Traditionally, the surgical treatment of acquired lumbar spinal stenosis has been wide laminectomy, which allows decompression of the neural structures by unroofing the spinal canal.2,6,39,46,80 The success rate of the procedure, however, is only 64%.81 The frequent surgical failures have been attributed to local tissue trauma1,87 and to postoperative spinal instability,26,42,50,57,79,87 which has led to a dramatic increase in lumbar fusion surgery.19,53

Increasing knowledge of the pathoanatomy, coupled with high-resolution imaging, has allowed a precise localization of nerve compression, which usually occurs at the level of the intervertebral space and the bulging yellow ligaments.78,87,93 Various authors have proposed more tailored and less invasive techniques in the treatment of acquired lumbar stenosis.11,54,66 In particular, bilateral 4,50,57,78,91,93 and unilateral laminotomy for bilateral decompression31,49,55,59,60,73,74,87 have been described. The reported results have been encouraging, with success rates as high as 90%, but most of these clinical series included small patient populations, recruited an inhomogeneous population, were retrospective, or lacked a control group. In the few comparative studies investigators did not find a significant benefit associated with a less invasive technique compared with laminectomy15,49,61,76 but reported a higher

Outcome after less-invasive decompression of lumbar spinal stenosis: a randomized comparison of unilateral laminotomy, bilateral laminotomy, and laminectomy

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Object. Recently, limited decompression procedures have been proposed in the treatment of lumbar stenosis. The authors undertook a prospective study to compare the safety and outcome of unilateral and bilateral laminotomy with laminectomy.

Methods. One hundred twenty consecutive patients with 207 levels of lumbar stenosis without herniated discs or instability were randomized to three treatment groups (bilateral laminotomy [Group 1], unilateral laminotomy [Group 2], and laminectomy [Group 3]). Perioperative parameters and complications were documented. Symptoms and scores, such as visual analog scale (VAS), Roland–Morris Scale, Short Form–36 (SF-36), and patient satisfaction were assessed preoperatively and at 3, 6, and 12 months after surgery.

Adequate decompression was achieved in all patients. The overall complication rate was lowest in patients who had undergone bilateral laminotomy (Group 1). The minimum follow up of 12 months was obtained in 94% of patients. Residual pain was lowest in Group 1 (VAS score 2.3 ± 2.4 and 4 ± 1 in Group 3; p < 0.05 and 3.6 ± 2.7 in Group 2; p < 0.05). The Roland–Morris Scale score improved from 17 ± 4.3 before surgery to 8.1 ± 7, 8.5 ± 7.3, and 10.9 ± 7.5 (Groups 1–3, respectively; p < 0.001 compared with preoperative) corresponding to a dramatic increase in walking distance. Examination of SF-36 scores demonstrated marked improvement, most pronounced in Group 1. The number of repeated operations did not differ among groups. Patient satisfaction was significantly superior in Group 1, with 3, 27, and 26% of patients unsatisfied (in Groups 1, 2, and 3, respectively; p < 0.01).

Conclusions. Bilateral and unilateral laminotomy allowed adequate and safe decompression of lumbar stenosis, resulted in a highly significant reduction of symptoms and disability, and improved health-related quality of life. Outcome after unilateral laminotomy was comparable with that after laminectomy. In most outcome parameters, bilateral laminotomy was associated with a significant benefit and thus constitutes a promising treatment alternative.

Key Words • lumbar stenosis • outcome • safety • laminectomy • laminotomy • minimally invasive surgery
incidence of perioperative (neurological) complications. As a result, the authors of review articles concluded that laminotomies should be reserved for cases in which the disease was far less severe or for specific subgroups of patients.\textsuperscript{7,24,70,77} Comparative data obtained in a population of sufficient size, however, have not been reported in a prospective trial.\textsuperscript{7}

The purpose of our prospective study was to compare the safety and the clinical outcomes after unilateral laminotomy, bilateral laminotomy, and laminectomy in patients with lumbar spinal stenosis who were randomized to one of the three treatment groups.

**Clinical Material and Methods**

The study protocol was approved by the institutional ethics committee. One hundred twenty patients (mean age 68 ± 9 years, range 44–86 years) with lumbar spinal stenosis refractory to adequate conservative treatment were recruited consecutively during a 30-month period. The following inclusion criteria were used: 1) symptoms of neurogenic claudication or radiculopathy; 2) radiological/neuroimaging evidence of degenerative lumbar stenosis; 3) absence of associated pathological entities such as disc herniations or instability; and 4) no history of surgery for lumbar stenosis or lumbar fusion.

Symptoms were considered refractory to nonsurgical management if conservative measures, particularly non-steroidal antiinflammatory drug and physical therapies, had been administered for at least 3 months without sufficient improvement. In contrast to previous studies in which the authors allowed discectomy to be part of the decompression\textsuperscript{11,49,57,61,66} or included fusion procedures,\textsuperscript{5,20,61} we attempted to study a more homogeneous patient population. Therefore, we excluded from outcome analysis three patients who required discectomies due to significant intraoperatively noted discogenic nerve compression, which had not been identified on preoperative imaging studies. Thus the study population was reduced to 117 individuals in whom follow-up data were obtained and evaluated. Spinal instability was defined as sagittal-plane translation of 5 mm or more documented on flexion–extension radiography.\textsuperscript{23,89} Patients presenting with stable spondylolisthesis or a history of surgery for herniated lumbar discs were not excluded.

**Preoperative Assessment**

All patients underwent a standardized neurological and clinical assessment to evaluate walking distance, and pain was measured separately for the low back and the legs according to a self-assessment 10-point VAS.\textsuperscript{68} Disability was assessed using the RMS (score range 0–24), which has been validated\textsuperscript{80} and reported on for German-language speakers.\textsuperscript{80} Physical and mental health status was measured using the SF-36 health survey.\textsuperscript{85} Possible depressive symptoms, known to influence outcome following spinal surgery, were assessed using a self-assessment depression scale (the ADS [score range 0–60]).\textsuperscript{16}

Radiological/neuroimaging workup included MR imaging, myelography, and postmyelography CT scanning for identification of the involved segments. In the majority (73) of patients we observed multisegmental stenosis, which required decompression of 207 levels overall (mean 1.7 ± 0.7 per patient). The L3–4 and the L4–5 levels were most commonly involved (in 83 [40.1%] and 95 [45.9%] of cases, respectively).

**Randomization Strategy**

Each patient’s admission number was used to blind the randomization to personal data. If a patient met the inclusion criteria according to the admitting physician and informed consent was obtained, a concealed computer-generated randomization list was used to assign the patient to one of the treatment groups: bilateral laminotomy (Group 1), unilateral laminotomy (Group 2), and laminectomy (Group 3).

**Surgical Procedures**

All patients underwent surgery after induction of general endotracheal anesthesia while in the prone position. An operating microscope (Carl Zeiss Co., Oberkochen, Germany) was used in all cases. Surgery was performed in a standardized manner. The surgical approach is represented by three-dimensional and axial postoperative CT scans in Fig. 1. All three techniques used in the groups had been routinely performed at our institution in the 2 years preceding the study.

**Bilateral Laminotomy (Group 1).**\textsuperscript{49,57,76,91,93} The bone from the inferior aspect of the cranial lamina and, to a minimal degree, from the superior aspect of the subjacent lamina was resected, and subsequent flavectomy was performed to expose the spinal canal. The medial aspect of the facet joint was resected to decompress the lateral recess. The spinous process, the supra- and interspinous ligaments, and a substantial portion of the lamina were preserved.

**Unilateral Laminotomy for Bilateral Decompression (Group 2).**\textsuperscript{49,48,55,59,60,73,74,87} Following an ipsilateral laminotomy as described earlier, the spinous process was undercut with a high-speed burr. By angling the microscopic view following ipsilateral decompression, the contralateral ligamentum flavum and the medial aspects of the contralateral facet joints were resected for contralateral decompression.

**Laminectomy (Group 3).** The spinous process and the laminae of the involved segment(s) as well as the medial aspects of the facet joints were resected (facet-sparing laminectomy).\textsuperscript{16} A hemifacetectomy was never performed.

High-speed burrs and Kerrison rongeurs were used in all procedures. Special care was taken in all three groups to minimize facet joint resection by using an undercutting technique. The laminotomy approaches were performed through speculum-type retractors. Suction drains were not routinely placed. Ambulation was encouraged on the day of surgery. Postoperative CT scans were acquired in all patients before discharge to evaluate the adequacy of the decompression.

**Assessment of Surgery-Related Morbidity**

Intraoperative parameters such as the length of skin incision, duration of the procedure, EBL, and intraoperative complications (for instance, incidental durotomy) were documented on a standardized form in the operating room. For comparison, these data were analyzed in relation to the
number of decompressed levels. Perioperative morbidity also included reoperations within 30 days and the presence of an increased postoperative radicular deficit such as a neural injury. The technical difficulty of the procedure was subjectively rated by the surgeon on a 10-point scale.

Assessment of Outcome

Standardized self-assessment questionnaires were used at follow-up examinations 3, 6, and a minimum of 12 months after surgery. Pain (VAS score), walking distance, RMS scores, and subjective overall success rate (0% no success; 100% complete success) were recorded. The SF-36 was used for assessment at the 12-month follow-up examination. To evaluate outcome of low-back pain and leg pain separately and to differentiate between resting conditions and walking, improvement of these parameters was analyzed on a self-assessment five-point scale (much improved, somewhat improved, unchanged, somewhat worse, and much worse). To evaluate patient satisfaction with the postoperative result, the PSI (a modified subitem of the NASS outcome questionnaire) was administered. Additionally, the questionnaire included items asking whether the patients were satisfied with postoperative pain reduction and the improvement in ability to perform everyday activities.

Patients presenting with significant residual or recurrent symptoms underwent postoperative MR imaging and flexion–extension radiography. In cases of instability, residual or adjacent-level stenosis, or lumbar facet syndrome, surgical intervention was performed and documented.

Statistical Analysis

All values are expressed as the means ± SDs. The unpaired Student t-test, Mann–Whitney rank-sum test, chi-square test, and Fisher exact test were used as applicable to analyze differences in the preoperative clinical and demographic characteristics (age, sex ratio, duration of symptoms, clinical presentation, VAS, RMS, and SF-36), in the intraoperative variables; and in clinical outcome variables between groups (VAS, RMS, SF-36, and PSI scores as well as reoperations). For analysis of overall complication rates, a patient’s course was defined as complicated if at least one complication was present perioperatively. The paired Student t-test and Wilcoxon signed-rank test were used to analyze changes over time within each group. Statistical significance was set at a probability value less than 0.05.

Results

Forty patients each were randomized to one of the three groups. Based on the VAS preoperative overall pain was 7.5 ± 2.3. The patients suffered from neurogenic claudi-
tion for a mean of 20.2 ± 29.7 months, and walking distance was reduced to 250 ± 370 m. The overall RMS disability score was 17 ± 4.3. There were no intergroup significant differences in the preoperative characteristics (Table 1). Cases of severe stenosis were evenly distributed among groups.

**Intraoperative Parameters**

Spinal canal decompression was adequately achieved in all cases according to the surgeon. Therefore, the scheduled procedure was adhered to in all patients. The duration of surgery was prolonged significantly in Group 1. The EBL was lowest in patients who underwent the unilateral approach in Group 2. No patient required a blood transfusion. The skin incision was significantly longer in Group 3 patients compared with those who underwent laminotomy. The technical difficulty of the procedures was rated highest in Group 2 (Table 2).

**Surgery-Induced Morbidity**

There were no perioperative deaths. Of all surgically treated levels unintended durotomy occurred in 3.2% (Group 1, two levels), 7% (Group 2, five levels), and 11% (Group 3, eight levels). Dural tears were not noticeably associated with postoperative morbidity, but they were with increased duration of surgery and increased EBL (data not shown). In most cases direct suturing was performed using special microinstruments. In difficult sites, such as contralaterally in the unilateral approach, Gelfoam and/or fibrin glue were applied. No subsequent postoperative CSF fistula was observed.

An epidural hematoma requiring reoperation was documented on MR imaging in two Group 2 patients, and two Group 3 patients who presented with postoperative urinary retention (two cases; both in Group 3), increased pain (one case; Group 2), or progressive radicular deficit (one case; Group 2). Overall, there were two patients in Group 2 who suffered deterioration of L-5 radiculopathy postoperatively, one case of which was minor and the patient recovered prior to discharge. One wound infection was noted in a laminectomy-treated patient after evacuation of an epidural hematoma requiring a second reoperation and antibiotic therapy (Table 3).

No patient in Group 1, three patients in Group 2 and two patients in Group 3 experienced symptomatic complications (NS). Overall, the perioperative morbidity rate, including the clinically occult incidental durotomies, was lower in Group 1 (5.0%) than in Group 3 (22.5%; p < 0.05 compared with Group 1) or Group 2 (17.5%).

**Follow-Up Status**

Follow-up data for outcome analysis were collected at 3, 6, and a minimum of 12 months after surgery. In most patients final assessment was conducted 12 to 18 months postoperatively (mean follow-up period 15.5 months). In that time period four patients died of unrelated causes. Two patients refused to participate in the study and one patient was lost to follow up. Thus, follow-up status of at least 1 year was determined in 110 patients (94% of the cohort and 97% of survivors; Table 4). In six patients, the latter part of the questionnaire (specific to the RMS and SF-36) was insufficiently completed, precluding analysis.

**Pain Assessment**

Surgical decompression resulted in a dramatic reduction of overall pain in all three groups (p < 0.001). Compared with that observed in Group 1, however, significantly more residual pain (Fig. 2) was documented in Groups 2 and 3—3.6 ± 2.7 (Group 2) and 4 ± 1 (Group 3) compared with 2.3 ± 2.4 (Group 1) at the 12-month follow-up evaluation (p < 0.05). Differentiating between low-back pain and leg pain during resting conditions and walking revealed that superior pain relief occurred in Group 1 patients, particularly during walking and especially in the legs (Fig. 3). The most prominent symptom of lumbar stenosis, neurogenic claudication (that is, leg pain during walking) improved in 92% of patients in Group 1 compared with 74 and 68% in Groups 2 and 3 (p < 0.05), respectively.

**Disability Assessment**

Walking distance varied greatly among individual patients, but overall ambulation recovered rapidly after decompression and remained stable during the follow-up period (Fig. 4 left). There was no significant difference among groups (3663 ± 3247, 2958 ± 3561, and 2318 ± 3509 m, compared with preoperative distances at 12 months in Groups 1, 2, and 3, respectively; NS among groups; p < 0.001) compared with preoperative distance. The same was
Outcome of less invasive surgery for lumbar stenosis

**TABLE 2**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>duration of op (mins/level)</td>
<td>90</td>
<td>77</td>
<td>73</td>
</tr>
<tr>
<td>EBL (ml/level)</td>
<td>212</td>
<td>147</td>
<td>227</td>
</tr>
<tr>
<td>length of skin incision (cm/level)</td>
<td>3.6</td>
<td>3.2</td>
<td>4.7</td>
</tr>
<tr>
<td>difficulty of op (range 0–10)</td>
<td>6.0</td>
<td>7.3</td>
<td>5.9</td>
</tr>
</tbody>
</table>

*p < 0.01 compared with Group 1.
† p < 0.05 compared with Group 1.
§ p < 0.05 compared with Group 3.
¶ p < 0.001 compared with Group 1.
‖ p < 0.001 compared with Group 3.

true for the RMS scores, which reached 8.1 ± 7 (Group 1), 10.9 ± 7.5 (Group 2), and 8.5 ± 7.3 (Group 3) (NS among groups; p < 0.001 compared with preoperative scores; Fig. 4 center).

**Health-Related QOL**

Comparison of pre- and postoperative SF-36 scores demonstrated a marked and significant improvement, particularly of the physical component but also of most mental subscales, in all three groups. Again, scores were highest in Group 1 patients, with the most pronounced and significant benefit in the bodily pain subscale compared with Groups 2 and 3 (Table 5).

**Patient Satisfaction**

Overall PSI scores were significantly superior after bilateral laminotomy. Overall 27.7% (one of 37; Group 1), 25.6% (10 of 39; Group 2), and 26.5% (nine of 34; Group 3) of patients were unsatisfied after 12 months (p < 0.01) (Table 6). This difference remained stable within the 1st postoperative year and is also reflected by a self-reported success rate of approximately 80% in Group 1 compared with approximately 65% in Groups 2 and 3 (Fig. 4 right). In general, patients were more satisfied with the reduced pain levels than with the improvement in everyday activities (Table 6).

**Necessary Reoperations**

Postoperative CT scanning demonstrated adequate decompression in all patients, and in no patient was reoperation required for residual or recurrent spinal stenosis at the same segment(s) within 12 to 18 months. Adjacent-level stenosis requiring decompression occurred in one Group 3 patient. Facet joint denervation was successfully performed in two patients who presented with lumbar facet syndrome. In five patients (three in Group 3 and two in Group 2) postoperative instability developed requiring instrumentation assisted fusion. Overall, the reoperation rate did not differ among groups (Table 7).

When clinical outcome is viewed by ranking the results according to each parameter a striking superiority is demonstrated in cases treated by bilateral laminotomy compared with laminectomy and unilateral laminotomy, although all three procedures dramatically improved clinical symptoms. The latter two approaches yielded comparable results (Table 8).

**Discussion**

We have presented the results of the first randomized prospective study to compare the safety and outcome of uni- and bilateral laminotomy compared with laminectomy in 120 patients with lumbar spinal stenosis. The incidence of complications did not differ significantly among groups, whereas overall perioperative morbidity was lowest after bilateral laminotomy. All three procedures yielded highly significant improvement in symptoms and scores; however, significantly superior outcome was demonstrated after bilateral laminotomy.

Acquired lumbar stenosis is the most common indication for lumbar spinal surgery in elderly patients (age > 65 years) and will continue to gain in importance as life expectancy increases and perioperative management improves. Decompressive laminectomy is the standard

**TABLE 3**

<table>
<thead>
<tr>
<th>Complications</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>incidental durotomy</td>
<td>2</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>increased radicular deficit</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>wound infection</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>total</td>
<td>2</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

* Complications were counted per patient—that is, the number of complicated cases per group was assessed regardless of whether one patient suffered from a single or multiple complications. Therefore, the total complication rates do not represent an arithmetic summation of detailed complication rates.
†p < 0.05 compared with Group 1.
‡p < 0.001 compared with Group 1.

**TABLE 4**

<table>
<thead>
<tr>
<th>Assessment Period</th>
<th>1 (%)</th>
<th>2 (%)</th>
<th>3 (%)</th>
<th>Total No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>preop</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>120</td>
</tr>
<tr>
<td>included in outcome analysis†</td>
<td>39</td>
<td>40</td>
<td>38</td>
<td>117</td>
</tr>
<tr>
<td>3 mos postop alive</td>
<td>38</td>
<td>40</td>
<td>37</td>
<td>115</td>
</tr>
<tr>
<td>FU (%)</td>
<td>37 (97.4)</td>
<td>39 (97.5)</td>
<td>34 (91.9)</td>
<td>110 (95.7)</td>
</tr>
<tr>
<td>6 mos postop alive</td>
<td>38</td>
<td>40</td>
<td>37</td>
<td>115</td>
</tr>
<tr>
<td>FU (%)</td>
<td>38 (100)</td>
<td>40 (100)</td>
<td>35 (94.6)</td>
<td>113 (98.3)</td>
</tr>
<tr>
<td>12 mos postop alive</td>
<td>38</td>
<td>39</td>
<td>36</td>
<td>113</td>
</tr>
<tr>
<td>FU (%)</td>
<td>37 (97.4)</td>
<td>39 (100)</td>
<td>34 (94.4)</td>
<td>110 (97.3)</td>
</tr>
</tbody>
</table>

* FU = follow up.
†One hundred twenty patients were initially randomized, three of whom were excluded from outcome analysis because of significant disc protrusion requiring additional discectomy.
surgical treatment in these patients, but according to the results of a metaanalysis, it was successful in only 64% of the cases. In particular, spinal instability has been implicated as a cause of surgical failures, because wide posterior decompression significantly alters spinal anatomy and biomechanics, thus prompting many spine surgeons to perform fusion procedures to treat lumbar stenosis. Although numerous studies have been conducted to address the impact of (instrumentation-augmented) fusion on outcome, overall results after decompression alone have not been surpassed. The frequency of fusion surgery, however, has been steadily increasing in the treatment of degenerative lumbar disease despite numerous concerns.

Instead of combining fusion with decompression and thus maximizing surgery and associated perioperative risks, other investigators have attempted to decrease the operative failure rate by minimizing the invasiveness of the decompressive procedure. Partial (interspinous) laminectomies have been introduced as well as modifications involving spinous process osteotomies. To spare the dorsal midline structures completely in contrast to laminectomy techniques, fenestration or laminotomy has also been propagated. Of the various decompressive techniques, encouraging results have been reported particularly for bilateral laminotomy and unilateral laminotomy in which contralateral decompression is achieved by undercutting the spinous process. We therefore undertook a randomized study of these two newer techniques in which they were compared with laminectomy. The latter was performed with maximal preservation of the facet joints.

**Patient Population**

Acquired lumbar stenosis often coincides with other consequences of spinal degeneration such as disc prolapse and instability, resulting in a heterogeneous patient population. Consequently, it has been suggested that the procedure should be tailored to each patient depending on symptoms and imaging findings—for example, unilateral approaches in cases of unilateral symptoms and/or discogenic nerve root compression. The authors of previous studies of decompressive techniques have commonly neglected the heterogeneity of the patient population by allowing limitation of surgery to unilateral decompression and including cases in which discectomies and/or even fusions were performed at the discretion of the surgeon. This may, of course, reflect the patient’s individual situation, but it prevents the drawing of solid conclusions regarding the efficacy of the studied decompressive procedure. This is one of the reasons why there is no existing clinical study in which a clear clinical advantage of one technique over the other is shown in the treatment of lumbar stenosis.

To minimize the heterogeneity of the patient population, factors affecting outcome such as spinal instability or discogenic neural compression were excluded in the present study. Noncompressive disc protrusions, which are abundant in these patients, were not an exclusion criterion, but at surgery we determined that a small number of patients would be excluded for later outcome analysis, because a disc protrusion was found to cause nerve compression and to require discectomy. Defining instability is an ongoing matter of debate, and multiple definitions have been proposed. Although various factors seem to be of importance, most clinicians rely on certain thresholds for sagittal motion on flexion-extension radiography. We have therefore used a rather simple definition of spinal instability without excluding cases of stable spondylolisis.

**Fig. 2.** Graph depicting time course of overall VAS-assessed pain score before and at 3, 6, and 12 months after bilateral laminotomy (B [Group 1]), laminectomy (L [Group 3]), and unilateral laminotomy (U [Group 2]). Note the significantly reduced pain in Group 1. Values are presented as the means ± SDs. ***p < 0.001 compared with preoperative scores; †p < 0.05 compared with Group 1 (B); ††p < 0.01 compared with Group 1 (B).
thesis. According to that definition, five patients in our series required fusion for symptomatic instability within 1 year of decompression and in all cases some sagittal-plane displacement without hypermobility was demonstrated preoperatively. Further follow-up evaluation in our patients may thus reveal that other radiological neuroimaging parameters should be added to define overall spinal instability.

In the present study we recruited elderly patients who almost all (117 of 120) suffered from rather severe neurogenic claudication refractory to conservative treatment. Demographic, clinical (for example, severity of the disease), and psychological (for instance, depression) factors potentially influencing outcome were assessed in a standardized fashion and were found to be evenly distributed among the randomized groups. Randomization also eliminates the relationship between rates (regional variations due to differing indications for surgery) and outcomes after operative treatment for lumbar stenosis, which makes comparisons of outcome studies difficult.

Intraoperative Parameters

This is the first study to demonstrate that adequate decompression could be achieved using the scheduled laminotomy technique regardless of the severity of stenosis. No conversion to laminectomy was performed, which had limited the power of previous studies. Obviously, the skin incision was longest in Group 3 and shortest in Group 2, which underscores the less invasive nature of the laminotomy approaches. Because all procedures were performed microscopically, however, the mean difference amounted to only 1.0 to 1.5 cm/level. Pertinent data in the literature are scarce, although the importance of the cosmetic result has been stressed.

Blood loss was reduced in the unilateral laminotomy group, but clinically detrimental EBL requiring transfusion is very rare in all decompressive procedures of lumbar stenosis.

Laminectomy is considered a simple and fast decompressive technique, whereas bilateral laminotomy has been associated with a longer operative duration and the unilateral approach has been deemed technically more challenging. In our study, the duration of surgery proved to be increased in Group 1. There was no significant difference between Groups 2 and 3. Khoo and Fessler reported an operative duration of 109 minutes for a single-level microendoscopic unilateral laminotomy and 88 minutes for open laminectomy. Others have reported shorter operative times for laminectomies, but data on laminectomy in which the facet joints are meticulously spared are scarce.

Outcome of less invasive surgery for lumbar stenosis

FIG. 3. Bar graphs. Relief of low back pain and of leg pain both at rest and during walking after bilateral laminotomy (B [Group 1]), laminectomy (L [Group 3]), and unilateral laminotomy (U [Group 2]) for decompression of acquired lumbar stenosis. †p < 0.05 compared with Group 1 (B); ††p < 0.01 compared with Group 1 (B); †††p < 0.001 compared with Group 1 (B).
Procedural Complications

The first step in evaluating a new technique or procedure consists of analyzing its safety compared with the current standard of care. This is mandatory when assessing a novel surgical treatment of a disease, such as lumbar stenosis that is prevalent in an elderly population, which is thought to be prone to perioperative morbidity.12,18,27 The authors of clinical series involving uni- or bilateral laminotomy have reported complication rates lower than or comparable with laminectomy,5,11,20,50,74,78,93 but the sizes of populations have been small and the studies were mostly retrospective or lacked a control group. In comparative studies, however, investigators revealed an increase in perioperative morbidity, namely neurological sequelae. Therefore, the main concern of spine surgeons in view of less invasive techniques to decompress lumbar stenosis has been an increased rate of neural injury.24,61,30,70,77 In the series reported by Verbiest,83 a postoperative increased radicular deficit was observed in 5% of laminectomy-treated cases, whereas this complication has been rarely reported since.61 Postacchini, et al.,81 reported a postoperative increase in radiculopathy in one (1.3%) of 32 patients after laminectomy compared with three (11.5%) of 26 patients after bilateral laminotomy, whereas others have reported this complication in only 1% when using the latter approach.7 According to our data, actual injury to a nerve root did not occur. Intraoperative manipulation and/or compression of nerve roots, however, may provoke radicular deficit. Both patients with these deficits affected in our study suffered from longstanding diabetes complicated by polyneuropathy and they presented preoperatively with a sensorimotor deficit. A higher incidence of complications and neurological dysfunction has been documented in patients with diabetes following decompression of lumbar stenosis.25

Unintended durotomy is another concern during spinal decompressive procedures, although no association with long-term sequelae has been found.9,72,84 Wang, et al.,84 reported an incidence of 13% for first-time stenosis surgery managed by direct suture repair and wound drainage. In using this management strategy without suction drainage postoperative CSF leaks were eliminated in our series. Overall, durotomy rates for laminectomy have been shown to range from 5 to 15%.21,48,72,84 Bilateral laminotomy is complicated by dural tears in 2 to 6%,5,56,78,93 and unilateral laminotomy with contralateral decompression in 3.5 to 12%.20,59,74 The unilateral microendoscopic approach is associated with an incidence of 16% (four of 25 patients).48 The results of the present study are in accordance with those in the literature, underscoring that bilateral laminotomy carries a very low risk of unintended durotomy, which may be somewhat higher in the technically demanding unilateral approach.

The wound infection rate is approximately 2% of all spinal surgery cases,72,84 and this complication was also rare in our study (0.8%). For postoperative epidural hematomas, the incidence ranges from 1 to 3%.5,21,25 This was somewhat surpassed in the laminectomy and unilateral laminotomy groups. Although contralateral control of epidural veins may be problematic in some unilateral procedures, the incidence of postoperative hematomas after bilateral laminotomy should not differ from the low rates after microdiscectomy, which corresponds well with our data.

In summary, the less invasive techniques are neither as demanding than bilateral laminotomy or laminectomy, whereas the latter two received a similar rating. This, however, did not translate in increased operative time, EBL, or perioperative morbidity compared with laminectomy.

Outcome Assessment

Attempts to analyze the literature to identify the optimal

C. Thomé, et al.
Outcome of less invasive surgery for lumbar stenosis

**TABLE 5**  
Summary of SF-36 subscales score before and 12 to 18 months after decompression*

<table>
<thead>
<tr>
<th>Subscale</th>
<th>Group</th>
<th>1</th>
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<tbody>
<tr>
<td>physical functioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>admission</td>
<td></td>
<td>17.8 ± 19.0</td>
<td>27.7 ± 27.4</td>
<td>22.8 ± 21.1</td>
</tr>
<tr>
<td>FU</td>
<td></td>
<td>63.6 ± 26.2</td>
<td>42.6 ± 31.8†§</td>
<td>51.4 ± 30.8§</td>
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<tr>
<td>role-physical functioning</td>
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<td>6.3 ± 19.3</td>
<td>9.6 ± 26.8</td>
<td>16.4 ± 29.0</td>
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<tr>
<td>admission</td>
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<td>53.2 ± 45.5</td>
<td>39.8 ± 44.0†§</td>
<td>52.9 ± 38.9†</td>
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<tr>
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<td>16.9 ± 17.7</td>
<td>16.7 ± 14.7</td>
<td>18.1 ± 18.2</td>
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<tr>
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<td>61.0 ± 25.3†§</td>
<td>46.6 ± 29.6</td>
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<tr>
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<td>46.1 ± 15.6</td>
<td>43.4 ± 18.8</td>
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<td>vitality</td>
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<td>47.0 ± 25.4‡</td>
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<tr>
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<td>31.8 ± 17.3</td>
</tr>
<tr>
<td>FU</td>
<td></td>
<td>53.7 ± 19.8†</td>
<td>45.4 ± 27.0</td>
<td></td>
</tr>
<tr>
<td>social functioning</td>
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<td>55.2 ± 30.4</td>
<td>40.8 ± 28.3</td>
<td>51.8 ± 30.0</td>
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<tr>
<td>admission</td>
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<td>80.2 ± 24.1†</td>
<td>65.3 ± 30.3§§</td>
<td>76.9 ± 32.2‡</td>
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<td>50.0 ± 48.0</td>
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<tr>
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<td>72.0 ± 43.1**</td>
<td>51.9 ± 45.6</td>
<td>71.8 ± 40.8**</td>
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<tr>
<td>mental health index</td>
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<td>46.4 ± 21.3</td>
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<tr>
<td>admission</td>
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<td>51.7 ± 18.3†</td>
<td>62.4 ± 24.3‡</td>
<td>69.4 ± 22.2†</td>
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<tr>
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<td>25.4 ± 7.3</td>
<td>25.8 ± 5.2</td>
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<tr>
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<td>40.2 ± 10.6†</td>
<td>33.9 ± 13.3</td>
<td></td>
</tr>
<tr>
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<td>43.8 ± 10.7</td>
<td>42.2 ± 13.0</td>
<td>41.2 ± 11.9</td>
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<tr>
<td>admission</td>
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<td>50.5 ± 10.3‡</td>
<td>46.1 ± 12.6</td>
<td>51.0 ± 12.9†</td>
</tr>
</tbody>
</table>

* Low values represent worse health status; normal values differ with age of the patient population.  
† p < 0.001 compared with admission.  
‡ p < 0.01 compared with admission.  
§ p < 0.01 compared with Group 1.  
¶ p < 0.05 compared with Group 1.  
** p < 0.05 compared with admission.

in the 1st postoperative year41 and/or thereafter.10,72,80 In our study, a minimum follow-up period of 12 months was available for all patients. Symptoms and scores remained stable during that period. Nevertheless, long-term follow-up data are mandatory and will be pursued.

**TREATMENT GROUPS**

**Laminectomy.** As mentioned previously, laminectomy is associated with improvement in 64% of patients at 3 to 6 years after surgery according to a metaanalysis.81 The authors of a study that used standardized patient-derived measures of symptom relief 4 years after decompression reported a success rate of just 57%.46 In a large retrospective study, Airaksinen, et al.,2 found good outcomes after 4 years in 62% of their 438 patients, whereas others have described satisfactory results in approximately 70%.4,72 In a literature review Herron and Mangelsdorf57 reported rates of good outcome ranging from 50 to 86% and stressed that results deteriorated over time. In the present study, the rate of patient satisfaction, self-reported success, and improvement of neurogenic claudication after laminectomy was 70%, which is in accordance with that in the literature. Regardless of meticulous sparing of the facet joints, instrumentation-assisted fusion was required in 9% of patients due to postoperative instability within the first 18 postoperative months.

Unilateral Laminotomy for Bilateral Decompression. In the goal to refine minimally invasive procedures, the unilateral approach for bilateral decompression, also termed the “ipsi-contra” procedure,40 was developed as an alternative to laminectomies.31,60 Although technically demanding,57 high success rates of 88% (in 22 of 25 patients),74 68% (in 15 of 22),53 and 87% (in 26 of 30)90 have been reported. In combination with contralateral fusion, the success rate was 69%.20 Khoo and Fessler39 compared data obtained in 25 patients in whom decompression was performed via microendoscopic unilateral approach with those acquired in 25 who underwent laminectomy. Success rates in both groups were nearly 90%. Most of the aforementioned studies, however, are characterized by only short-
term follow-up periods, small patient populations, and the lack of a control group which limit the power of their conclusions. In the present study, we found no benefit to the unilateral laminotomy compared with laminectomy (success rates ~ 70%). Interestingly, unilateral laminotomy was superior to laminectomy in terms of improving leg pain but inferior in terms of low-back pain, although these differences were not statistically significant. Why the asymmetrical approach leaves more residual pain, particularly in the low back, compared with the bilateral laminotomy, remains unclear. Residual canal compromise can be excluded as causing unsatisfactory results in the present study because adequacy of decompression was evaluated on postoperative CT scanning in all patients. Despite minimal removal of bone, postoperative instability was demonstrated in 5% of the patients during the follow-up period.

**Bilateral Laminotomy.** Following the description of the bilateral laminotomy technique, the authors of clinical case series demonstrated good results in 91% (29 of 32 patients) at 1 year; 82% (28 of 34), 87% (13 of 15), 78% (21 of 27), and 68% (34 of 50 patients) at 2 years; 85% (27 of 32) at 3 years; and 74% (76 of 102 patients) at 6 years. When performing a limited decompression by laminotomy tailored to the individual symptoms (uni- or bilateral) some surgeons have reported success rates of 60 to 80%. These encouraging results compared favorably with those of laminectomy. As previously stated, however, retrospective study designs, inclusion of fusion surgery as well as discectomies, and insufficient outcome measures limit the reliability of these studies. Additionally, deterioration of results was documented over time. In a prospective outcome study of 54 patients, Kleeman, et al. in contrast, reported good outcome in 88% and patient satisfaction in 100% after 4 years without deterioration.

Controlled studies involving laminotomy techniques are scarce. Thomas, et al. and Kalbarczyk, et al. retrospectively compared bilateral laminotomy and laminectomy and found no difference in outcome. The same was true for the prospective nonrandomized comparison published by Postacchini, et al. and Delank, et al. The study protocols, however, were open allowing intraoperative change of procedure or even free choice of procedure. In the present randomized study, the success rate of bilateral laminotomy was 80%, its improvement rate was 92% and patient satisfaction was 97% during the 12- to 18-month follow-up period, which supports the data of the aforementioned case series. These results are significantly superior to laminectomy and/or unilateral laminotomy.

**TABLE 7**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group (%)</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of cases</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>facet joint deretration</td>
<td>1 (2.7)</td>
<td>1 (2.6)</td>
<td>0 (0.0)</td>
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<tr>
<td>same-level decompression</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
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<tr>
<td>adjacent-level decompression</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>1 (2.9)</td>
<td></td>
</tr>
<tr>
<td>instrumented fusion</td>
<td>0 (0.0)</td>
<td>2 (5.1)</td>
<td>3 (8.8)</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>1 (2.7)</td>
<td>3 (7.7)</td>
<td>4 (11.8)</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 8**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group (%)</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of periop complications</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pain</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>overall pain</td>
<td>1 (2.7)</td>
<td>2*</td>
<td>3*</td>
<td></td>
</tr>
<tr>
<td>pain relief</td>
<td>1 (2.7)</td>
<td>2*</td>
<td>3*</td>
<td></td>
</tr>
<tr>
<td>LBP at rest</td>
<td>1 (2.7)</td>
<td>3*</td>
<td>2*</td>
<td></td>
</tr>
<tr>
<td>LBP during walking</td>
<td>1 (2.7)</td>
<td>2*</td>
<td>3*</td>
<td></td>
</tr>
<tr>
<td>leg pain at rest</td>
<td>1 (2.7)</td>
<td>3*</td>
<td>2*</td>
<td></td>
</tr>
<tr>
<td>leg pain during walking</td>
<td>1 (2.7)</td>
<td>3*</td>
<td>2*</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>1 (2.7)</td>
<td>2*</td>
<td>3*</td>
<td></td>
</tr>
<tr>
<td>disability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>patient satisfaction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>self-reported success rate</td>
<td>1 (2.7)</td>
<td>3*</td>
<td>2*</td>
<td></td>
</tr>
<tr>
<td>PSI w/ pain reduction</td>
<td>1 (2.7)</td>
<td>2*</td>
<td>3*</td>
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</tr>
<tr>
<td>PSI w/ improved performance</td>
<td>1 (2.7)</td>
<td>2*</td>
<td>3*</td>
<td></td>
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<tr>
<td>self-reported success rate</td>
<td>1 (2.7)</td>
<td>3*</td>
<td>2*</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>1 (2.7)</td>
<td>2*</td>
<td>3*</td>
<td></td>
</tr>
<tr>
<td>no. of reops</td>
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<tr>
<td>overall pain</td>
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</tr>
<tr>
<td>pain relief</td>
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<tr>
<td>LBP at rest</td>
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<tr>
<td>LBP during walking</td>
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<td></td>
</tr>
<tr>
<td>leg pain at rest</td>
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<td></td>
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</tr>
<tr>
<td>leg pain during walking</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
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</table>

* The difference is statistically significant compared with Group 1 (p < 0.05); no significant difference was demonstrated between Groups 2 and 3 for any parameter.

Other outcome parameters, such as overall pain and health-related QOL, support this conclusion. Fusion was not indicated in any patient. If analysis of long-term follow-up data confirms these results, bilateral laminotomy may prove advantageous for patients with lumbar stenosis, reducing the need for additional fusion surgery.

**Conclusions**

Bilateral and unilateral laminotomy allow adequate and safe decompression of the spinal canal in patients with lumbar stenosis. These limited decompression procedures resulted in a highly significant reduction of symptoms and disability and improve health-related QOL. Outcome after unilateral laminotomy is comparable with that after laminectomy. Bilateral laminotomy was associated with a significant benefit in most outcome parameters during a minimum follow-up period of 12 months and thus constitutes a promising treatment alternative.

**Acknowledgments**

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Outcome of less invasive surgery for lumbar stenosis

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References


C. Thomé, et al.
Outcomes of less invasive surgery for lumbar stenosis


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