4.2.1 Bilateral decompression in lumbar spinal stenosis through a microscope-assisted monolateral approach

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1 Historical perspective

Lumbar spinal stenosis is a pathology that is characterized by the narrowing of the central spinal canal and nerve root canals, and which involves a triad of symptoms: hypertrophy of the ligamentum flavum; hypertrophy of degenerated facet joints; and an anterior, space-occupying, bulging intervertebral disc.

More than 200 years ago, Portal [1] described a narrowed spinal canal both with and without neurological deficit. More than 100 years later, Sumita [2] reported on the narrowing of the spinal canal in achondroplastic individuals while Dejerine [3] described the symptoms of spinal claudication. In 1911, Bailey and Casamajor [4] published a study on the implication of vertebral osteoarthritis in the compression of neural intraspinal structures. In the same year, independently of each other, Goldthwait [5] and Middleton and Teacher [6] provided the first descriptions of a herniated nucleus pulposus. Then in 1934, following an increasingly large number of publications, Mixter and Barr [7] presented the first case series of surgically-treated disc herniations. They demonstrated the association between sciatica and lumbar disc herniation, and, consequently, lumbar disc herniation was seen as the major cause of the narrowing of the spinal canal for more than a decade. It was not until 1954 that Henk Verbiest [8] made a breakthrough by introducing the concept of developmental stenosis and the pathological narrowing of the lumbar vertebral canal. Subsequent definitions of lumbar spinal stenosis were largely based on Verbiest´s original findings.

Some anecdotal reports on laminectomy had already appeared in the 19th century (in 1814, Clyne reported on spinal abscess drainage; in 1829, Alban Gilpin Smith described treatment for secondary worsening of a fracture that had failed to respond to primary treatment [9]), while larger series using this same technique [10] were already being reported by the early 20th century. Much later on, Verbiest [8] established laminectomy as the gold standard and treatment of choice for lumbar spinal stenosis. In large case series, each including more than 450 patients treated by laminectomy for lumbar spinal stenosis, a very successful outcome was obtained in 85% of cases, with excellent or good postoperative results and a high patient satisfaction rate [11, 12]. Several modifications of the laminectomy technique were introduced after 1980 [13–15], however, in parallel to studies on the use of this technique and its modifications, reports also appeared in the literature demonstrating the risk of postoperative translational instability [16, 17]. Consequently, especially after the adoption of microscope-assisted techniques in neurosurgery in 1977/1978, more sophisticated procedures for decompression using bilateral approaches with mono- to multisegmental laminotomy of the index segments were used on an increasingly widespread scale [18, 19]. Young et al [20] and McCulloch [21] then modified the microscope-assisted techniques by limiting the approach to only one side and performing an ipsilateral and contralateral "over-the-top" bilateral decompression of both the spinal canal and nerve root canals with subarticular fenestration, partial removal of the facet joints, undercutting of the remaining joint, and fenestration of the ligamentum flavum through a monolateral approach. Spetzger et al [22] provided sufficient anatomical considerations for using this technique. Recently, a similar approach has been described using tubular retractors [23, 24].

This chapter examines the microscope-assisted minimally invasive bilateral decompression of the central and lateral aspects of the spinal canal for the treatment of lumbar spinal stenosis using a monolateral approach and avoiding destructive laminectomy.

2 Terminology

With the assistance of a surgical microscope, bilateral microsurgical decompression of the central and lateral spinal canal via a monolateral approach using an "over-the-top" technique with inner osteoclastic laminoplasty for the enlargement of the central and lateral spinal canal represents a modification of established, traditional approach and decompression techniques such as laminectomy aimed at treating a narrow lumbar spinal canal. This technique can be adopted for mono-, bi-, or multisegmental and mono- or bilateral surgery. Using the monolateral approach, the contralateral paravertebral muscles remain untouched and the contralateral facet remains mostly intact, resulting in complete protection of the contralateral paravertebral compartment. This technique can be used for decompression procedures alone, or in combination with fusion surgery. The term "tubular laminectomy" has been adopted to refer to surgery in which tubular retractors are used [23, 24].

3 Patient selection

In general, the above-mentioned decompression procedure can be applied to all patients suffering from acquired lumbar central and/or lateral spinal stenosis, independent of the number of affected segments or the extent of narrowing. In the case of exclusive or dominating leg symptoms, with or without intermittent claudication, the decompression procedure can be performed with no additional surgical steps. If the degree of back pain is similar to the leg pain, or if it is the dominating symptom, and in the case of severe translational rigid or functional displacement and/or major curvature in the frontal plane, additional stabilizing or reconstructive techniques—such as pedicle-based screw-rod instrumentation—should be considered.

3.1 Indications for surgery

The following clinical symptoms should be taken into account as indications for surgery:

- Monolateral or bilateral leg pain with sensation of heavy legs. Pain in the buttocks or thighs
- Nonspecific weakness of the lower limbs. Sensory disturbances and paresthesia. Reduced or absent reflex pattern. Usually no distinct radicular symptoms
- Progressive neurological deficits
- Neurogenic gait disturbances ("intermittent spinal claudication") with reduced walking distance
- Reduced ability to remain standing
- Less pain experienced on bending forward and flexing the spine (eg, moving a shopping trolley)
- Increased pain when standing, walking, and upon hyperextension of the back
- Reduction of lumbar lordosis with flat-back syndrome
- Low back pain
- Bladder dysfunction, ie, cauda equina syndrome.

3.2 Contraindications for surgery

The following contraindications for exclusive microsurgical over-the-top decompression without additional segmental instrumentation should be taken into consideration, particularly in the case of concomitant degenerative scoliosis [25]:

- Dominating back pain
- Significant vertical instability
- Significant translational instability with concomitant dynamic canal narrowing
- Segmental stable translational displacements > Meyerding I°
- Lateral olisthesis > 6 mm
- Scoliosis > 30 °
- Patients that have undergone previous extensive intraspinal decompression procedures
- Contraindications for general anesthesia and surgery
- Congenital central spinal stenosis.

4 Pros and cons of bilateral decompression in lumbar spinal stenosis through a microscope-assisted monolateral approach

The main advantage of this decompression technique lies in the bilateral enlargement of both the entire spinal canal and the lateral recess ipsi- and contralaterally. In addition, decompression of the contralateral neuroforamen can be achieved via a unilateral approach, thus preserving the complete contralateral paravertebral compartment including the paravertebral muscles, their innervation and vascular support.

A significant number of intra- and postoperative benefits is obtained, including reduced blood loss, less postoperative scar-tissue formation, as well as quicker patient recovery and mobilization. The most relevant advantage could well be the preservation of the ligamentous and bone anatomy, which ensures preserved stability and less need for instrumentation and fusion surgery down the line [26, 27]. The technique itself, however, requires experience in microscope-assisted surgery and a practical and in-depth knowledge of the intraspinal anatomy. The specific benefits of the procedure as well as the limitations of this technique are noted in the following:

4.1 Pros

- Small skin incision with improved postoperative cosmesis
- Unilateral approach with bilateral decompression
- Reduced damage to ipsilateral paravertebral muscles and ipsilateral facet joint

- Preservation of contralateral paravertebral muscles, ligaments, and other extravertebral soft tissue
- Preservation of the contralateral facet joint
- Preservation of the supraspinous and interspinous ligaments maintaining the posterior tension band complex
- Maintenance of segmental stability without creating segmental hypermobility or instability, therefore with a possibly reduced need for fusion postoperatively
- Good overview of the neural structures within the central spinal canal as well as the nerve root canal bilaterally (lateral recess), with visual control of the dura and nerve roots
- Meticulous and effective intraspinal hemostasis possible
- Reduced soft-tissue trauma
- Reduced blood loss
- Reduced scar-tissue formation
- Quick patient mobilization and rehabilitation
- Less postoperative pain.

4.2 Cons

- Limited visualization outside the target area with the risk of inadvertent destruction of anatomical structures or damage to concealed or not clearly visible neurological structures, possibly resulting in neurological deficits
- Technically demanding procedure, especially as regards contralateral decompression—insufficient decompression could lead to unsatisfactory results
- Far lateral ("far out") stenosis [28] is not possible (ipsilaterally) or difficult (contralaterally) to address surgically
- Longer operative time for multisegmental cases when compared to a laminectomy procedure
- Microsurgical training required, with a "learning curve" for surgery performed through a narrow working channel
- Not possible without the use of a microscope or at least head lamps and loops.

5 Preoperative planning and positioning

5.1 Planning procedures

Meticulous preoperative planning is mandatory for an optimal surgical outcome and in order to avoid incomplete/faulty intraoperative management of the pathology in question. The more that minimization is used, the more accurate the preoperative evaluation and planning procedure should be.

Imaging studies should include standard x-rays in both anteroposterior (AP) and lateral view, and also functional x-rays in lateral projection in order to detect any possible vertical and translational segmental instabilities. Anteroposterior x-rays show the spinal configuration in the frontal plane, and provide information on spinal curvature and the size of the interlaminar window for entry towards the spinal canal. Only in rare selected cases are functional x-rays in frontal projection with left and right lateral bending performed for the analysis of frontal tilt hypermobility or instability. Oblique x-rays are not recommended as they involve an unnecessary dose of radiation, without providing any additional information.

MRI represents the radiological diagnostic tool of choice for evaluating the situation within the central spinal and nerve root canals. It provides the most comprehensive information about soft-tissue structures that may limit the size of the spinal canal such as bulging yellow ligaments, discogenic pathologies, and canal-narrowing synovial cysts. In extremely stenotic segments, remaining fatty tissue, mostly located in the dorsal parts of the canal, can be detected and used to guide the surgeon towards a safety zone when entering the spinal canal. Contrast medium can be used to differentiate between remaining scar-tissue formation following prior surgery and primary pathologies. T1- and T2-weighted sagittal and T2-weighted axial images are most frequently used in this regard (**Fig 4.2.1-1**). The additional value of frontal images is largely underestimated. Taking the nerve root sedimentation sign into account, as a new radiological sign, could gain increasing significance in the future [29]. Evaluation of the neuroforamina is best carried out by analyzing T1-weighted sagittal images. Functional upright MRI, which is not widely available at present, may replace x-ray with contrast medium for the detection of a dynamic stenosis of the lumbar spinal canal.

With the widespread availability of MRI and in comparison to the latter, the CT scan has lost much of its importance in the diagnosis of lumbar spinal stenosis due to its poor resolution of soft-tissue structures and its radiation emissions. If the use of MRI is contraindicated (eg, in the case of patients with a pacemaker, or metal implants in the index segment), CT represents the diagnostic tool of choice (eg, Postmyelo-CT) and is best used in combination with x-ray and contrast medium, which can provide additional information regarding a dynamic stenosis in lateral flexion/extension views (**Fig 4.2.1-2a–b**). The narrowing of the central spinal canal and compression of nerve roots in the lateral recess can be detected in this way (**Fig 4.2.1-2c–d**). However, only limited diagnostic information regarding the neuroforamina can be obtained due to anatomical constraints.

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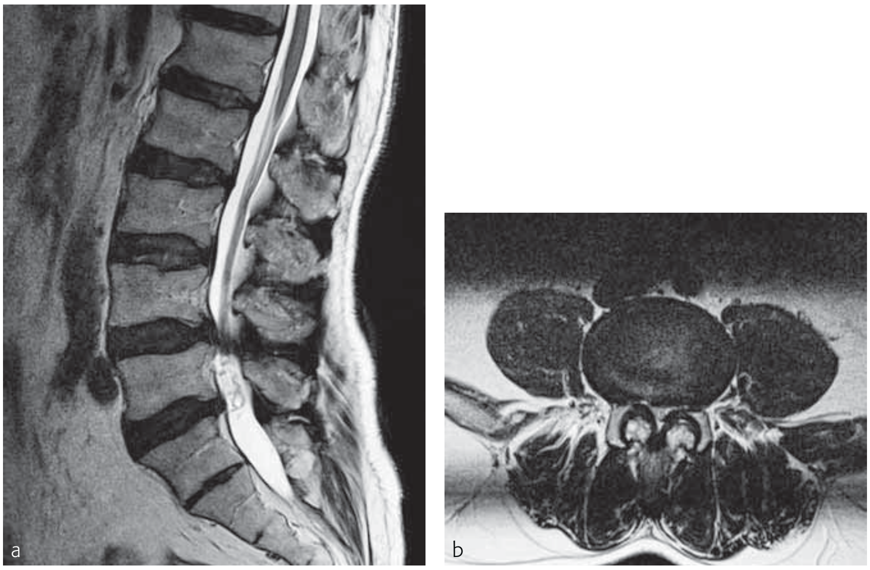

Fig 4.2.1-1a–b

a Preoperative T2-weighted MRI in sagittal projection showing a monosegmental narrow central spinal canal as well as curling nerve roots below the stenotic level at L4/5

b Preoperative T2-weighted MRI in axial projection showing a narrow central spinal canal, and lateral recess bilaterally in the same segment.

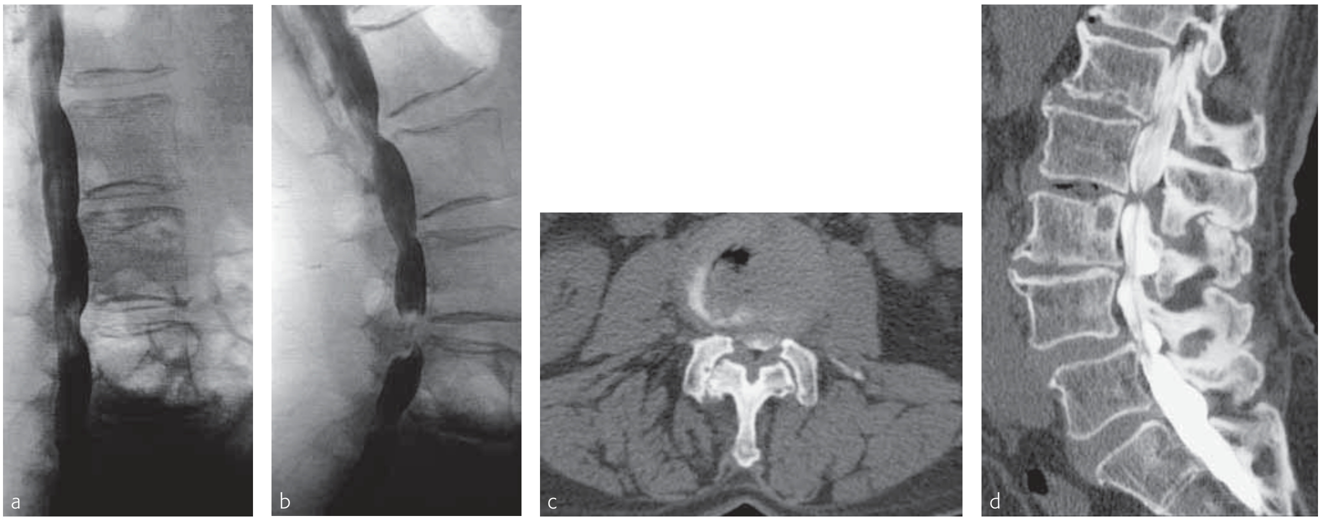

Fig 4.2.1-2a–d

a X-ray with contrast medium (myelography) showing reduced narrowing of the spinal canal at L2/3 and L4/5 in flexion.

b X-ray with contrast medium (myelography) showing increased narrowing of both stenotic segments in extension, thus demonstrating the dynamic character of the stenosis

c Post-myelographic CT scan axial view of a separate case showing a stenosis at L2/3.

d Post-myelographic CT scan; sagittal view of same case as **Fig 4.2.1-2c**.

5.2 Patient preparation and positioning

No specific patient preparation is required the day before surgery. Prior to surgery, shaving of the surgical area is performed, if necessary.

General anesthesia with the patient's body in complete relaxation is required for the operation. Venous and arterial lines are placed. Anesthetic intraoperative monitoring has to be adapted to the possible comorbidities of these mostly elderly patients. A urinary catheter is not necessary for mono- and bisegmental cases, however, for multilevel cases, its use is strongly recommended. Cell-saving procedures as well as blood transfusion are not routinely required. Single-shot antibiotics 20 minutes prior to the skin incision should be given with a second shot after 2 hours for longer operative procedures. As a routine procedure for all surgical interventions, the present author utilizes a surgical "time out" safety checklist in order to minimize perioperative complications.

The patient is placed in a prone knee-chest position with hips and knees flexed at 90° with the abdomen hanging free without any compression (**Fig 4.2.1-3a**). Hyperflexion of the hip and knee joint should be avoided to prevent restriction of venous blood flow from the legs with the accompanying major risk of deep venous thrombosis. A support bracket is placed on the buttocks. In the case of difficulty in correctly obtaining this positioning (eg, restricted knee/hip flexion, abdominal aortic aneurysm), prone positioning using a Wilson frame is a possible alternative. Careful padding of the anatomical weight-bearing areas (knee and tibia, chest, elbows, head) should be performed using soft cushion pads. Arms are placed in a 90°/90° position for shoulder and elbow to avoid hyperabduction so as to minimize the risk of brachial plexus irritation. In younger patients, the head is placed in slight rotation, but this should be no more than 60–70°. However, in elderly patients with limited flexibility of the cervical spine, a prone head position with a gel pad under the forehead is more appropriate. On the side opposite the surgeon, a separate lateral support is placed at trochanter level to maintain the patient in position when tilting for the over-the-top procedure (**Fig 4.2.1-3b**). After final positioning, the operating table can be adjusted at the level of the lumbar spine in order to compensate for lumbar lordosis and provide an open interlaminar access corridor.

Preoperative localization of the index segment is performed using sterile needle placement under lateral image intensifier control to identify the trajectory to the disc space (**Fig 4.2.1-4**). Needle placement is usually performed contralaterally to the approach side in order to avoid hematoma formation at the access corridor. The needle trajectory must be parallel to the disc space and endplates of the index level, and in order to avoid wrong-level surgery, the surgeon must ensure that it does not follow an oblique approach corridor (**Fig 4.2.1-5**). In the case of bi- or multilevel surgery, separate needle placement for each segment is helpful; at least the most cranial and caudal segment should be identified clearly. The skin incision line is marked slightly para-

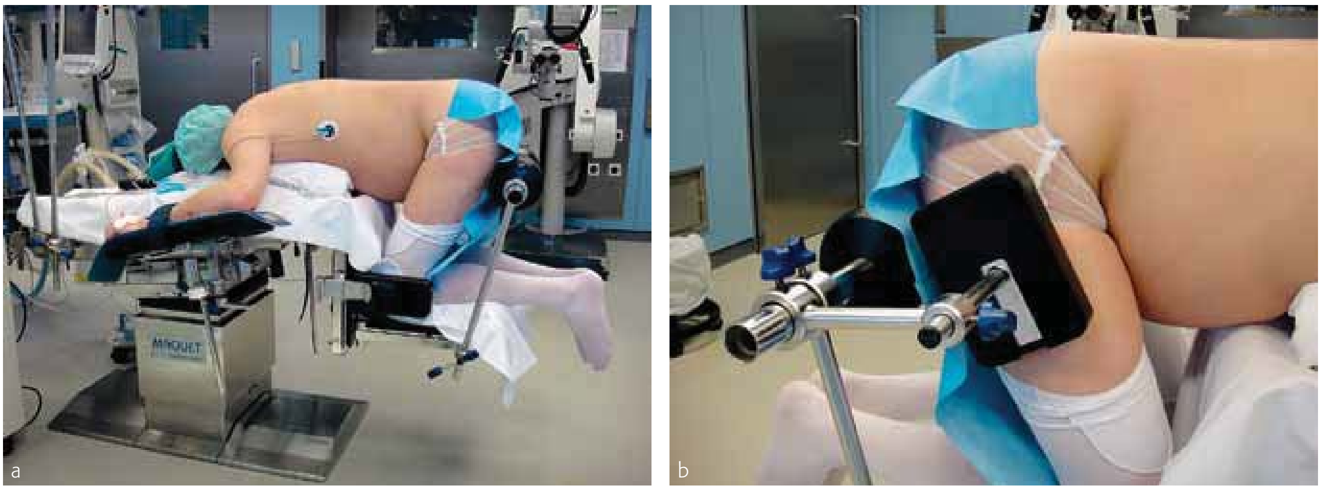

Fig 4.2.1-3a–b
a Left-sided view of patient placed in the knee-chest position.
b Contralateral view of same patient with additional lateral support against the trochanteric region in preparation for the over-the-top procedure.

median to the midline, exceeding the index level marking by about 15–20 mm in the craniocaudal direction (**Fig 4.2.1-4a**). Separate incision lines should be marked in the case of spared segments (eg, L2/3 and L4/5) or in the event of opposite approach sides.

The approach side has to be chosen preoperatively. In most cases surgery is performed from the side where the leg symptoms are more dominant. In the absence of unilateral dominance of pain syndromes, the surgeon may then choose whichever approach side is considered best. However, in the case of a deformity in the frontal plane, an approach via the convex side is mostly chosen due to the fact that the corresponding segment(s) is/are rotated towards the convexity, and also because the over-the-top procedure would be difficult if not impossible from the concave side. In multilevel procedures, decompression can be performed either from one side or from alternate sides with one midline incision or separate incisions for each segment (**Fig 4.2.1-6**).

6 Surgical technique

In routine practice, for both mono- and bisegmental decompression procedures, surgery begins with the microscope already in place. After the skin incision and sharp dissection of subcutaneous tissue have been carried out, a semicircular fasciotomy is followed by blunt subperiosteal mobilization of the paraspinal muscles laterally towards the facet joint. Adjacent superior and inferior hemilaminae are exposed. An articulated or solid-frame speculum retractor is placed. For monosegmental decompression, mini-retractors are available (**Fig. 4.2.1-7**). Blunt preparation after skin incision using tubular retractors is also an alternative. The interlaminar window is cleaned completely of soft tissue.

Using a high-speed drill with cylindrical, conical, or Rosen burrs, modified osteoclastic hemilaminotomy of the superior hemilamina is carried out until the insertion zone of the yellow ligament at the hemilamina is reached and epidural fat or the dura becomes visible (**Fig 4.2.1-8**). At this stage, a switch to diamond burrs is strongly recommended in order to avoid damage to the dura. In addition, the anterior part of the spinous process could be thinned until epidural fat becomes visible. The exposure of the interlaminar window is completed by removal of the superior part of the caudal hemilamina. In the case of a hypertrophic facet joint, the inferior facet has to be thinned medially by sparing osteoclastic facetotomy.

As a first step, decompression of the ipsilateral central spinal canal is performed (**Fig 4.2.1-9**). Using dissectors, exploration hooks and Smith-Kerrison-like rongeurs, the yellow ligament is mobilized and removed entirely. Upward-cutting rongeurs are more practical than 90°-angled rongeurs as they permit better visibility during handling. In the case of adhesions, mobilization of the dura and removal of the adhesions medially to laterally is possible. Residual compression of the dura by the adjacent hemilaminae can be resolved by superior and inferior sublaminar undercutting. Synovial cysts in the central spinal canal can be removed during this step under direct visual control to ensure that the dura is not violated.

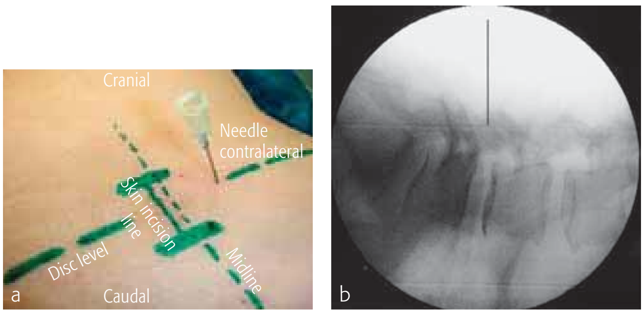

Fig 4.2.1-4a–b

a Preoperative localization of the index segment with correct needle placement and marked skin incision line.

b Lateral x-ray control demonstrating correct needle placement

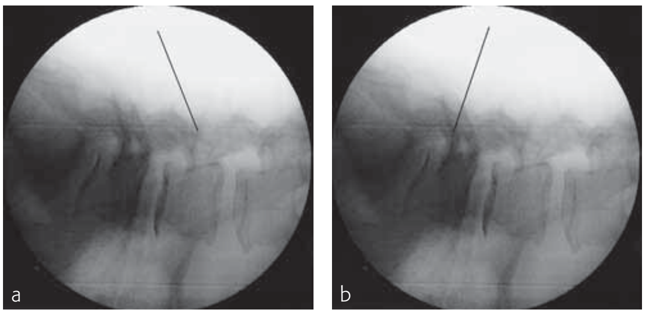

Fig 4.2.1-5a–b

a Incorrect needle placement for cranial corridor marking, demonstrating the risk of wrong-level surgery.

b Incorrect needle placement for caudal corridor marking, demonstrating the risk of wrong-level surgery.

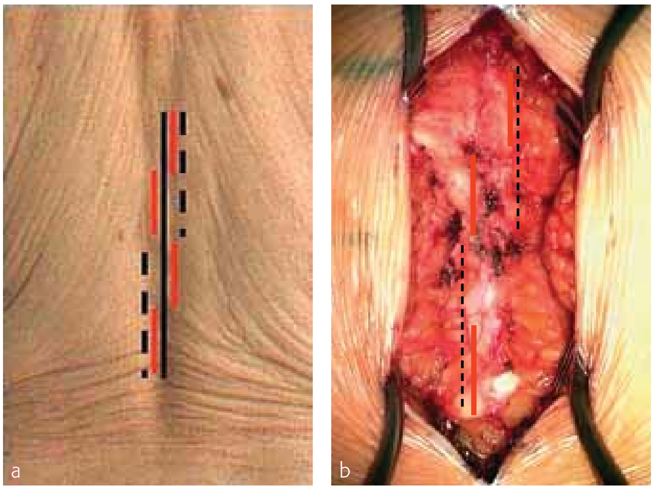

Fig 4.2.1-6a–b Different approach possibilities for bi- and multisegmental decompression surgery with different skin incisions. Continuous black line: midline skin incision; broken black line: two segments per side; red line: separate cutaneous and/or separate subcutaneous/subfascial approach.
a Single skin incision.
b Separate subcutaneous/subfascial approaches.

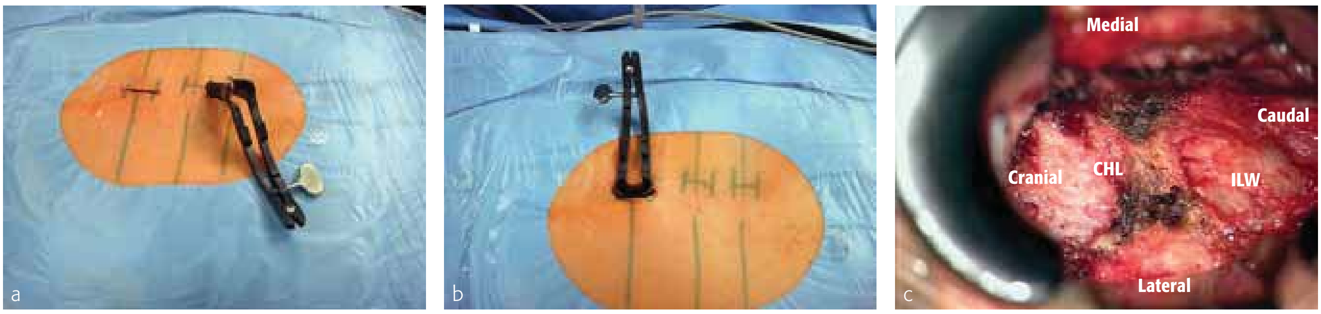

Fig 4.2.1-7a–c
a Mini-retractor used for monosegmental decompression.
b Mini-retractor in place in a three-segmental ipsilateral approach with a separate incision for each segment.
c Mini-retractor with microscopic view of the target interlaminar window.
ILW: interlaminar window; CHL: cranial hemilamina.

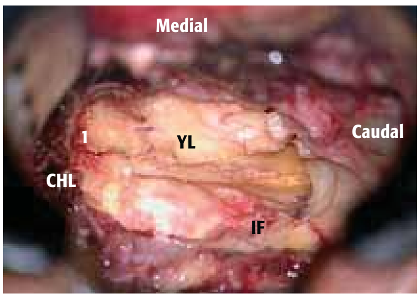

Fig 4.2.1-8 Enlarged interlaminar window with the yellow ligament still in place.
1: the initial opening of the spinal canal;
YL: yellow ligament; CHL: cranial hemilamina;
IF: inferior facet.

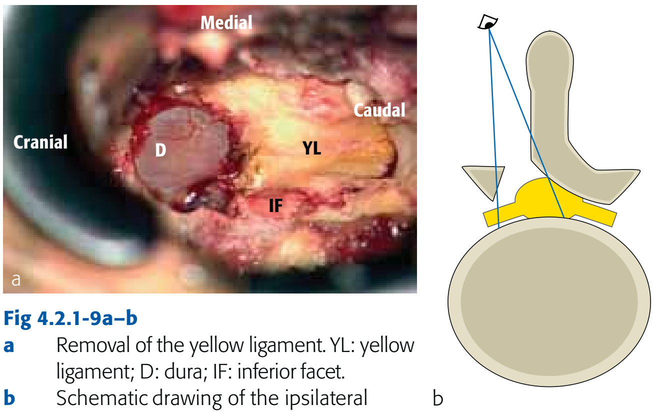

Fig 4.2.1-9a–b
a Removal of the yellow ligament. YL: yellow ligament; D: dura; IF: inferior facet.
b Schematic drawing of the ipsilateral target area.

The ipsilateral lateral recess, consisting of parts of the superior facet, the joint capsule and remaining yellow ligament and covering the exiting nerve root, can now be approached. The lateral border of the dura and the exiting nerve root are mobilized with a dissector. Remaining yellow ligament and compressive parts of the joint capsule are removed by small-caliber rongeurs (**Fig 4.2.1-10**). Using small diamond burrs, the medial part of the superior facet is thinned out. Subarticular undercutting decompression enlarges the corridor for the exiting nerve root. In the event of substantial pedicular compression of the nerve root, additional partial resection of the medial pedicle is required. Osteoclastic hemilaminotomy of the inferior lamina might also be necessary. Starting with the nerve root decompression at the shoulder reduces the risk of nerve root damage. At the end of lateral recess decompression, sufficient posterior and lateral nerve root decompression as far as to the foramen can be visualized under microscopic control (**Fig 4.2.1-11**).

For decompression of the contralateral central canal and lateral recess, the table is tilted approximately 20° away from the surgeon with the microscope aligned to deliver a sufficiently oblique corridor (**Fig 4.2.1-12**). The anterior part of the interspinous ligament and the base of the spinous process are removed. Then the contralateral yellow ligament is stripped off entirely with rongeurs under direct visual control of the thecal sac (**Fig 4.2.1-13**). Adhesions can easily be mobilized by dissectors. In the case of osseous compression of the dura, the medial part of the facet is thinned with a diamond drill. If necessary and for safety reasons, the dura can be gently retracted medially with a nerve hook. Superior and inferior hemilaminae are then undercut by rongeurs for further enlargement of the canal and better visualization of the neural structures. Contralateral lateral recess decompression includes partial removal of the joint capsule and enlarged osteoclastic thinning of the medial parts of the superior facet. Exposure and decompression of the exiting nerve root is completed by subarticular undercutting until the nerve root passes the contralateral inferior pedicle (**Fig 4.2.1-14**). A comparison of pre- and postoperative images demonstrates the effectiveness of the decompression (**Fig 4.2.1-15**).

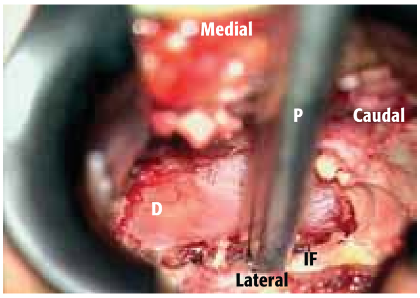

Fig 4.2.1-10 Decompression of the ipsilateral lateral recess with rongeur targeting towards the lateral recess, away from the dura.
IF: inferior facet; D: dura; P: punch.

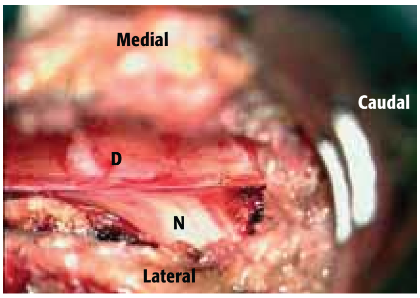

Fig 4.2.1-11 Ipsilateral complete decompression with relieved nerve root.
D: dura; N: nerve root.

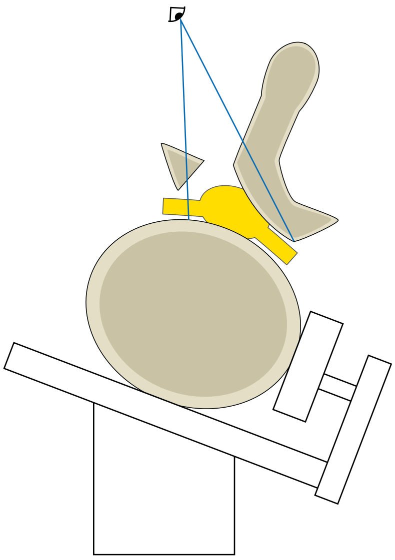

Fig 4.2.1-12 The tilted table with lateral support for an optimal oblique view and working corridor for the contralateral over-the-top decompression procedure.

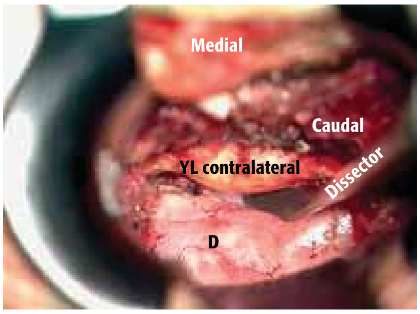

Fig 4.2.1-13 Over-the-top decompression with the dura (D) and dissector visible beneath the contralateral yellow ligament (YL).

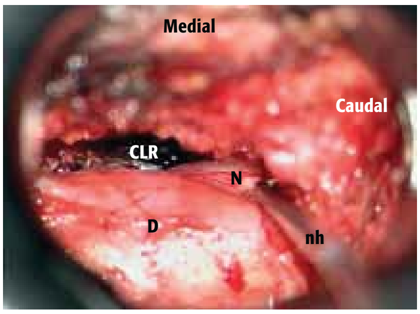

Fig 4.2.1-14 Decompressed contralateral central canal and lateral recess with the exiting nerve root visible. D: dura; N: exiting nerve root; nh: nerve hook; CLR: contralateral lateral recess.

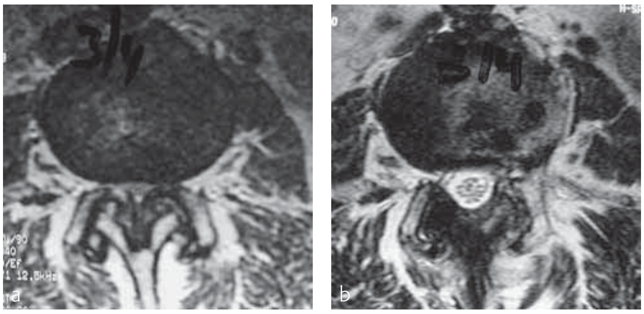

Fig 4.2.1-15a–b
a Preoperative axial MRI showing index segment at L3/4 with severe central canal stenosis and bilateral recess stenosis.
b Postoperative axial MRI showing index segment at L3/4 and demonstrating the effective bilateral enlargement of the spinal canal and lateral recess.

At this point, a final check for complete decompression of the neural structures (dura, nerve roots) and meticulous epidural hemostasis including the possible use of adequate hemostatic agents should be performed. In the case of bone bleeding, bone wax or high-speed drilling without irrigation helps to close the bony surface. The use of a subfascial drain (without suction) is rarely indicated. After closure of the fascia and adaptation sutures of the subcutaneous tissue, the skin is closed by resorbable intracutaneous running suture.

Since in routine practice decompression surgery is a procedure that does not require instrumentation, navigational techniques are normally not necessary as a standard add-on. Additional instrumentation may be necessary for certain indications. Different types of instrumentation include interspinous spacers (see chapter 4.2.5 Interspinous spacers) and pedicle-based fusion procedures (see chapter 4.2.4 Mini-open and percutaneous pedicle instrumentation and fusion).

7 Postoperative care

Independently of the number of levels that have been decompressed, the patient can be mobilized within hours following surgery. If additional instrumentation procedures have been performed or in the case of elderly patients, mobilization is delayed until the day after surgery. Drain removal is carried out within 24–48 hours of surgery. Sterile adhesive plaster is placed for 48 hours. If wound healing progresses satisfactorily, no further wound covering is necessary afterwards. After initial patient mobilization, there are no restrictions concerning different mobility patterns such as sitting, standing, or walking. A brace is not routinely used. However, depending on the patients´ complaints, the number of decompression levels (over 2 levels), and if translational immobile displacements or degenerative deformities are present, temporary soft bracing is reasonable for 4 weeks. Thromboembolic prophylaxis with fractionated heparin is performed until full mobilization. Prolonged antibiotic therapy is not recommended.

8 Evidence-based results

With the technique of bilateral decompression using a monolateral approach, 1914 patients were operated on at the author's spine center between June 1998 and June 2008. An initial series consisted of 275 patients (52% men, 48% women; mean age 69 years, range 34–89 years) with symptomatic central lumbar spinal canal stenosis and bilateral lateral recess stenosis, who underwent decompression without additional instrumented fusion procedures. This series was analyzed retrospectively at a mean follow-up of 24 months; monolateral isolated lateral recess stenosis was excluded from this analysis [30]. Nonsurgical treatment over a long preoperative period had proved unsuccessful in all patients. Intermittent neurogenic claudication (91.6%) and leg pain with unspecific sciatica (73%) were the dominant symptoms, with 52% of patients experiencing additional subordinate back pain. In 54.5% of cases, accompanying mono- or polyradicular symptoms, including pain and varying degrees of sensorimotor deficit, were found depending on which nerve roots had been compromised. Only 75 patients (27.3%) presented with sciatica alone. Preoperatively the average walking distance amounted to 250 meters, with a few patients being unable to walk at all. Preoperative average standing time was 10 minutes.

Ninety-nine percent of the patients required elective surgery. However, due to the intensity of the pain syndromes and the presence of neurological symptoms, 52% underwent surgery within 1–2 weeks of the first contact. One percent of all patients were operated on without delay, due to chronic cauda equina syndrome with bladder and/or bowel dysfunction. In total, 568 segments were decompressed with the majority being at L4/5 (252/275) and L3/4 (178/275). There were more cases of bisegmental decompression (44%) compared to monosegmental (29%) and trisegmental (22%) procedures. The mean time of surgery amounted to 37 minutes per segment, and mean blood loss to 57 ml per segment. Twenty-four months after surgery, leg pain had significantly decreased in 71% of patients, but this symptom remained unchanged in 29% of cases. No increase in unspecific sciatica or radicular symptoms was found. Back pain decreased in 40% of patients, remained unchanged in 57.5%, and increased in 2.5% of cases. Pain-free standing time improved from 10 minutes preoperatively to 82 minutes postoperatively, and pain-free walking distance from 250 meters preoperatively to approximately 5000 meters postoperatively. When questioned about general satisfaction, 74% of the patients reported a better postoperative overall quality of life, 14% reported an unchanged situation, and 12% felt dissatisfied.

The perioperative surgery-related complication rate amounted to 10% overall. The majority of complications involved dural tears (5%) requiring immediate intraoperative activities or early revision, followed by hematomas (3.8%). In one case, an unplanned segment was decompressed.

Similar results were published by Costa et al in 2007 [31] using an identical over-the-top decompression technique for the treatment of degenerative lumbar spinal stenosis. In a retrospective study with a mean follow-up of 30.3 months, the postoperative outcome of 374 patients was analyzed. Outcome measurements included the visual analog scale (VAS) and the Prolo Economic and Functional Scale. Five hundred and twenty levels were decompressed with a predominance of segments at L4/5 and L3/4. Monosegmental pathologies dominated in 76.2 % of cases. The mean time of surgery was 75 minutes (without differentiating between the number of levels included) and the estimated blood loss was 60 ml. Clinical and functional improvement was reported in 87.9% of cases. In patients with preoperative radiculopathy, 40% demonstrated some postoperative sensorimotor deficit. Three out of 374 (0.8%) patients developed a mild segmental instability, however, without the need for surgical intervention. For the economic and functional assessments, subjective postoperative evaluation demonstrated a statistically highly significant benefit with a mean decrease in VAS from 8.9 preoperatively to 4.2 postoperatively and a mean increase in the Prolo score of 3 (± 2).

In a prospective study, Anjarwalla et al [32] analyzed the 5-year outcome of patients that had undergone decompression surgery for lumbar spinal stenosis. The long-term outcome evaluation, made on the basis of general health questionnaires, included the VAS, the Oswestry Disability Index (ODI) and the Short Form 36 (SF-36). Statistically significant improvement was found over the follow-up period for postoperative leg and back pain, predominantly at 1-year follow-up, with some deterioration in the improvement of pain level at 5-year follow-up. Improvement measured by the ODI was also found to be statistically significant at the 1-year and 5-year intervals. As regards general health, the SF-36 documented improvement for both follow-up intervals, mainly at the 1-year interval. However, for the assessment of social functioning, only at the 1-year interval was significant improvement found. In this study, the indication group included patients that had undergone bilateral (83%) and monolateral (17%) surgical procedures, and thus differed from the study groups mentioned earlier.

In a prospective study with a mean follow-up of 5.4 years, Cavusoglu et al [33] compared two treatment groups (n = 50 patients per group) that underwent decompression surgery for lumbar spinal stenosis—ie, unilateral laminectomy versus unilateral laminotomy—in both instances, for bilateral decompression. No difference in outcome was found in favor of either technique. Considerable enlargement of the spinal canal was noted postoperatively in all cases, as documented by comparison between pre-and postoperative MRI (unilateral laminectomy, 4.0–6.1-fold, unilateral laminotomy, 3.3–5.9-fold enlargement). Both groups showed statistically significant improvement in the ODI scores at early (1-year) as well as late (5-year) follow-up intervals, whereas for the evaluation of general health the SF-36 showed a remarkable improvement at late (5-year) follow-up evaluation, which was, however, without statistical significance.

Several studies have been published on the use of tubular retractors for a unilateral "over the top" approach. Parikh et al [24] reported results comparable to those in the published literature using open surgery in patients that underwent one- and two-level tubular laminectomy for lumbar spinal stenosis. A significant learning curve was required. Rahman et al [34] compared 38 patients that underwent minimally invasive tubular decompression for stenosis to 88 patients undergoing standard open decompression. The minimally invasive lumbar laminectomy patients experienced shorter operating times, less blood loss, shorter length of hospital stay, and fewer complications. Celik et al [35] compared open total laminectomy to bilateral microdecompressive laminotomy in 34 and 37 patients respectively, each group with a mean follow-up of 5 years. The clinical outcome was comparable in both groups, but the complication rates and postoperative instability rates were significantly higher in the total laminectomy group.

9 Complications and avoidance

The overall complication rates, when using microscope-assisted decompression techniques for the treatment of acquired lumbar spinal stenosis, have been reported as being between 7% and 17% [36, 37]. As regards complication rates for minimally invasive decompression procedures there is a tendency toward fewer new neurological deficits, as well as fewer overall complications [36]. No difference is found when comparing the described method with other microsurgical bilateral techniques.

Incidental dural tears with subsequent cerebrospinal fluid leakage represent the major complication associated with decompression surgery, amounting to 8–13% for primary surgery [38, 39]. Especially in the elderly population, the dura becomes thinner and frequently more adherent to the surrounding structures, with the inherent risk of increased vulnerability. Immediate repair of a dural tear by suturing, surface sealing with fibrin glue, or the application of a tamponading fleece (eg, TachoSil, Nycomed Pharma GmbH, Konstanz/Germany) helps to avoid the development of a pseudomeningocele or persisting cerebrospinal fluid (CSF) fistulas.

Nerve root injury is a less frequent occurrence, with a reported rate of 1–2% [40, 41]. The over-the-top decompression procedure for the reduction of contralateral spinal canal narrowing might in particular lead to a possible temporary compression of the cauda equina if the entrance corridor of the decompression route is too narrow due to insufficient undercutting of the lamina. On analyzing the present author's own data pool, no direct nerve root injury could be found. However, one transient hemicaudal syndrome was observed.

The postoperative development of epidural hematoma following decompression surgery is a relatively frequent occurrence with a reported 58% incidence thereof, most cases being asymptomatic and usually extending to adjacent levels in 28% of patients [42]. Meticulous intraoperative hemostasis using bipolar coagulation or hemostatic (eg, Surgicel, Ethicon GmbH, Somerville, USA) or sealing agents (FloSeal, Baxter GmbH, Deerfield, USA) helps to reduce the risk of epidural hematoma. In the case of increasing dull leg pain or increasing radicular pain during the postoperative course, MRI examination is recommended to exclude the presence of a possible compression that may require surgical revision.

As regards decompression surgery for lumbar spinal stenosis, to date no evidence-based studies are available on the relationship between the degree of postoperative asymptomatic or symptomatic epidural scar-tissue formation and the specific decompression technique used. However, since the amount of bleeding and subsequent scar-tissue formation is directly related to the extent of the exposure chosen, microsurgical approaches as presented in this chapter may help to reduce postoperative symptomatic epidural scar tissue formation.

Wrong-level decompression is a rare occurrence (1/275 in the author's series ie, 0.4% [30], up to 3.3% in the literature [43]). For the most part, meticulous preoperative planning including x-ray-controlled needle placement for level localization and intraoperative x-ray verification of the target segment before perforation of the yellow ligament should help to avoid this complication.

Incomplete decompression might affect both the ipsilateral and contralateral cranial and caudal areas. Care must in particular be taken when decompressing the ipsi- as well as the contralateral cranial area, since remaining parts of the tip of the superior facet might continue to impinge on the exiting nerve root. With proper over-the-top decompression, recurrence of an acquired lumbar spinal stenosis is extremely rare. In most cases, "recurrent" stenotic segments are a result of insufficient primary decompression. In the present author's series, no patient had to be operated on within a follow-up period of 8 years due to recurrent stenosis. Reoperation rates amounting to 11–13% have been reported, but without precise details regarding the indication [44, 45].

As with all advanced surgical techniques, microsurgical over-the-top decompression includes a steep learning curve. Initially, the time of surgery per segment might be increased when switching from macrosurgical laminectomy techniques to microsurgical procedures performed through a small working channel [24]. Previous intraoperative routine use of a microscope, however, will shorten the learning curve. The surgeon should be familiar with the microanatomy of the lumbar spine. The over-the-top decompression procedure, contralaterally within the canal itself, cranially and caudally, as well as in the lateral recess, presents a particular challenge both as regards anatomical orientation and the manual skill required.

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Segmental instability is a potential risk following decompression surgery. Extensive decompression procedures such as laminectomy may worsen existing instability, or lead to the development of previously nonexistent instability. On the contrary, microsurgical interventions such as the decompression technique presented herein, which preserves the entire contralateral paravertebral musculature including the nervous structures and vascular supply, will generally not trigger or accelerate segmental instability [33]. Already existing large hypermobile translational instabilities or stable displacements exceeding slips greater than grade I or frontal tilts of over 30° are considered risk factors that could result in increased instability and are therefore viewed as contraindications for decompression procedures without additional stabilization [25]. Instability does not usually depend on the number of levels that are decompressed [46], however, an accompanying symptomatic large disc herniation treated by sequestrectomy or even discectomy could result in segmental instability. When fusion is also performed, however, combined decompression and fusion surgery imply an increased risk of complications, as a statistically higher postoperative neurological complication rate has been reported [36].

10 Tips and tricks—with special emphasis on tubular decompression surgery

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10.1 Patient selection

Patients with lumbar central spinal stenosis, lateral recess stenosis, foraminal stenosis herniated or bulging discs, synovial cysts, and other intraspinal pathologies are suitable candidates for tubular decompression surgery [23]. Tubular decompression further limits approach-related morbidity, as it involves a muscle-splitting ligament-sparing technique.

Patients with grade I spondylolisthesis are suitable candidates for decompression surgery without stabilization [47]. However, patients with overt instability with motion ≥ 4 mm on flexion-extension, with significant scoliosis or lateral listhesis, should be considered for stabilization surgery.

10.2 Operative procedures

The treatment approach is normally from the most symptomatic side unless a specific intraspinal pathology dictates otherwise. This would be the case for synovial cysts or disc herniations contralateral to the most symptomatic side.

Image intensification is highly recommended for localization, as there a greater risk of inadvertently straying from the intended level with minimally invasive techniques.

It is also helpful to remember that in a degenerated spine the inferior edge of the lamina has often migrated caudally with disc-space collapse; therefore, the surgeon should target the lower edge of the disc space. It is better to err on being too low than too high, so that at least the inferior edge of the lamina is visible at the end of the tube. Ideally, it should be possible to see the inferior edge of the lamina in the middle of the tube.

After exposure of the inferior edge of the superior lamina, initial dissection is carried out with a straight curette to separate the ligamentum flavum. The ligamentum is usually quite thick and drilling can be safely performed with a 3 mm diamond drill until only a thin layer of bone remains to be removed with a Kerrison rongeur. On the contralateral side once the ligamentum flavum has been removed, the medial aspect of the contralateral facet can be seen. It is important to remove as much of the facet complex as necessary to fully decompress the opposite lateral recess.

Often the most stenotic portion, the waist of the stenosis, is located at the superior border of the lower lamina. It is important to fully remove this inferior attachment of the ligamentum flavum and to visualize or palpate the nerve root along the lower pedicle. This ensures the complete decompression of the nerve root. Palpation of the disc space and removal of any offending protrusion completes this evaluation.

The primary aim in decompressive surgery for spinal stenosis is to achieve a satisfactory decompression. However, this is often compromised by an attempt to limit any potential postoperative instability. Achieving an adequate decompression may require partial removal of the pars on the ipsilateral side. This is particularly the case at or above L3/4, where the facets tend to become progressively more vertical. If the pars interarticularis is compromised during the surgical procedure the loose inferior articular process should be removed, as if it is left this could result in postoperative pain. It is not necessary to perform fusion at this time. The patient should nevertheless be informed of the situation, and appropriately monitored for the potential need for stabilization. In the present author's experience, the incidence of postoperative instability is less than 5% for all patients, and no significant difference has been noted in patients in whom a pars interarticularis has been sacrificed.