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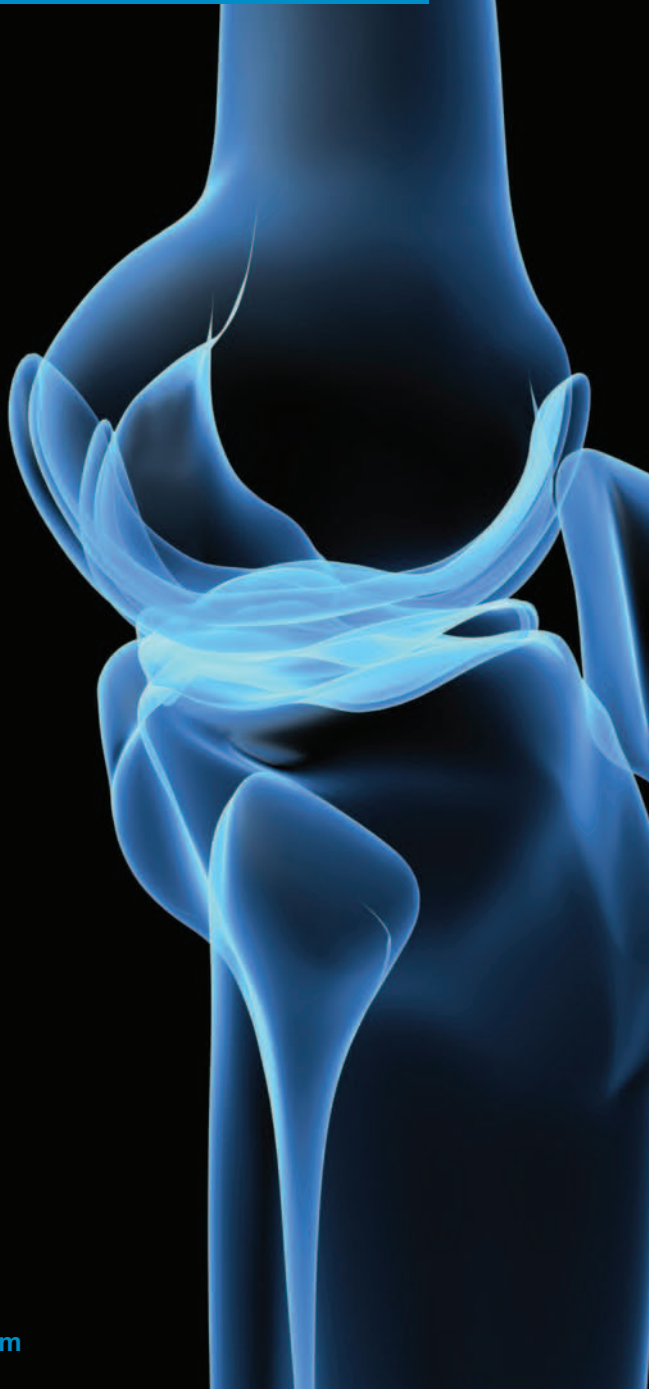
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Pre-operative Planning
for Endoscopic
Lumbar Foraminal
Decompression –
A Prospective Study

a report by

Kai-Uwe Lewandrowski

*Center for Advanced Spinal Surgery
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Minimally invasive techniques for the treatment of lumbar spinal stenosis have found their way into mainstream spinal surgery. Many surgeons report faster recovery, rehabilitation and return to work with the use of mini-open exposures to the lumbar spine. Endoscopic techniques are evolving and there are number of innovative systems available that offer improved optical equipment and surgical instrumentation, allowing for true minimally invasive percutaneous foraminal decompression.¹⁻⁴

This approach is attractive for a number of reasons. First, the incision for a transforaminal endoscopic surgery (TES) is extremely small, and the surgery can be performed under local anaesthesia with sedation in an outpatient setting.⁵⁻⁸ Second, patient expectations nowadays are high as percutaneous procedures are the standard of care in other surgical subspecialties – examples include the laparoscopic cholecystectomy, appendectomy and a multitude of other general and urological procedures. Third, the long-term side effects of open spinal surgery for laminectomy and/or fusion – such as post-laminectomy instability and epidural fibrosis – often prompt more spinal surgery later in the patient's life, which further complicates the reconstructive problem for both the patient and the surgeon. Last but not least, health policy-makers, review boards, granting agencies and payers continue to look for services that can be provided to their beneficiaries in a more cost-effective manner in an outpatient surgical facility.

While the question remains of whether or not these perceived advantages are actually associated with improved clinical outcomes, it seems intuitively clear that a percutaneous, transforaminal, endoscopic approach to the compressed neural elements is by far less disturbing to the spinal motion segment than a traditional open laminectomy approach, where post-laminectomy instability and epidural fibrosis rates have been reported to be as high as 25%.⁹⁻¹²

In this study, we evaluated the feasibility of predicting post-operative outcomes with the endoscopic foraminotomy procedure by stratifying patients based on radiographic classification systems (computed tomography [CT] and magnetic resonance imaging [MRI]). Patients with lumbar spinal claudication and related symptoms due to bony foraminal stenosis were treated with endoscopic foraminoplasty via

the transforaminal approach. We intended to analyse clinical failures and to discuss whether certain risk factors for fair and poor outcomes with this procedure can be identified for clinical guidelines.

Materials and Methods

Patient Population

All patients provided informed consent to be included in this case series. The study group consisted of 40 patients with single radiculopathy due to bony foraminal spinal stenosis. All patients were treated by a single surgeon. The inclusion criteria were: clinical signs of neurogenic claudication, including radiculopathy, dysesthesias and decreased motor

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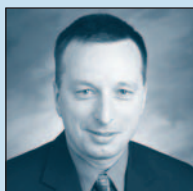
function; symptoms correlating with foraminal stenosis (defined as height of the lateral recess and width of the neuroforamen in the axial plane of $\leq 3\text{mm}$) demonstrated on pre-operative MRI and CT scans; unsuccessful non-operative treatment, including physical therapy and transforaminal epidural steroid injections for at least 12 weeks; and age between 35 and 85 years.

Patients were excluded if they showed segmental instability on pre-operative extension flexion radiographs and had central stenosis ($\leq 8\text{mm}$).

Pre-operative Work-up and Clinical Follow-up

Pre-operatively, radiographs and MR and CT images were obtained in all patients. Post-operatively, CT images were taken if the patient showed no improvement of clinical symptoms at least six weeks after surgery. Patients returned for clinical follow-up at six weeks post-operatively, and at three, six and 12 months, respectively. Patients were seen at six-month intervals after the first year post-operatively.

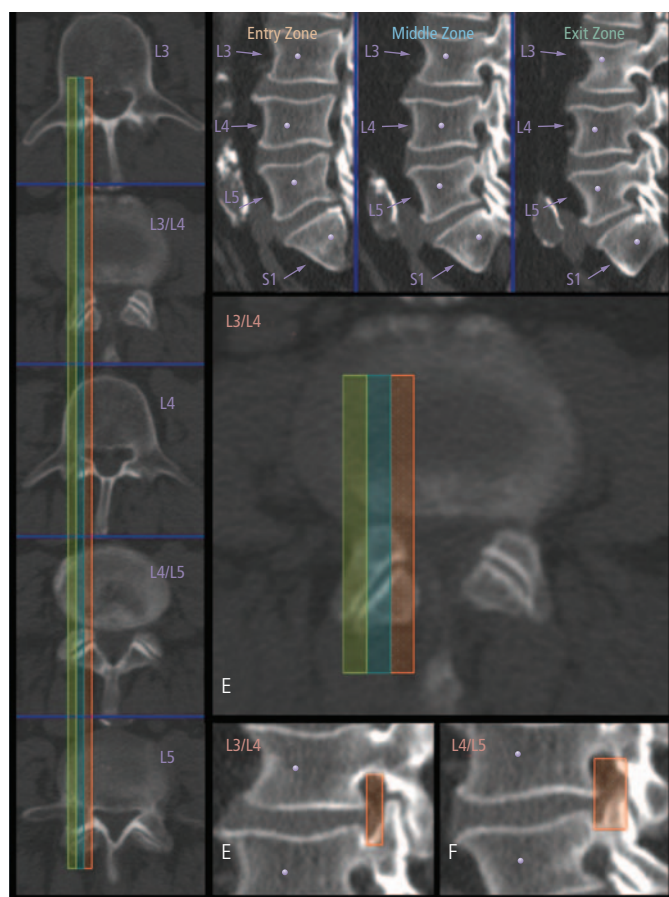
Clinical outcomes were assessed by the patient using the visual analogue score (VAS) for leg pain, ranging from no pain (0) to worst pain (10), and by the treating surgeon using the McNab criteria.¹³ Briefly, at latest follow-up results were classified as 'excellent' if the patient had no pain and no limitation of activities; 'good' if the patient



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Figure 1: Pre-operative Computed Tomography Scans of a 70-year-old Male



A: panel on the left shows axial computed tomography (CT) cuts from L3 to L5; B–D: panel shows sagittal CT cuts through the entry (shaded orange), middle (shaded turquoise) and exit zone (shaded green) of the lumbar neuroforamina; E: axial CT cut through the L3/4 disc space showing the stenotic lesion in the middle zone at that level; F–G: sagittal CT cuts through the middle zone at L3/4 and the L4/5 level. The neuroforaminal height (orange shade area) is less than 3mm and hence consistent with spinal stenosis. At L4/5, the neuroforaminal height is less than 5mm and hence suggestive of spinal stenosis (orange shade area).

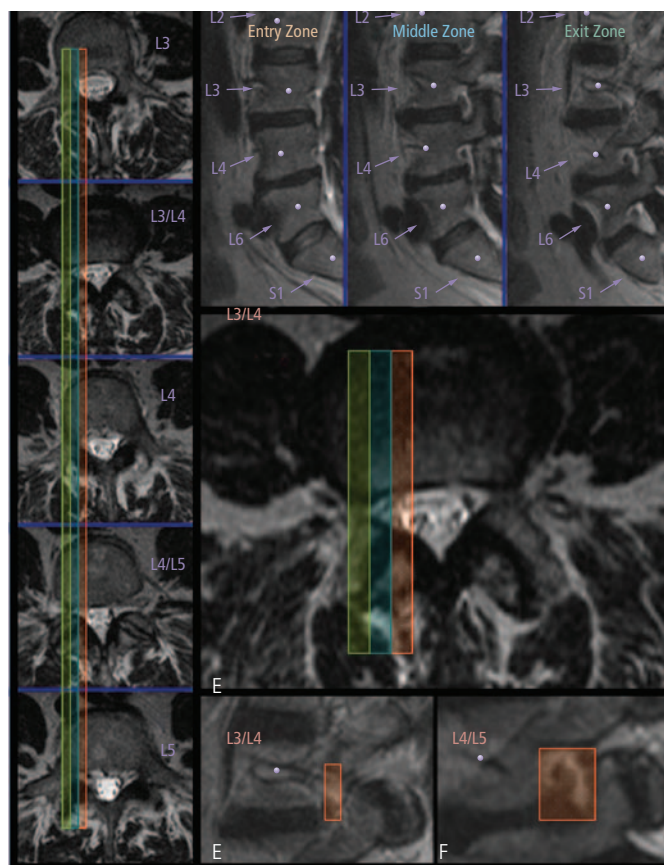
reported occasional pain or dysaesthesia without any restriction of daily activities, and did not need any pain medication; and patients were assigned to one of the two remaining categories if their pain improved somewhat but they continued to need pain medication ('fair'), or if their function worsened or they needed additional surgery to address their symptoms ('poor').

Radiological Classification of Foraminal Stenosis

Lee's classification of foraminal stenosis was used to define the location of the offending bony pathology within the neuroforamen by dividing it from medial to lateral into entry (dura to pedicle; zone 1), middle (medial pedicle wall to centre pedicle; zone 2) and exit zone (centre pedicle to lateral border of the facet joint; zone 3).¹⁴ Bony foraminal stenosis in the entry zone was frequently found to be due to hypertrophy of the superior articular facet in the mid-zone due to an osteophytic process underneath the pars interarticularis, and in the exit zone due to a subluxed and hypertrophic facet joint (see Figure 1).

The height of the intervertebral disc and lumbar foramina was evaluated according to Hasegawa,¹⁵ who described a height of 5mm or more as normal, a reduced height of 3–4mm as suggestive of spinal stenosis and a height of 2mm or less as stenotic. Pre-operative sagittal and axial MR and CT images were used to assess the location and extent of foraminal

Figure 2: Pre-operative Magnetic Resonance Imaging Scans of a 64-year-old Female



A: panel on the left shows axial magnetic resonance imaging (MRI) cuts from L3 to L5; B–D: panel shows sagittal MRI cuts through the entry (shaded orange), middle (shaded turquoise) and exit zone (shaded green) of the lumbar neuroforamina; E: axial MRI cut through the L3/4 disc space showing the stenotic lesion in the exit zone at that level; F–G: sagittal MRI cuts through the exit zone at L3/4 and the L4/5 level. The neuroforaminal height (orange shade area) is less than 3mm and hence consistent with spinal stenosis. At L4/5, the neuroforaminal height is 5mm and hence of normal height (orange shade area).

stenosis. Only patients with stenotic lesions producing a neuroforaminal width of ≤ 3 mm on the sagittal MRI and CT cuts or lateral recess height of ≤ 3 mm on the axial MRI and CT cuts were included in this analysis. One predominant zone of foraminal stenosis was assigned per patient (see Figure 2).

Surgical Techniques

All surgical procedures were performed with the Transforaminal Endoscopic Surgical System (TESSYS™; joimax® system; joimax GmbH, Karlsruhe, Germany). The endoscopic transforaminal approach is used as an 'outside-in' technique in which the working cannula is placed into the epidural space in the lower portion of the neuroforamen, thus avoiding the nerve root.

No part of the cannula tip is positioned in the disc space. Procedures were performed in prone positions under local anaesthesia and sedation in all patients. In some instances, where access to the L5/S1 neuroforamen was difficult due to a high riding ilium, patients were positioned in the lateral decubitus position. Techniques to define the skin entry point and the surgical trajectory have been described elsewhere. Entry points were generally laterally at 8–10cm at the L3/4 level, 10–12cm at the L4/5 level and 12–14cm at the L5/S1 level. The respective angular trajectories for foraminal access in the coronal, axial and sagittal plane are shown in Figures 3–5.

Figure 3: Angular Trajectories for Transforaminal Access Planning in the Coronal Plane (Dorsal View) for the L3/4 Level (25–35°), the L4/5 Level (30–40°) and the L5/S1 Level (40–50°)

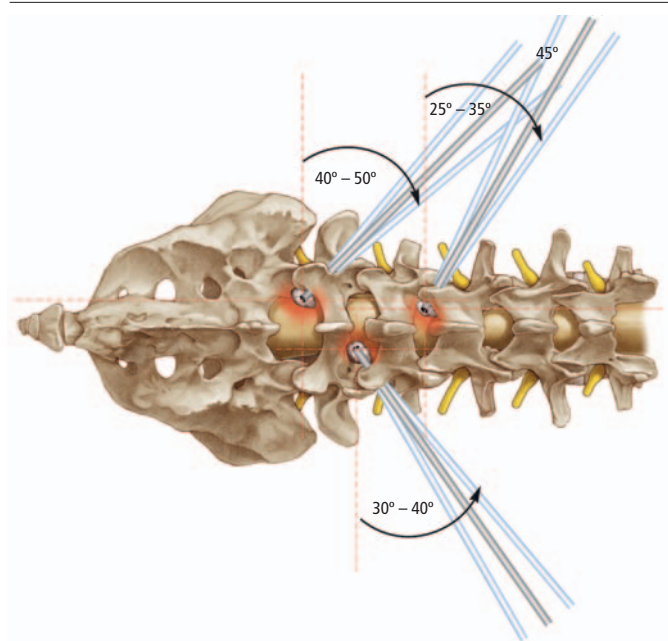
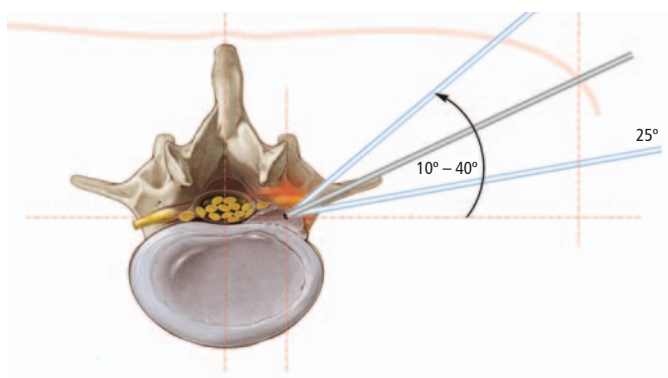


Figure 5: Angular Trajectories for Transforaminal Access Planning in the Axial Plane for the L3/4, L4/5 and the L5/S1 Level (10–40°)



The targeted neuroforamen was accessed as follows. First, an 18-G (150mm in length) needle is inserted into the safe zone of Kambin's triangle bordered by the dural sac medially, the exiting nerve root laterally and the lower adjacent pedicle distally.⁵ Ideally, the targeting needle is placed on the lateral view into the lower portion of the neuroforamen as close to the disc as possible without puncturing the intervertebral disc. On the anterior–posterior view, the needle tip should be at the medial interpedicular line.

A steel guidewire was then inserted into the intervertebral disc and the 18-G spinal needle was removed. Three sets of dilators and reamers of increasing diameters (5.0, 6.5 and 7.5mm) are used for foraminal reaming. Additional reamers measuring 4 and 8mm in diameter are available, but were not routinely used in this study (see Figure 6).

The removal of bone from the hypertrophied superior and inferior articular facets was facilitated by changing the trajectory of the reamers to aim for the compressive pathology identified on pre-operative studies. Loose disc material was removed using forceps

Figure 4: Angular Trajectories for Transforaminal Access Planning in the Sagittal Plane (Lateral View) for the L3/4, L4/5 and the L5/S1 Level (55–65°)

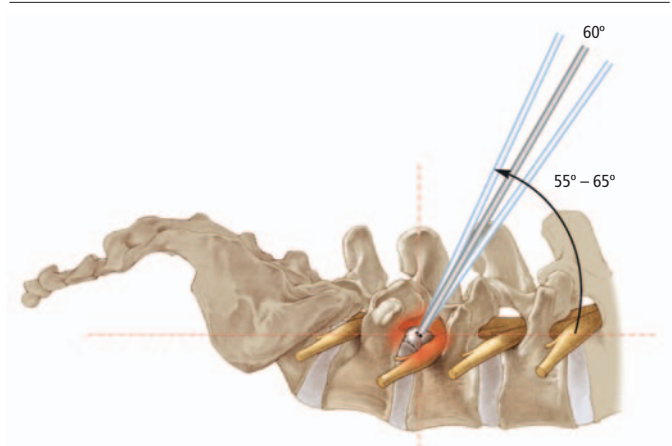
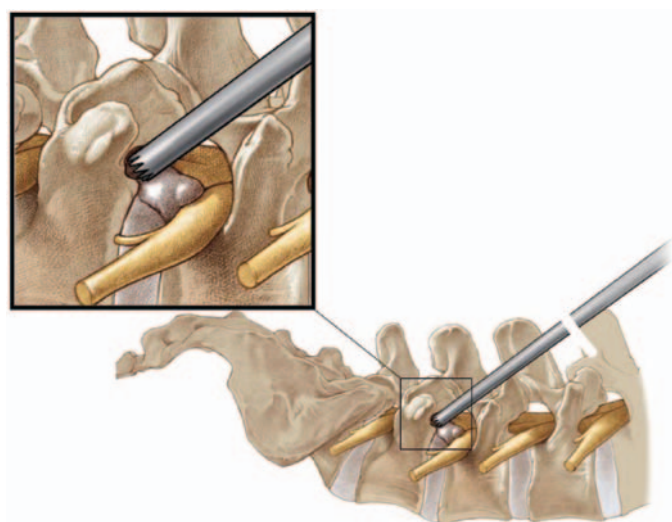


Figure 6: Transforaminal Reaming of the Inferior Portion of the Neuroforamen (Enlarged Inset)



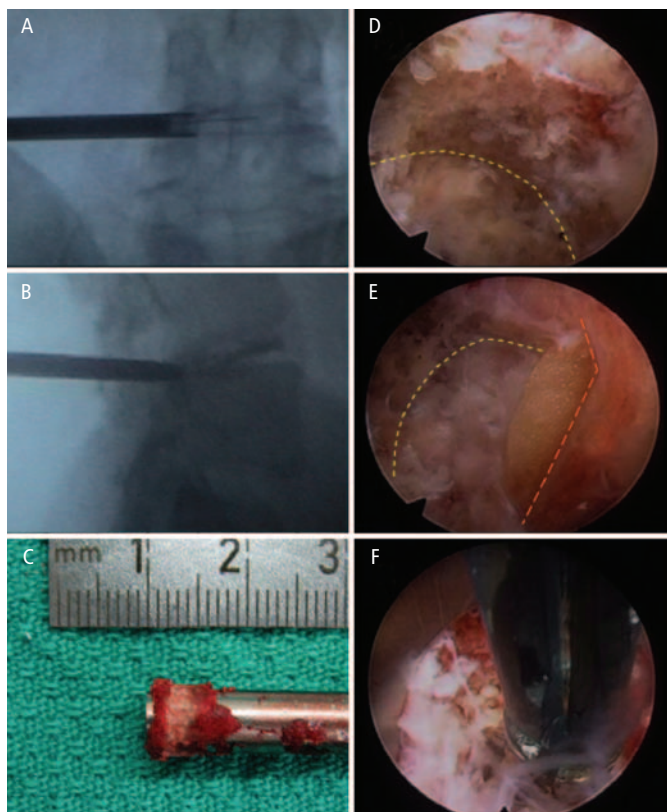
After the targeting needle is placed on the lateral fluoroscopic view into the lower portion of the neuroforamen as close to the disc without puncturing the intervertebral disc, and on the anterior–posterior fluoroscopic view at the medial interpedicular line, a steel guide wire is inserted into the intervertebral disc. Three sets of dilators and reamers of increasing diameters (5.0, 6.5 and 7.5mm) are used for foraminal reaming. Additional reamers measuring 4 and 8mm in diameter are available.

and pituitary rongeurs if found on endoscopic examination of the neuroforamen. This also facilitated the creation of a working space.

The neuroforaminal reaming and debridement procedure was repeated several times in different trajectories as needed to remove the compressive pathology. Epidural bleeding was controlled with a radiofrequency probe (Ellman®; Ellman International LLC, US) under cold saline irrigation. The decompression was assessed intraoperatively by direct visualisation of the exiting nerve root and by evaluating the extent of the facet resection (see Figure 7).

Statistical Methods

Cross-tabulation statistics and measures of association were computed for two-way tables using SPSS Version 15.0. Using the modified McNab criteria and foraminal zone classification as row and column variables, and age (above and below 50 years of age) as the control variable (layer factor), the cross-tabulation procedure was employed to form one panel of associated statistics and measures for each value of the layer factor (or a combination of values for two or more control variables). This correlation matrix allowed calculation of the expected

Figure 7: Typical Radiographic and Endoscopic Views during Transforaminal Decompression

A–B: intraoperative fluoroscopy images in the AP (Figure 7a) and in the lateral (Figure 7b) plane. Note, the reamer is advanced to the medial interpedicular line on the AP and to the posterior vertebral body wall on the lateral view; C: typical view of an endoscopic reamer after transforaminal decompression with bone wrapped around the instrument; D–F: endoscopic views after transforaminal placement of the endoscope showing reamed facet joint (F) and debrided intervertebral disc (D); E: decompressed neuroforamen with F, D, epidural fat (EF) and exiting nerve root (N); and F: application of the radiofrequency probe (RFP) for shrinking disc material and controlling epidural bleeding.

counts of variable combinations if no association was found between clinical outcome and zone classification of foraminal stenosis and variable distribution was equal. The Pearson chi-square and the likelihood-ratio chi-square tests were used as statistical measures of association.

Results

There were 40 patients (26 females and 14 males). The average age was 52.4 years, ranging from 37 to 86 years. The follow-up period ranged from 12 to 15 months. Each patient underwent a single-level operation. Thus, the number of levels equals the number of patients. The L5–S1 segment was the most commonly involved level (22 cases, 55.0%) followed by L4–5 (16 cases, 40.0%) and L3–4 (two cases, 5.0%). Stenotic lesions were localised in the entry zone in 14 patients, in the middle zone in 12 patients and in the exit zone in another 14 patients (see Table 1). According to modified McNab criteria, 16 patients had excellent outcomes and 13 patients had good outcomes. Eleven patients had fair to poor outcomes, and nine of these 11 patients required re-operation with laminectomy. Complications included transitory neurogenic leg pain in six cases due to dorsal root ganglion (DRG) irritation. There were no infections.

The mean VAS score decreased from 7.2 ± 1.4 pre-operatively to 2.3 ± 1.6 at final follow-up ($p < 0.01$). According to the modified Macnab criteria, excellent and good results were mostly seen in patients with middle and exit zone foraminal stenosis (see Table 1).

Table 1: Clinical Outcomes Using Modified McNab Criteria versus Foraminal Zone Classification

Outcome		Zone			Total
		Entry Zone	Exit Zone	Middle Zone	
Excellent	Count	3	7	6	16
	Expected count	5.6	5.6	4.8	16.0
	Within outcome (%)	18.8	43.8	37.5	100.0
Good	Count	2	6	5	13
	Expected count	4.6	4.6	3.9	13.0
	Within outcome (%)	81.8	9.1	9.1	100.0
Poor/Fair	Count	9	1	1	11
	Expected count	3.9	3.9	3.3	11.0
	Within outcome (%)	81.8	9.1	9.1	100.0
Total	Count	14	14	12	40
	Expected count	14.0	14.0	12.0	40.0
	Within outcome (%)	35.0	35.0	30.0	100.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson chi-square	14.660 ^a	4	0.005
Likelihood ratio	14.774	4	0.005
Valid cases (n)	40		

a. Seven cells (77.8%) have an expected count of less than 5. The minimum expected count is 3.30.

Table 2: Chi-Square Tests

Z		Value	df	Asymp. Sig. (2-sided)
Over 50	Pearson chi-square	11.606 ^a	4	0.021
	Likelihood ratio	14.883	4	0.005
	Valid cases (n)	18		
Under 50	Pearson chi-square	3.858 ^b	4	0.426
	Likelihood ratio	4.573	4	0.334
	Valid cases (n)	22		

a. Nine cells (100.0%) have an expected count of less than 5. The minimum expected count is 0.82.

b. Nine cells (100.0%) have an expected count of less than 5. The minimum expected count is 1.11.

Fair and poor results were seen in 11 patients and 81.8% of these occurred in patients with foraminal stenosis in the entry zone (see Table 1). The differences in clinical outcomes were statistically significant ($p < 0.005$; see Table 1). Age above 50 years was identified as an additional risk factor for fair to poor outcomes with statistical significance ($p = 0.021$; see Table 2 and Figures 8–10). Seven of the 11 patients with foraminal stenosis in the entry zone and fair to poor clinical outcomes were above 50 years of age.

Discussion

Pre-operative planning is essential in achieving excellent and good outcomes with the TES for foraminal stenosis. Although the effectiveness of the procedure has been demonstrated by multiple investigators,^{1–12,15–18} clinical data are less favourable for foraminal stenosis than for herniated disc, where clinical success rates upwards of 90% are expected. This is certainly demonstrated by our studies, which showed excellent and good results in 72.5% (29/40) of the patients undergoing foraminoplasty in the exit and middle zone of the neuroforamen.

Since sciatica and neurogenic claudication were the main reasons for surgical intervention, reduction of leg pain was analysed using a VAS. There was a significant improvement in the VAS and the clinical

outcome at final follow-up. Our success rate was similar to clinical success rates¹⁹ and to success rates reported by patients undergoing laminectomy for spinal stenosis.²⁰

The importance of pre-operative planning of transforaminal endoscopic removal of herniated discs has been stressed by Lee et al., who suggested a classification based on the location of a migrated disc fragment.¹⁸ According to pre-operative sagittal MRI images, he defined four zones depending on the direction and distance from the disc space as follows: zone 1 – from the inferior margin of the upper pedicle to 3mm below the inferior margin of the upper pedicle; zone 2 – from 3mm below the inferior margin of the upper pedicle to the inferior margin of the upper vertebral body; zone 3 – from the superior margin of the lower vertebral body to the centre of the lower pedicle; and zone 4 – from the centre to the the inferior margin of the lower pedicle.

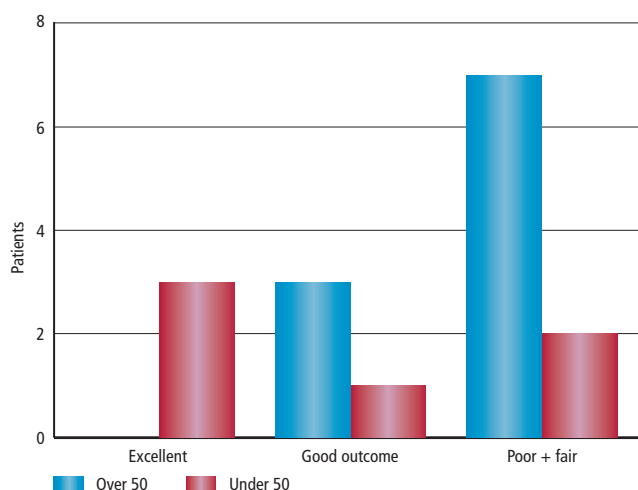
In this study we employed previously published radiographic classification systems^{14,15} in pre-operative decision-making for patients with symptomatic foraminal stenosis, and correlated them with clinical outcomes according to the modified McNab criteria.¹³ In 1988, Lee published on a three-zone classification of the neuroforamen by dividing it into entry, middle and exit zone.¹⁴ In 1995, Hasegawa defined the height of the neuroforamen of 5mm or more as normal.¹⁵ He suggested that a reduced height of 3–4mm is suggestive of spinal stenosis and that a height of 2mm or less is associated with nerve root compression approximately 80% of the time.

As demonstrated by this study, the application of radiographic grading systems of foraminal stenosis may assist in selecting appropriate surgical candidates for the procedure. Our results indicated that patients with stenosis in the entry zone of the neuroforamen fared worse than those with stenosis in the middle and exit zone. These types of stenotic lesions should perhaps be avoided until advanced endoscopic instrumentation such as the Morgenstern endoscopic spinal stenosis system become widely available. These newer instrumentation sets include reamers, chisels and awls that may be positioned under direct visualisation through the centre working channel of the endoscope, and thus may allow a more sophisticated endoscopic decompression.

Conclusion

Foraminal decompression is feasible through the percutaneous transforaminal endoscopic approach and works well in patients with bony stenosis in the mid- and exit zone of the neuroforamen. Decompressive surgery through a laminectomy approach should be considered for neuroforaminal stenosis in the entry zone. Regardless of the instrumentation, pre-operative classification of the neuroforamen into three zones may prove useful in the pre-operative patient selection process. ■

Figure 8: Clinical Outcomes with Entry Zone Stenosis Using Modified McNab Criteria



Note: clinical failures occurred significantly more frequently in patients over 50 years of age (see Table 2).

Figure 9: Clinical Outcomes with Middle Zone Stenosis Using Modified McNab Criteria

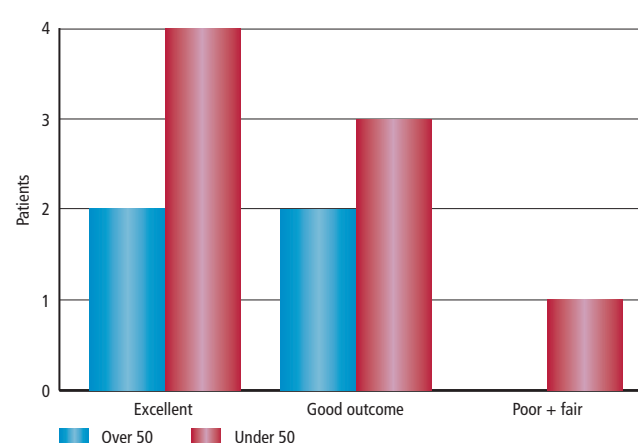
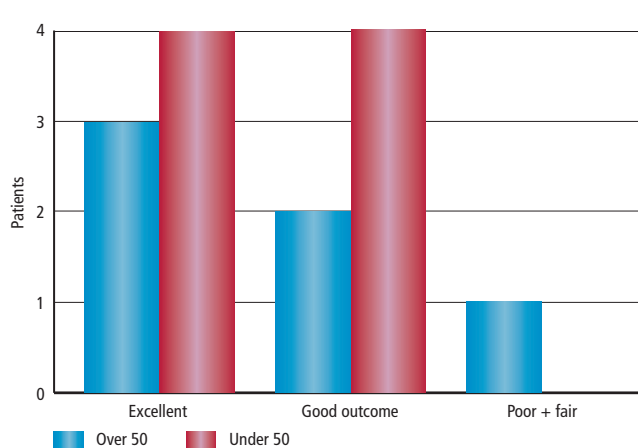


Figure 10: Clinical Outcomes with Exit Zone Stenosis Using Modified McNab Criteria



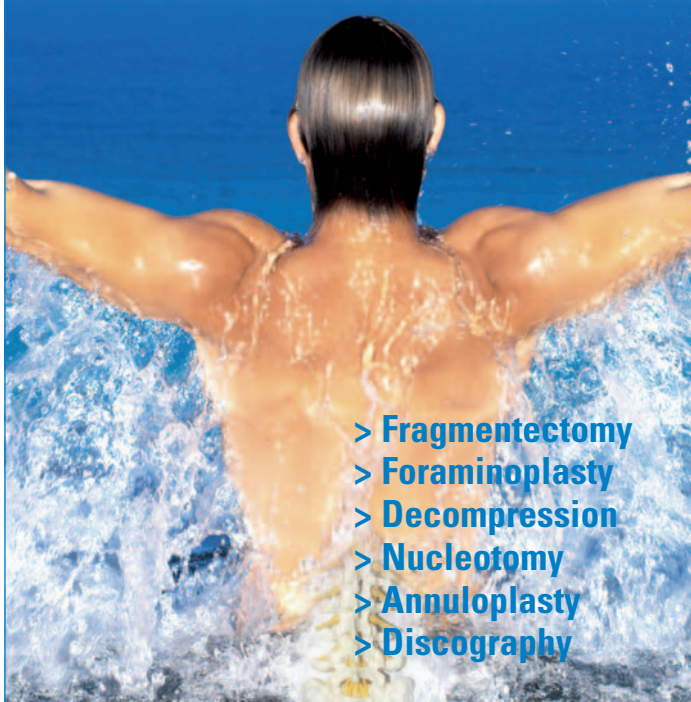
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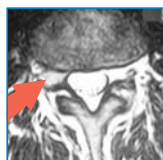
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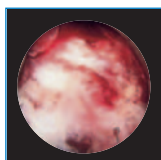
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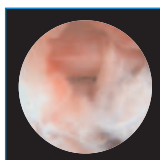
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