothesis is that decompression was incomplete in patients with scoliosis. In these patients, foramen height on the concave side is decreased, so nerve root compression occurs not only in the ventro-dorsal direction but also in the rostro-caudal direction. Decompression is technically challenging, as it requires removing either part of the laterally protruding disc, or vertebral body or part of the pedicle. Therefore, it may be advantageous to perform interbody fusion with cages to enlarge the disc space, indirectly increasing foramen height. Another strategy would involve meticulous decompression to increase the height of the foramen.^{35,36)} It is our belief that further refinement of the microsurgical decompression

technique may improve the outcome of patients associated with lumbar scoliosis.

Our estimated 5-year reoperation rate of 6.7% is compatible with previous results.^{37–39)} However, preoperative scoliosis did not increase the reoperation rate, contradicting suggestions that patients with scoliosis have higher reoperation rates. This may reflect the minimum amount of facet joint violation in our technique.

Overall, we believe that our technique is quite useful for patients with lumbar foraminal stenosis associated with a mild degree of scoliosis. It will be especially useful for aged or medically complicated patients who may not be feasible for complicated fusion surgery. It may even benefit those patients with a moderate degree of scoliosis as our data show. On the other hand, its benefit may be limited in patients with severe coronal and sagittal deformity.

This study has shortcomings. The number of patients and follow-up rates were smaller in longer subcohorts. As a prospective cohort study of a single surgical technique, different techniques were not compared. This comparison would require a randomized controlled trial. Linear mixed-effects models, although appropriate for our data, are not widely used in neurosurgical studies.

Conclusion

Our results showed that facet-sparing microsurgical foraminotomy through Wiltse's approach produces excellent results in patients with lumbar foraminal stenosis. Although preoperative scoliosis adversely affected outcomes, these effects were relatively small and may be overcome by further improvements in surgical techniques.

Conflicts of Interest Disclosure

The authors have no COI to disclose.

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