Microendoscopic decompression for lumbosacral foraminal stenosis: a novel surgical strategy based on anatomical considerations using 3D image fusion with MRI/CT

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OBJECTIVE Persistent lumbar foraminal stenosis (LFS) is one of the most common reasons for poor postoperative outcomes and is a major contributor to “failed back surgery syndrome.” The authors describe a new surgical strategy for LFS based on anatomical considerations using 3D image fusion with MRI/CT analysis.

METHODS A retrospective review was conducted on 78 consecutive patients surgically treated for LFS at the lumbosacral junction (2013–2017). The location and extent of stenosis, including the narrowest site and associated pathology (bone or soft tissue), were measured using 3D image fusion with MRI/CT. Stenosis was defined as medial intervertebral foraminal (MF; inner edge to pedicle center), lateral intervertebral foraminal (LF; pedicle center to outer edge), or extraforaminal (EF; outside the pedicle). Lumbar (low-back pain, leg pain) and patient satisfaction visual analog scale (VAS) scores and Japanese Orthopaedic Association (JOA) scores were evaluated. Surgical outcome was evaluated 2 years postoperatively.

RESULTS Most instances of stenosis existed outside the pedicle’s center (94%), including LF (58%), EF (36%), and MF (6%). In all MF cases, stenosis resulted from soft-tissue structures. The narrowest stenosis sites were localized around the pedicle’s outer border. The areas for sufficient nerve decompression were extended in MF+LF (10%), MF+LF+EF (14%), LF+EF (39%), LF (11%), and EF (26%). No iatrogenic pars interarticularis damage occurred. The JOA score was 14.9 ± 2.6 points preoperatively and 22.4 ± 3.5 points at 2 years postoperatively. The JOA recovery rate was 56.0% ± 18.6%. The VAS score (low-back and leg pain) was significantly improved 2 years postoperatively (p < 0.01). According to patients' self-assessment of the minimally invasive surgery, 62 (79.5%) chose “surgery met my expectations” at follow-up. Nine patients (11.5%) selected “I did not improve as much as I had hoped but I would undergo the same surgery for the same outcome.”

CONCLUSIONS Most LFS existed outside the pedicle’s center and was rarely noted in the pars region. The main regions of stenosis were localized to the pedicle’s outer edge. Considering this anatomical distribution of LFS, the authors recommend that lateral fenestration should be the first priority for foraminal decompression. Other surgical options including foraminotomy, total facetectomy, and hemilaminectomy likely require more bone resections than LFS treatment. The microendoscopic surgery results were very good, indicating that this minimally invasive surgery was suitable for treating this disease.

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KEYWORDS lumbar foraminal stenosis; 3D image fusion with MRI/CT; anatomical consideration; surgical strategy; pathologic constriction

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Lumbar foraminal stenosis (LFS) at the lumbosacral junction, including the notorious “far-out syndrome,” is one of the most common reasons for poor postoperative outcomes, and a major contributor to “failed back surgery syndrome.” Because the recent advent of 3D imaging has vastly improved diagnostic accuracy such that LFS can be more accurately identified and defined, the number of surgical cases of LFS has increased in recent years. Among available imaging options, 3D image fusion with MRI/CT can be utilized to visualize nerve pathways within and beyond the intervertebral foramen; this is very useful for the recognition of any impingement and preoperative surgical planning for LFS.

Several neural decompression procedures have been utilized to treat LFS, including foraminotomy, osteoplastic hemilaminectomy, and lateral fenestration with and without fusion (Supplementary Fig. S1). Adequate decompression of LFS can be technically demanding. Traditional open operative methods often require extensive removal of bone structures for visual confirmation of sufficient nerve decompression. These approaches carry an increased risk of inducing segmental instability because of the violation of the pars interarticularis, and excessive resection of the facet joint. Preservation of bone structures, however, may result in inadequate decompression of the foramen, resulting in persistent symptoms and the consequent need for further surgery.

The challenges of direct foraminal decompression have led to an increasing trend toward solving these problems using interbody fusion techniques and indirect foraminal decompression. There are substantial downsides to fusion procedures, including increased costs and a higher complication profile comprising adjacent-segment disease and the possibility of pseudoarthrosis, with associated interbody displacement or hardware failure. Furthermore, many patients with LFS are elderly; for them, fusion surgery is associated with higher morbidity and mortality rates, although the benefits of such surgery might be amplified.

Minimally invasive decompression procedures with microendoscopic approaches may allow for appropriate visualization and resection of compressive structures in the context of LFS while preserving stability and avoiding the need for fusion. In order for minimally invasive decompression procedures with microendoscopic approaches to be successful, it is important to accurately understand the location where the nerve root is compressed and the component of the compression.

The primary purpose of this study was to elucidate the location and extent of stenosis, including the narrowest site and associated pathology (bone or soft tissue) based on our new anatomical classification of LFS. The secondary purpose was to determine the efficacy of microendoscopic surgery for the treatment of LFS.

**Methods**

**Study Design and Population**

We retrospectively reviewed the medical records of all consecutive patients who underwent surgery for fifth lumbar (L5) radiculopathy caused by LFS at the lumbosacral junction at Wakayama Medical University and had evidence of associated LFS at the lumbosacral junction between January 2013 and December 2017. All patients underwent posterior spinal endoscopic surgery. The inclusion criteria were as follows: 1) neurogenic claudication or radicular leg pain with associated neurological signs suggestive of L5 radiculopathy, 2) LFS on cross-sectional MRI, and 3) failure of conservative treatment for at least 3 months. For the second inclusion criterion, LFS was determined as follows: 1) a decrease in or disappearance of perineural fat tissue surrounding the nerve root observed on the parasagittal MRI scan, and 2) nerve root swelling observed on the 3D MRI scan. There were many patients with lesions in both the intracanal at L4–5 and the extraforaminal zone at the lumbosacral junction along the nerve pathways on preoperative imaging findings. To investigate L5 radiculopathy at the lumbosacral junction, patients with double lesions confirmed by preoperative imaging findings were excluded. The exclusion criteria were as follows: 1) dynamic segmental instability, such as degenerative spondylolisthesis greater than grade II and isthmic spondylolisthesis; 2) history of spine surgery; 3) bedridden status due to preexisting problems; and 4) current severe infection or concurrent acute fracture. Eighty-five cases met the initial criteria for inclusion. Four patients who had a history of cervical spinal surgery and 3 patients who had dynamic segmental instability were excluded. After exclusions, 78 patients were included in the final analysis (Fig. 1).

**Ethical Statements**

All procedures performed in this study, as pertaining to human participants, were in accordance with the ethical standards of the institutional research committee (the Research Ethics Committee of Wakayama Medical University) and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Informed consent was obtained from all participants.

**Anatomical Classification of LFS for Preoperative Surgical Planning**

There is no global consensus concerning the anatomic definition of the intervertebral foramen; however, it generally refers to the region from the inner edge to the outer edge of the pedicle, with the region medial to the inner edge of the pedicle classified as the spinal canal, and the lateral side from the outer edge of the pedicle classified as extraforaminal. The center of the pedicle mostly aligns with the outer edge of the pars interarticularis; therefore, in this study, lesions in the intervertebral foramen area were further subcategorized into two groups. Lesions located between the inner edge and the center of the pedicle were newly defined as medial intervertebral foraminal stenosis (MF), whereas lesions located between the center and the outer edge of the pedicle were newly defined as lateral intervertebral foraminal stenosis (LF). Stenosis outside the foramen was classified as extraforaminal stenosis (EF) as in previous classifications (Fig. 2).

**Surgical Procedures**

Patients were operated on under general anesthesia. After intubation, the patient was placed prone on a 4-poster...
spinal frame. Before microendoscopic spinal decompression for LFS, the transverse process, lateral aspect of the L5–S1 facet, and sacral ala (known as the TLS triangle) were drawn on the surface of the skin using fluoroscopy. A 16-mm skin incision was made in the TLS triangle, and a tubular retractor was introduced into the extraforaminal zone. After removing the soft tissue of the posterior surface of these bone structures, the lumbosacral ligament was first identified as a landmark for bone decompression. The lower border of the L5 transverse process, the upper border of the sacral ala, and the lateral osteophyte of the S1 superior articular process were drilled out until the lumbosacral ligament was released from the surrounding bone structures. After resection of this ligament, the L5 spinal nerve could be identified. After releasing the constricted fibrous band, further decompression was performed along the nerve laterally and caudally by additional resection of the sacral ala, if necessary. When the nerve was not released completely through this procedure and/or concomitant foraminal stenosis was present, the authors attempted to remove the inferior half of the pedicle to enlarge the foramen, instead of removing the osteophyte and bulging disc at the L5–S1 segment.

Clinical Outcome Measurements

CT-MRI fusion software (SYNAPSE VINCENT version 5.3, Fujifilm Medical Co.) was used for preoperative CT and MRI analysis (Fig. 3). On the basis of our new anatomical classification of LFS, the location and extent of stenosis, including the narrowest site and associated pathology (bone or soft tissue), were measured using CT-MRI fusion software. Images were provided to the read-

FIG. 1. Flow diagram for the present study.

FIG. 2. Proposed anatomical classification for the vertebral body. A: Simple radiographic image of the L5 vertebral body (front). B: Schematic of the vertebral body. The center of the pedicle mostly aligns with the outer edge of the narrow part of the vertebral arch (pars interarticularis). C: Schematic of structural detail between the inner edge and the center of the pedicle (MF), between the center and the outer edge of the pedicle (LF), and outside the foramen (EF).
ers on CDs and viewed with commercial software (SYNAPSE VINCENT). The radiological evaluation and LFS classification were performed by two independent readers (K.N. and M.O., orthopedic surgeons and board-certified spinal experts of the Japanese Orthopaedic Association [JOA]), who did not know the clinical information of the patient. Each reader attended a lecture by a coauthor (H.Y.) explaining a standardized definition of image features, and consensus for interpretation of the radiological evaluation and the LFS classification was obtained among the readers before the start of the study. All MRI/CT fusion images were independently evaluated twice by the 2 readers with a 1-month interval between readings. The actual decompression range of the stenosis was investigated by comparing pre- and postoperative CT and MRI scans via the CT-MRI fusion software.

The surgical outcome was evaluated using the JOA scoring system (JOA score) for low-back pain before and 2 years after surgery. The JOA scoring system (full score = 29 points) and visual analog scale (VAS) for low-back and leg pain (full score = 100 mm), and perioperative complications were used to measure neurological and axial pain outcomes, respectively. At the > 2-year postoperative visit, a routine planned visit for all patients who underwent microendoscopic spinal surgery in our institution, the JOA and VAS scores were reevaluated. Successful treatment was defined as a recovery rate > 25%. Furthermore, the achievement of a minimum clinically important difference (MCID) in low-back pain VAS (decrease by ≥ 22 mm) and leg pain VAS (decrease by ≥ 50 mm) was investigated.

To evaluate the patient’s satisfaction with this minimally invasive surgery, the patient was asked to choose one of the following responses about the assessment of surgical treatment according to the criteria adopted from the North American Spine Society Low Back Outcome Instrument: 1) “Surgery met my expectations”; 2) “I did not improve as much as I had hoped, but I would undergo the same surgery for the same outcome”; 3) “Surgery helped but I would not undergo the same treatment for the same outcome”; or 4) “I am the same as or worse than I was before the surgery.”

We evaluated lumbar VAS scores (low-back pain, leg pain) and patients’ satisfaction VAS scores as patient-based items, and JOA score results as medical staff–based items. All other parameters were evaluated before and 2 years after surgery. The results were filed in each patient’s medical records and did not play a role in any decision-making. All results were collated and analyzed independently of the operating surgeon.

**Statistical Analysis**

The Wilcoxon/Kruskal-Wallis test was used to compare preoperative JOA and lumbar VAS scores with the same scores assessed at the 2-year postoperative visit. All statistical analyses were performed using the JMP statistical program (version 11, SAS Inc.), with the level of significance set at p < 0.05.

**Results**

Seventy-eight patients (47 men and 31 women, mean age 69.1 ± 20.6 years) were included in the study (Table 1). Among the 78 patients, 44 (57%) had spondylosis, 26 (33%) had degenerative scoliosis, and 8 (10%) had herniated discs (Table 1). All patients were surveyed 2 years after the surgery.

The narrowest parts of stenosis were the MF, LF, and
EF in 5 (6%), 45 (58%), and 28 (36%) patients, respectively. Therefore, 73 patients (94%) had the main lesion of stenosis outside the center of the pedicle. Bone stenosis was observed in 41 patients (53%), and stenosis was caused by soft tissue in 37 patients (47%). Bone stenosis accounted for 50% of the EF cases and 60% of the LF cases, but 0% of the MF cases. Bone stenosis was concentrated close to the outer edge of the pedicle, while MF cases only had stenosis caused by soft tissue such as herniated or bulging discs, and no bone stenosis was observed (Table 2).

The actual decompression range of stenosis was MF+LF in 8 patients (10%), MF+LF+EF in 11 patients (14%), LF+EF in 30 patients (39%), LF in 9 patients (11%), and EF in 20 patients (26%; Fig. 4). No patients required bone decompression of the vertebral arch.

The mean JOA score was 14.9 ± 2.6 points preoperatively and 22.4 ± 3.5 points at 2 years postoperatively. The mean JOA recovery rate was 56.0% ± 18.6%. The success rate of microendoscopic surgery was 94.9% (74/78 patients). The VAS score for low-back pain and leg pain at 2 years postoperatively was significantly improved (p < 0.01). The achievement rates of low-back pain MCID and leg pain MCID were 52.6% (41/78 patients) and 62.8% (49/78 patients), respectively (Table 3). There were 4 patients who did not achieve the expected improvement as assessed by the JOA score. Three patients were in the LF group and had residual compression due to insufficient resection of the superior articular process in the lateral intervertebral foraminal zone, not in the medial intervertebral foraminal zone. Although another patient showed insufficient decompression from the foraminal to extraforaminal zone, the recovery was suboptimal as assessed by the JOA score; the reasons for this were unclear.

According to patients’ self-assessment of the minimally invasive surgery, 62 patients (79.5%) chose “surgery met my expectations” at the follow-up. Nine patients (11.5%) selected “I did not improve as much as I had hoped but I would undergo the same surgery for the same outcome.” Of the remaining 7 patients, 4 answered “surgery helped but I would not undergo the same treatment for the same outcome,” and 3 answered “I am the same as or worse than I was before the surgery” (Fig. 5).

In this series, there were no major complications. However, 5 patients suffered from painful dysesthesia after surgery, which may have been caused by mechanical stimulation to the dorsal root ganglion. All patients were treated with steroids, and these symptoms were completely relieved in the following weeks.

Discussion
In this study, we investigated the preoperative incidence and location of LFSs as assessed using 3D image fusion with MRI/CT. Most instances of stenosis were noted outside the center of the pedicle (94%, including the LF in 58% and EF in 36%), and it was noted in the MF in 5 cases (6%). Most areas of LFS existed outside the center of the pedicle and were rarely seen in the pars region. The main regions of stenosis were localized to the outer edge of the pedicle. In addition, the surgical results of the microendoscopic surgery were very good, indicating that this minimally invasive surgery was suitable for treating this pathological disease. Considering this anatomical distribution of LFS, we recommend that lateral fenestration should be the first priority for foraminal decompression. Other surgical options including foraminotomy, total facetectomy, and hemilaminectomy likely require more bone resections than necessary for the treatment of LFS.

It is extremely important to properly conceptualize spinal anatomy, including the osseous and soft-tissue structures, when treating patients with lumbar degenerative diseases (Supplementary Fig. S2). The articular segment includes the intervertebral disc, ligamentum flavum, and facet joint. These are the major anatomical components that produce symptoms and signs (e.g., claudication or radiculopathy) resulting from lumbar degenerative diseases. The intraosseous segment is formed by the continuous bony rim of the vertebral body, pedicles, pars interarticularis, laminae, and spinous process. Because this segment is composed of contiguous bone tissue alone, it is theoretically considered a place where bone stenosis does not occur, and only soft-tissue pathology, such as combined lateral disc herniation, may cause symptoms in this region. The results of our investigation support such a concept.

Decompression procedures such as foraminotomy, total facetectomy, and osteoplastic hemilaminectomy have been generally used for the treatment of LFS, in which the pars interarticularis is completely opened to confirm nerve pathology. However, iatrogenic spinal instability often occurs, resulting in poor surgical outcomes.

Our study revealed that the predominance of LFS exists lateral to the center of the pedicle and extraforaminally, and rarely involves the more medial aspect of the foramen, in the absence of disc herniation or other soft-tissue component. In most cases of foraminotomy, total facetectomy and osteoplastic hemilaminectomy are not

| Table 1. Demographics of the 78 patients in the study |
|---------------------------------|-------------|
| Characteristic                  | Total       |
| Sex                             | Male 47     |
|                                 | Female 31   |
| Mean age (range), yrs           | 69.1 (33–88) |
| Pathology                       |            |
| Spondylosis deformans           | 44          |
| Degenerative scoliosis          | 26          |
| Herniated discs                 | 8           |

| Table 2. Areas with the narrowest stenosis and the causes of stenosis |
|---------------------------------|-------------|
| Stenosis elements              | Total       |
|                                | MF 5 (6%)   |
|                                | LF 45 (58%) |
|                                | EF 28 (36%) |
| Narrowest part                 | 5 (6%)      |
| Bone tissue (n = 41)           | 0           |
| Soft tissue (n = 37)           | 27          |

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necessary for almost all cases of LFS. The use of these procedures should be limited to the cases combined with lateral disc herniation in the pars interarticularis.

It is strongly recommended that the foramen should be decompressed laterally, not medially, because the main regions of stenosis were commonly located around the outer edge of the pedicle. Taking into consideration this anatomical distribution of LFS, lateral fenestration should be the first priority for foraminal decompression (Supplementary Fig. S3).

By using the normal posterior approach, the facet joints are inevitably sacrificed to a certain degree to expose the nerve tissue; however, if a lateral approach with the use of a spinal microendoscope is applied, then it should be possible to preserve the facet joints. We use spinal microendoscopy for LFS because it not only provides new recognition of the pathology of LFS, but also enables us to develop new treatment strategies. As a result, favorable surgical outcomes were achieved by obtaining sufficient nerve decompression while sparing the facet joints and pars interarticularis, which could not be achieved using conventional methods.3

Nevertheless, this study had some limitations. First, this study follows a retrospective design; thus, further studies will be needed to compare this patient group as the size of this patient population increases. Second, we did not evaluate the degree to which our approach is applicable in the cephalad levels, and therefore further investigations

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<th>Variable</th>
<th>Preop</th>
<th>2 Yrs</th>
<th>Postop</th>
<th>p Value</th>
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<tr>
<td>Mean VAS score ± SD (mm)</td>
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<tr>
<td>Low-back pain</td>
<td>51.6 ± 28.6</td>
<td>21.8 ± 22.9</td>
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<td>Leg pain</td>
<td>70.5 ± 21.4</td>
<td>21.5 ± 23.9</td>
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<td>Achievement rate of MCID (%)†</td>
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<tr>
<td>Low-back pain VAS score</td>
<td>52.6 (41/78)</td>
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<tr>
<td>Leg pain VAS score</td>
<td>62.8 (49/78)</td>
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<tr>
<td>Mean JOA score ± SD</td>
<td>14.9 ± 2.6</td>
<td>22.4 ± 3.5</td>
<td>&lt;0.01*</td>
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<tr>
<td>Mean recovery rate ± SD (%)</td>
<td>56.0 ± 18.6</td>
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<td>Success rate (%)</td>
<td>94.9 (74/78)</td>
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In the JOA scoring system, a full score = 29 points. The JOA score recovery rate is determined by the formula: 100 × (postoperative JOA score − preoperative JOA score)/(29 − preoperative JOA score).

* Statistically significant (p <0.05).

† MCID = low-back pain VAS score decrease by ≥ 22 mm, leg pain VAS score decrease by ≥ 50 mm.
are needed. Third, this study included only patients who underwent endoscopic surgery and did not include patients who underwent other procedures. In our institution, all patients with L5 radiculopathy caused by LFS at the lumbosacral junction are treated with endoscopic surgery. We recommend multicenter studies to evaluate patients treated with other procedures.

Conclusions

Most areas of LFS existed outside the center of the pedicle, and LFS was rarely seen in the pars interarticularis. The main regions of stenosis were commonly located around the outer edge of the pedicle. Therefore, lateral fenestration should be the first priority for foraminal decompression. Surgical options such as foraminotomy, total facetectomy, and osteoplastic hemilaminectomy are not necessary for the treatment of LFS.

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References


Disclosures

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Author Contributions

Conception and design: Murata. Acquisition of data: Murata, Iwasaki, Nagata. Analysis and interpretation of data: Murata, Minamide, Yukawa, Schoenfeld, Simpson. Approved the final version of the manuscript on behalf of all authors: Murata. Drafting the article: Murata. Critically revising the article: Iwasaki, Nagata. Analysis and interpretation of data: Murata. Conception and design: Murata. Acquisition of data: Murata, Minamide, Yukawa, Schoenfeld, Simpson. Approved the final version of the manuscript on behalf of all authors: Murata. Statistical analysis: Hashizume. Administrative/technical/material support: Minamide, Nakagawa, Tsutsui, Takami, Okada, Yoshida. Study supervision: Yamada.

Supplemental Information

Online-Only Content

Supplemental material is available with the online version of the article.


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